Economic Arguments for Denying an Aquifer Exemption Request for the Madison Formation, Wind River Basin, WY

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Summary of Findings

This economic analysis -- presented respectfully for review and consideration by the U.S. Environmental Protection Agency (USEPA), Region 8 -- illustrates that the Madison Formation in the Wind River Basin, in Wyoming, is an economically viable and practical future source of drinking water. Our analysis reveals there is considerable value in, and a reasonable cost for using the aquifer to address a wide array of near-term and potential future water needs across a wide geographic area.

This analysis provides USEPA Region 8 reviewers of the Aethon Energy request for an Aquifer Exemption with an understanding of the enormous potential economic value, practicality, and feasibility of the Madison Formation groundwater resource to meet *future* drinking water and other water supply needs, both within the surrounding counties, and across broader regions of the State of Wyoming and beyond.

Aethon Energy's request for an Aquifer Exemption for the Madison Formation should be denied based on the high value that the aquifer system holds as an economically practical source of drinking water in the future, as demonstrated for the following reasons:

1. Aethon's Aquifer Exemption request fails to show that the formation "cannot now and will not in the future serve as a source of drinking water because it is situated at a depth or location which makes recovery of water for drinking water purposes economically or technologically impractical." (40 CFR 146.4(b)(2))

2. The economic information provided by Aethon's consultant, Tetra Tech (Percy 2020), is very limited and improperly interpreted, and it fails to demonstrate that using the aquifer as a potential future source of drinking water is "economically or technologically impractical."

3. Using the raw data provided by Tetra Tech (Percy, 2020), the cost of using the aquifer as a potential source of drinking water for a municipal or regional Public Water System (PWS) is shown to be very economical (e.g., costing an estimated $134 per household per year, or less, for the two examples we evaluate).

4. The opportunity to potentially tap the aquifer as a high-yield, high-quality source for a regional PWS would provide a wide array of benefits to the communities and enterprises in the region currently supplied by a small PWS or self-served.

5. There are numerous examples of drinking water sources (including recycled wastewater effluent, and desalination of high TDS groundwater or seawater) that were initially considered too expensive and technologically impractical, but that are now tapped in many locations across the United States. Potable reuse and desalination are typically more expensive than the estimated cost of using the Madison Formation as a drinking water source, yet these supplies are now considered economically practical, even though the source waters were initially considered too expensive and technologically challenging to tap.

6. The Madison Formation needs to be evaluated within the context of the water supply challenges faced throughout the Arid West, including the Colorado River Basin. Extended severe drought and growing water demands place Wyoming and the other Upper Basin states at risk of a "Compact Call" that would have dire economic and social consequences for local and regional water availability. The Madison Formation – as well as the produced water that Aethon wishes to dispose in it – provide Wyoming with a critically important and economically valuable hedge against the risks of such a call.

7. Climate change is placing significant risks on Wyoming's and the broader region's water supply, water quality, and water infrastructure. Access to the Madison Formation is becoming increasingly likely and valuable as a potential future source of high-quality and climate-independent water to meet drinking and other water supply needs.

8. Produced water may itself be viewed as a valuable water resource, rather than as a waste residual to be disposed of by despoiling other water resources. The reuse of produced water is being explored by the oil and gas industry and as part of the USEPA's Water Reuse Action Plan (WRAP). Produced waters currently are being reused in some locations, including for crop irrigation in California, which the state recently reported as a safe practice (California Regional Water Quality Control Board, 2021).

9. In addition to being economically practical, it also is technologically feasible and practical to tap the deep waters of the Madison Formation using available well drilling technologies (Wireman and Spencer, 2021).

1. Introduction

Aethon Energy (Aethon) has requested and received initial support from the Wyoming Oil and Gas Conservation Commission, for an Aquifer Exemption that would allow disposal of produced waters into the Madison Formation underlying the Wind River Basin. We understand that the Wyoming Oil & Gas Conservation Commission may recommend that USEPA approve the Aquifer Exemption proposed by Aethon. Under the federal Safe Drinking Water Act, no injection of oil and gas waste into a potential drinking water source may occur without USEPA's approval.

This report presents a professional economic analysis that clearly demonstrates the economic practicality of using the Madison Formation groundwater resource to meet future drinking water and other water supply needs for the communities in the watershed, the northern part of the state of Wyoming, and the broader region including the Colorado River Basin. As such, Aethon's request fails to meet the criteria established in Code of Federal Regulations (CFR, Figure 1) that would justify an Aquifer Exemption.

Figure 1: The criteria to exempt an aquifer (40 CFR 146.4(b)(2)) states, [the aquifer] "cannot now and will not in the future serve as a source of drinking water because it is situated at a depth or location which makes recovery of water for drinking water purposes economically or technologically impractical."

Our analysis concludes that the Madison Formation has significant economic and other values as a potential future source of drinking water, and for meeting other critical water supply needs. As such, an Aquifer Exemption should be denied to those who wish to avoid some near-term expense by accessing this resource for waste disposal. Continued protection of the Madison Formation groundwater resource is well justified by the value of a protected Madison Formation for the future, for Wyoming and beyond.

2. Overview and Outline of this Report

Our economic analysis includes and is structured as follows:

1. A review of the limited economic analysis developed by Tetra Tech on behalf of Aethon's request for the Aquifer Exemption.

2. An expanded economic analysis that illustrates the economic practicality of tapping the Madison Formation as a future drinking water source:
    a. Locally
    b. As part of a regional drinking water system
    c. To the state of Wyoming as a potential water supply to meet needs in other parts of the state, including as a potentially valuable water resource if or when Wyoming needs to meet a potential "Compact Call" on the Colorado River.

3. Examples of relatively expensive water supply options currently adopted in many locations across the United States – such as water reuse and desalination -- that previously were considered to be economically and technologically impractical as a water supply source, but that now are adopted and widely accepted as economically justified, practical, and feasible.

4. A brief overview of climate change implications for the economic practicality, value, and technical viability of the aquifer as a water supply, as well as the need to think more broadly about water and water sector infrastructure and risk planning in the context of our changing climate.

5. A review of the potential economic value of the Aethon Energy's produced water as a valuable water resource, rather than as a waste residual to be disposed as cheaply as possible.

6. A summary of our primary economic practicality insights.

The analysis provided in this report concludes that the Madison Formation has significant potential to serve as an economically practical future source of drinking water. As such, in accordance with the applicable governing framework, an aquifer exemption should be denied. The economic analysis presented here makes clear that using this high-quality water resource for waste disposal will degrade a very valuable potential future source of drinking water for many households, businesses, and water agencies in Wyoming, and across the states throughout the broader region of the western United States.

3. Review of Aethon's Limited Economic Analysis

In Appendix B of their Aquifer Exemption application to the Wyoming Oil and Gas Commission, Aethon presents an economic and technical analysis that is significantly limited by an overly narrow conception of what is "economically and technologically impractical."

The applicant's basic economic analysis – as prepared and submitted by Tetra Tech (and signed with the seal of B. Percy) -- may appear sound at a rudimentary level (e.g., developing cost estimate components for tapping the aquifer and delivering treated drinking water to communities in the region).[1] However, the conclusions do not draw upon an analysis that is considered "robust" by most economists and, therefore, is incomplete in its determination of what is necessary to illustrate what is "economically or technologically impractical."

More specifically, the analysis developed by Tetra Tech (Percy, 2020), submitted to the Wyoming Oil and Gas Commission in support of Aethon's aquifer exemption request, is flawed because it:

[1] The Percy 2020 document, labeled as "Appendix B" in Aethon's 2020 submittal to the Wyoming Oil and Gas Conservation Commission, may be a resubmittal of an older analysis originally prepared and submitted in or about 2013.

- Limits its assessment solely on *current* circumstances. However, the statute – as well as core economic principles -- call for a much broader interpretation, including the potential for *future use* of the aquifer for drinking water [40 CFR 146.4(b)(2); Figure 1, emphasis added]. The Tetra Tech analysis did not include any consideration of *future* economic practicality.

- Confines its assessment within a very limited geographic scope. The Tetra Tech analysis did not include any consideration of economic value and practicality to households, farmers, businesses, water districts or states beyond local communities.

- Provides cost estimates that are not placed into a proper economic assessment framework. The Tetra Tech analysis inappropriately merges one-time capital outlay expenses for very long-lived infrastructure (e.g., well development and pipeline construction) with annual expenses (e.g., for water treatment), resulting in a misleading portrayal of the estimated annualized expense for supplying drinking water to area communities. In the next section of this report, we provide a more suitable economic evaluation of the costs for tapping the Madison Formation as a potential future source of drinking water.

As a consequence, Aethon's argument (as articulated by the Tetra Tech analysis) -- that local communities neither need additional drinking water supplies and, even if they did, tapping this formation would be too expensive -- misses the critically important economic value perspectives that apply when:

1. The geographic horizon is expanded beyond individual communities to include the value of the resource to a suite of communities in the region, the state of Wyoming, and perhaps across a broader portion of the Arid West.

2. The temporal horizon is expanded to consider the value of a high yield, high quality (TDS at 1000 ug/L, per Encana, 2012) water source under anticipated and highly plausible future conditions presented by climate change, population and economic growth, and other considerations.

3. The cost estimates are placed into a more suitable "apples-to-apples" context, revealing the expense is well within the bounds of what has been shown for the economic practicality and feasibility of water supply projects in the Western U.S.

Overall, the Aethon argument does not address the potential future value of the Madison Formation as an extremely valuable natural asset that is worthy of continued prudent protection. Aethon also fails to consider that its produced water is itself a valuable resource that can and should be reused (after made fit for purpose by applicable treatment), rather than a waste to be disposed of in a manner that contaminates high quality water resources.

4. The Economic Practicality of Tapping the Madison Formation as a Public Water Supply for Wind River Basin Communities

4.1 Aethon's Economic Assessment Approach

The Aquifer Exemption request from Aethon includes, in its Appendix B, an engineering estimate of the expense of developing a deep well to tap the Madison Formation (e.g., at a depth of ~15,000 feet), developing rights of way and constructing pipelines to convey the water to several regional communities, and treating the high-quality groundwater to potable standards. The work, performed by engineering consultants at Tetra Tech, presents the basic parameters as follows (Percy, 2020):

- $3.0 million in initial (one-time) capital outlay to develop a well to 15,000 feet
- $10,000 per mile of one-time capital outlay for pipeline procurement and installation, and associated procurement of rights of way for the pipelines
- $50 per barrel ($1.19 per gallon) for treating the high-quality raw water from the Madison Formation to full potable standards.

The Tetra Tech analysis then combines the one-time capital outlays with the annualized cost of treatment to report what they infer to an exorbitant cost for using the Madison Formation for area communities' water supply. For example, they state a cost estimate of $8.7 million to serve the residents in Casper (Percy, 2020). However, the Aethon-sponsored analysis portrays a mix of upfront one-time costs for very long-lived assets (e.g., the well and pipelines, which may have service lifetimes of up to 100 years, or longer) with annualized treatment costs, resulting in a misleading "apples and oranges" total cost estimate.

More appropriate use of economic concepts and standard practice calls for evaluating the capital (up front, one-time) cost of the well and pipeline construction based on an annualized expense over their extended anticipated lifetimes (e.g., of 30 to 50 or 100 years). These annualized capital costs (reflecting a projected annual debt service expense) should then be added to the annualized cost of treatment to derive a total annualized cost. Examples are developed below for two potentially served geographic areas, based on the raw data provided by Tetra Tech.

4.2 An Example of Economic Practicality for Casper, WY

For the City of Casper, the Tetra Tech cost components (as described above) -- when properly interpreted in annualized terms -- amount to the following:

- $138,000 per year for well development ($3 million annualized over a 30-year lifetime, at an interest rate of 2.25%).

- $275,000 per year for 70 miles of pipeline development, including rights of way ($7.39 million for the pipeline, plus $700,000 for the rights of way, annualized over a 50-year lifetime[2] at 2.25%)
- $625,000 for each year of water treatment.

Combining the above, the suitable annualized interpretation of the Aethon-provided cost estimates results on a combined total expense of less than $1.04 million per year. This amounts to only $18.76 per Casper resident per year, or less than $57 per year for a 3-person household (applying the 2010 population estimate of 55,316, reported by Tetra Tech, citing the 2010 US Census). This amounts to a cost of only $4.69 per household per month.[3] This is less than the current (as reported in 2018) average monthly household water bill of $44.51 in Casper (Wyoming Water Development Commission, 2018).

Clearly, a cost of less than $60.00 per year per household represents an economically practical, feasible, and affordable cost for delivery of a reliable supply of high quality and treated water to the City. And, tapping the Madison Formation would also provide a water supply not subject to drought, wildfire, numerous sources of existing and potential contamination, instream flow limitations, or other typical risks posed to municipal water supplies drawn from surface waters or shallower groundwaters. The tapping of a high-quality groundwater supply also would spare the City of anticipated expenses for forthcoming Safe Drinking Water Act regulations, such as an anticipated Stage 3 of the Microbial/Disinfection Byproducts Rule or potential Maximum Contaminant Levels for PFAS/PFOS or other contaminants of emerging concern.

4.3 Economic Practicality for a Potential Regional Public Water System (PWS)

For a regional system perspective, consider a pipeline-based regional Public Water System (PWS) developed to supply a series of communities in the Wind River basin. Such a regional system would likely supply Riverton and Mountain View Acres (45 miles away), Shoshoni (30 miles) and, presumably, other communities within reasonable proximity to the main transmission pipeline (e.g., Pavillion, Lander, Ethete, and the Wind River Reservation population served by the Arapahoe Water Supply system). Such a regional system also would potentially serve ranches, irrigation systems, other entities and enterprises along or in proximity to the pipeline.

Applying the engineering cost estimates provided by Percy (2020), we apply the following information as described previously:

[2] Note that a properly designed, installed and maintained pipeline is likely to last far longer than 50 years (perhaps 100 years or more). Likewise, a properly constructed water supply well may have a lifetime beyond 30 years.
[3] The Casper water utility will also continue to bear its other normal expenses – such as for operating, maintaining, and periodically renewing the City's existing water distribution system – regardless of the source of its water supply. However, the potential switch to the Madison supply will allow the utility to forgo the expense of tapping and treating its existing supplies, or of enduring shortages.

- $138,000 per year for well development ($3 million annualized over a 30-year lifetime, at an interest rate of 2.25%).
- $275,000 per year for an assumed 70 miles of pipeline development, including rights of way ($7.39 million plus $700,000, annualized over a 50-year lifetime at 2.25%, and assuming that 70-miles of pipe in total is sufficient to serve the relevant communities along the corridor, given Riverton is located at a distance of 50 miles)
- $625,000 for each year of water treatment.

As with the illustration above for Casper, we combine the above components to develop an economically suitable annualized cost interpretation of the Aethon-provided cost estimates from Tetra Tech (Percy, 2020). This results in a combined total expense of less than $1.04 million per year.

The combined 2019 populations of Shoshoni, Riverton, Lander, Pavillion, Mountain View Acres, Ethete, and the Arapahoe Water Supply amounts to 23,307 people [applying the 2019 population estimates as reported by Google (2021)]. In addition to the households, there also will be the businesses, schools, and other entities within and in proximity to these communities that also will rely upon and share the cost of the new water source and supply system. Further, it is likely additional communities and households – as well as agricultural and other entities – will be served by the regional PWS. However, for this illustration, we apply the estimated annual cost solely to the residents housed in the communities noted above.

The regional PWS would provide a reliable supply of high-quality tap water to the residents of these communities at an average cost of $44.62 per resident per year, or less than $134 per 3-person household per year. This translates to $11.16 per household per month ($3.72 per person per month).[4] While more expensive on a per capita basis than calculated above for the more populous community of Casper, this cost of $11.16 per household per month is a fraction of the current (as of 2018) average household water bill for Riverton ($41.03) or the statewide average ($40), per the Wyoming Water Development Commission (WWDC, 2018). As such, tapping the Madison Formation to supply a regional PWS is clearly an economically practical and feasible expense for delivery of a reliable and affordable supply of high quality (and treated) water to the regional communities.

In addition, tapping the Madison Formation would provide a supply not subject to drought, wildfire, contamination, instream flow limitations, future regulatory compliance costs, or other typical risks posed to municipal water supplies drawn from surface waters or shallower groundwaters. These risks to current water systems indicate a likely increase in cost, and

[4] Even if we assume the Percy (2020) cost estimates from Aethon's Aquifer Exemption submittal's Appendix B are low, we can still obtain very economical costs per household. For example, if the new well were to cost $30 million (rather than $3 million as quoted by Percy), and the 70-mile pipeline cost $35 million (rather than the $8.1 million derived from the Percy figures), then the total annualized cost amounts to $3.2 million per year. $3.2 million annually translates into $413 per year for a 3-person household, or $34.42 per month per 3-person household.

decrease in reliability, for continued reliance on their existing water supply sources for the communities potentially served by a Madison Formation-sourced regional PWS.

The communities potentially served by a future Madison Formation-based regional PWS currently face significant water supply challenges that would be alleviated with access to a deep groundwater-based regional system. The Wyoming Water Development Commission's legislative report documents several of these challenges (WWCD, 2020):

- The Ethete area water system (operated by Northern Arapaho Utilities) relies solely upon highly variable (in both quantity and quality) surface water diverted from the Little Wind River. Low flows, due to irrigation demands in the summer and natural low flows in the winter often leave Arapaho Utilities (NAU) unable to divert enough water to meet domestic water needs. High turbidities during runoff and after the South Fork II fire (June 2002) have also caused significant operational problems, which reinforces the need for a reliable ground water source.

- The City of Lander face[s] deficits in meeting their current demands based on both water supply and not having the most senior water rights. Also, the City of Lander cannot do maintenance on the water treatment plant or intake infrastructure and supply water to their customers at the same time. The City of Lander also believes that they are nearing ultimate capacity of their current supply and need additional supply to allow for future demand. Finding an alternate potable water supply is of high priority of the city.

- The town of Riverton relies on wells completed in the Wind River Aquifer (WRA) for their water supply. The WRA is a relatively shallow aquifer that is comprised of alternating layers of sandstones, siltstones, and shales. The sandstone lenses are the source of groundwater for the aquifer. Water quality in the WRA can be highly variable with high levels of radionuclides and TDS in some areas. Zones of poor water quality and low production are hard to predict when siting wells due to the variable nature of the location and thickness of sandstone lenses that supply water to wells completed in the aquifer. Because of localized recharge to the aquifer, the WRA is also susceptible to drought conditions. In some areas, such as the greater Pavillion area, the WRA has been contaminated by oil and gas activity so there is no other viable water supply source for those residents.

- The town of Pavillion is supplied by WRA wells. Water quality from the wells is marginal and the town faces the same issues as other towns that rely on the WRA. However, Pavillion area residents that live outside the town limits have private wells also completed in the WRA. The aquifer is contaminated in the vicinity of the Pavillion gas field where many of those residents live, so many of them have no access to clean water. They have relied on bottled water supplied by the WWDC and Encana for many years… The town of Shoshoni is faced with the same problem as other communities that rely on the WRA as their sole source supply (WWDC, 2020).

4.4 The Value of Developing a Large Regional PWS that is Madison-Sourced

There is considerable value in retaining the option of converting the region's numerous communities from individual small Public Water Systems to a larger, centrally managed regional supply system. The benefits of consolidating numerous small PWS into a larger regional system are well documented (e.g., Raucher et al, 2010; Henderson et al., 2019). Among the several important public health and cost-saving benefits to be realized are the following:

- Economies of scale in water purification for treatment facilities as well as on-going operations and maintenance, and in overall utility management – resulting in significant cost savings per unit of water delivered (and, hence, lower water bills for served household and business customers).

- Access to a cadre of highly trained professionals as water system operators and managers, dedicated to a full-time focus on both long-term and day-to-day operations, maintenance, and technical and management oversight (compared to part-time side-job operations and management as often seen across a series of small water utilities).

- Improved and centralized technical, managerial, and financial (TMF) capabilities, including better capabilities for accessing favorable financing.

- Improved regulatory compliance and related public health protection, resulting from a combination of improved source water (e.g., the Madison Formation) and enhanced utility capabilities.

- Streamlined and simplified regulatory oversight burdens on primacy agencies (state and/or EPA Regions), working with a larger well-managed PWS instead of several smaller utilities.

- Improved water system resilience and reliability, by switching to a climate-insensitive water source from current sources more vulnerable to contamination, drought, and other threats to water quantity and quality.

Further, Wyoming has a successful track record in developing large regional groundwater-based water supply systems to consolidate/replace collections of smaller PWS. As a prime example, the Big Horn Regional Water Supply System has more than 70 miles of pipeline serving what was previously 15 individual modest-sized public water systems, spanning 3 counties and covering more than 800 square miles (Rosenlund, 2018; Doyl, 2021).[5] The State has invested

[5] The Big Horn Regional Water System (BHRWS) serves a large area, extending from Greybull on the north to the town of Kirby and the Lucerne Water and Sewer District (Lucerne) on the south, a distance of more than 70 miles. The system serves several entities and consecutive water systems in Big Horn, Washakie and northern Hot Springs

more than $39 million in developing the regional system,[6] effectively consolidating multiple small PWS as well as serving numerous other entities.

4.5 Conclusions

Using cost estimates developed for Aethon by consultants at Tetra Tech, it is evident that drawing on the Madison Formation to provide high quality yields as a PWS serving regional communities is very much economically practical. Indeed, the State of Wyoming has previously invested considerable sums in developing large regional groundwater-based systems with pipelines of similar distance in other portions of the state. It is clear that the Madison Formation can be accessed and used in an economically practical and affordable manner to serve the communities in the region – communities that currently are facing significant challenges providing reliable, safe drinking water. It also is technically practical to tap the high-quality waters of the Madison Formation as a future source of drinking water.[7]

5. Examples of the Costs of Emerging Water Supply Options that Provide Benchmarks for What is Considered Economically Practical

Additional relevant context for considering the economic practicality of using the deep Madison Formation as a potential water supply may be found by examining typical costs for developing new water supplies elsewhere in the nation. In this section, we place the Madison Formation costs into perspective by examining the economic expense of developing other new water supplies throughout the Arid West.

Counties. The water system has been operating successfully for several years, using three high quality, high yielding water sources which are artesian well fields in the Madison Limestone aquifer.

[6] Including $11.4 M (completed 1998) on the NW Rural Water District, $23.1 M on the Joint Powers Board pipeline, completed 2012), and $4.7 M on the regional well collector (completed 2012) (Wyoming Water Development Commission, 2019). Additional data from the Wyoming Water Development Commission (2020) reveals an investment of more than $38.5 million in building the transmission lines, exclusive of well development and improvements, storage tanks, and other key capital outlays.

[7] As noted in Wireman and Spencer (2021), "While historically producing groundwater from these depths has not been necessary or practical and relatively expensive, a 2015 search of the Wyoming State Engineer's Office database indicates that there were 4 permitted water wells in the state of Wyoming with a depth greater than 15,000 feet, 27 permitted wells that range in depth from 10,000 to 15,000 feet, and 240 water supply wells that range between 5,000 and 10,000 feet deep. It is likely that many of these wells are oil and gas wells that have been re-permitted as water wells. As climate change continues to affect water availability, and population increases in the western states, characterizing and developing sustainable ground water supplies from deep aquifers is likely to increase."

For example, water reuse projects tapping and further treating wastewater effluent are being deployed to provide safe and reliable potable water for Public Water Supply (PWS) use; and/or to provide nonpotable water for irrigation, ecologic, cooling, or industrial process purposes. Such water recycling projects are widely implemented across the western states, and many more such projects are anticipated for the coming decades. The USEPA's on-going efforts under its national Water Reuse Action Plan (WRAP, as detailed below) provides an indication of the high-level efforts to expand opportunities and facilitate the suitable applications of water reuse across the nation (USEPA, 2021).

Likewise, desalination of high TDS and other impaired groundwaters has also been adopted to provide a reliable source of potable water to communities in the U.S., converting what had previously been perceived as an economically and technically impractical groundwater resource into an accepted drinking water source (e.g., the El Paso Water Utilities, in Texas, and the Inland Empire Utilities Agency in southern California, now provide desalinated brackish groundwaters as an integral part of their communities' drinking water supply). Seawater desalination is a similarly established, economically practical approach to tapping what was traditional considered an impractical water source, converting those waters into a valuable supply for drinking and other PWS uses, and is now in place in Florida, California, and many other locations globally.

The typical cost for potable water reuse and groundwater desalting projects is on the order of $2,000 or more per acre-foot (AF) of potable water produced (though they may range from nearly $1,000/AF at the low end to well over $3,000/AF in some settings) (Raucher and Tchobanoglous, 2014). These water recycling and desalting projects may appear expensive relative to long-established water supplies accessing surface water or local groundwater. However, these emerging new water supply sources are cost-effective when compared to other potential new water supply options.

For a typical American household of 3 persons, annual water consumption is on the order of one-third of an AF per year.[8] For a water supply costing $2,000 per AF to produce potable water for a PWS, the typical household is paying more than $600 per year (e.g., roughly one-third of $2,000). The estimates developed above for potentially tapping, piping, and treating Madison Formation deep waters to serve Wyoming communities in the region are a fraction of this cost (at roughly $57 to $134 per 3-person household per year).

Further, desal and water reuse projects generate additional values for reliability and resilience, because they are largely drought-proof, climate insensitive water supplies. The potential for tapping the Madison Formation would provide similar benefits to the region because it would offer a reliably strong yield of high-quality water (TDS of ~1000 mg/L, per Encana, 2012), and it

[8] Based on a 3-person household, with indoor water use averaging 58.6 gallons per capita per day (DeOreo et al., 2019), and a household with a yard typically using 30,000 to 50,000 gallons per year outdoors (Mayer, P. Water Demand Management, personal communication, 16 January 2021). These data yield an estimated 104,167 gallons per household per year, or ~32% of the 325,850 gallons in an AF.

is not subject to drought or other climate change impacts. The Madison Formation also is well insulated from contamination sources by virtue of its depth (assuming the aquifer remains protected under the Safe Drinking Water Act).

6. The Economic Value of Madison Formation Water in the Context of the Arid West and Colorado River Basin

The growing scarcity of water in Wyoming, the Colorado River Basin, and the U.S. Arid West in general, is widely recognized (e.g., Hartman, 2019). This growing scarcity is a product of dwindling *supplies* due to prolonged and severe drought, coupled with the increasing *demand* from regional population growth, economic growth, and the increased needs to meet instream ecologic considerations and hydropower demands. Climate change will continue to exacerbate the imbalance between regional water supply and water needs and demands, as well as exert additional pressures and needs for how the region's water resources are viewed, valued, and managed (e.g., USEPA, 2019; Loll et al., 2019).

This section examines the value of the Madison Formation within the context of increasing water scarcity in Wyoming and beyond. The Madison Formation, underlying much of the state of Wyoming, provides a valuable hedge against anticipated water shortages and associated increases in water scarcity in adjacent basins as well – reflecting the increasing need for and reliance on inter-basin transfers. As such, the Madison Formation will provide an important water resource for future use for other portions of Wyoming, and throughout the Colorado River Basin. Section 7 of this report then provides a further discussion of climate change in the context of water resource values and risk management across the region.

6.1 Water Tapped as an Investment Commodity

Increased regional water scarcity means that there is an increasing *economic value* of all water in the region, including its value as a commodity for financial investors. The increasingly high value of water in the Basin has led to financial institutions recognizing the value of water as a lucrative investment opportunity. Water futures are traded on NASDAQ [e.g., Nasdaq Veles California Water Index (NQH2O)]. A recent New York Times article provides relevant examples of investors – such as the hedge fund, Water Asset Management -- purchasing water rights and selling them at high prices (i.e., with strong profit margins) to growing metropolitan areas (Howe, 2021). A resource such as the Madison Formation is likely to eventually attract attention as a valuable natural asset by water resource managers and water investors alike, as the growing gap between dwindling regional water supplies and growing regional demands makes this resource a highly valuable potential future source of drinking water.

6.2 The Colorado River Compact and the Potential Call for Water from Upper Basin States

Increased water scarcity is evident in the highly interconnected nature of water across the entire breadth of the states within the Colorado River Basin. Water anywhere in proximity of

the Colorado River Basin has value connected to the needs for water spanning across all the states served by (and relying upon) the Basin.

Under the 1922 Colorado River Compact, every year the "upper basin" states of Wyoming, Colorado, New Mexico and Utah, are obligated to send large volumes of Colorado River water downstream to the "lower basin" states of Nevada, California and Arizona. Drought and declining inflows and reservoir levels are sparking widely documented concern all along the Colorado River Basin, leaving utilities and districts in all seven states planning ways to avoid shortfalls on the river that could threaten water supplies from Wyoming and the Colorado Front Range downstream to Arizona, Nevada, and Southern California.

As an upper basin state in the Colorado River Compact, Wyoming has legal obligations to ensure lower basin states are able to draw their full water allocations. Long-term drought and other factors have led to a situation in which the upper basin states may soon face the first ever "Compact call" on water upon which the upper basin states currently rely for other valued purposes. A call on upper basin water, as could very well occur if the current 20-year drought period extends for an additional two years (Richter, 2021), will impose significant water shortages and expense to the upper basin states and their water agencies. For example:

> Under Colorado water law, Front Range cities from Colorado Springs to Fort Collins would be among the first to lose their water entitlements, curtailing their transmountain diversions from the [Colorado] river. More than half of Denver's water is supplied by these diversions (Richter, 2021).

Because of the physical linkages and Compact-binding legal connections between the upper and lower portions of the Colorado River system, upper basin states and PWS relying on the Colorado River are actively seeking alternative water sources and other costly strategies to hedge against the high probability-high consequence risk of an impending Compact call. For example:

- Paying farmers to forgo irrigation: Large water utilities and districts are being encouraged to pay upper basin farmers to forgo their rights to irrigation water from the Colorado River, as part of a broader effort that is necessary to ensure sufficient flows reach the Lower Basin states: Richter (2021) notes the following:

  > Given the dangerous water shortage risks mounting in the Colorado River basin, Colorado's political leaders and water managers must heed those lessons and act quickly... In 2000, the [Lake Powell and Lake Mead] reservoirs were nearly brim full. There seemed to be enough water for everyone to do everything...
  >
  > Then the climate began to change. Scientists now label the past twenty years as a "megadrought," one of the two driest periods in the past 1200 years. The river's flow has decreased by 20% but we have not lowered our water use accordingly; the water demands of 40 million people now regularly exceed annual river flows. Each year,

water managers must tap deeper into reservoirs to meet these needs. Lake Mead and Lake Powell – our nation's two largest reservoirs — are now 60% empty. Lake Powell dropped 27 feet during the past year alone (Richter, 2021).

Just two more years like 2020 could set off a chain of damaging consequences. The hydropower turbines in Glen Canyon Dam would stop spinning, sending a shockwave of electricity shortages across the Southwest. Lacking outflow through the turbines, water remaining in Lake Powell becomes entrapped, shutting off flow into the Grand Canyon and jeopardizing endangered fish and ecosystems. Without replenishment from the river, Lake Mead would be rapidly drained by tens of millions of water users in California, Arizona, and Nevada.

Those water-starved 'Lower Basin' states would no longer be receiving their share of water as mandated by the 98-year-old Colorado River Compact. If the seven states sharing the river cannot work out an emergency solution, the case would move quickly into the courts, with the expected ruling that the 'Upper Basin' states of Colorado, Utah, Wyoming, and New Mexico must immediately and drastically reduce their use of the river (Richter, 2021).

- Accessing additional water supplies provides low-cost insurance against the large adverse impact of a potential Compact call. Denver Water reports that climate change, drought and overuse are taking a heavy toll on the Colorado River and those who depend upon it. Denver Water, like other major water users, is planning ways to avoid shortfalls on the river that could threaten its water supplies. These "drought contingency plans" require states in the upper and lower basins of the Colorado River to map out ways to ensure enough water remains in Lake Mead and Lake Powell (two mammoth reservoirs) that are key to managing water supplies in the river basin. Ultimately, the states want to manage their water sources, and the Colorado River system, so that they can continue to support their growing populations, agricultural economies and the environment (Hartman 2019).

  Wyoming's ability to tap large quantities of high-quality groundwater from the Madison Formation – and/or use suitably treated produced waters -- may very well become a highly valuable asset for the state. Having access to additional water supplies provides low-cost insurance against a highly plausible near-term outcome in which Wyoming and other states need to divert scarce water it currently uses elsewhere to meet its Compact obligations to lower basin states. Or, Wyoming may be able to sell the Madison Formation waters to Colorado Front Range communities, such as Denver Water, that would lose half of its supply portfolio under a Compact call. As Hartman (2019) notes:

  > "With a repeat of historic hydrology since 2000, Lake Powell would be dry — empty — within about three years," [Denver Water Director Jim] Lochhead urgently told a meeting of the Colorado Water Conservation Board in September

2018. “If you doubt this possibility, consider that the August inflow into Lake Powell was 2 percent of average.”

… As Lake Powell loses elevation… and runs too low, Colorado and its fellow upper basin states would have to pull from their own supplies — water these states use for farms, cities, recreation and industry… “There’s no precedent for it, and no one can quite say how it would unfold, only that it would create confusion and controversy as states scramble to comply and leave water users — including Denver Water and its customers — at risk of surrendering half of Denver’s supplies,” Lochhead said.

Lochhead is leading the charge for the creation of a “storage pool” in Lake Powell. This would be a pool of water, about 500,000 acre-feet, that could be dispatched to the lower basin in times of major shortages. Think of it as a “reservoir within a reservoir” to be filled with contributions across the upper basin states. Just how it would be filled, and who would contribute how much, are complicated matters still to be worked out… The water in the storage pool would amount to its own kind of bank account, there to be used specifically for a call on the upper basin. Think of it as a kind of insurance policy that would spare Colorado, Wyoming, New Mexico and Utah from a full-out scramble if they fell short of their delivery obligations.

“The mere prospect of these events argues that it would be foolish to do nothing and wait until we are in a crisis,” Lochhead told the CWCB. “I certainly hope we don’t have to implement any countermeasures to an extended drought. But if we need to, we should have them in place before the system collapses.”

The Upper Colorado River Basin has another key reason to push Lake Powell levels up: If the reservoir sinks too much more, it would jeopardize its ability to produce hydropower. Revenues from the dam’s hydropower sales fund a suite of projects crucial to water users in the basin, including operations at other federal reservoirs, desalination efforts and work to protect endangered fish — all programs with a big presence [in upper basin states] (Hartman, 2019).

- Wyoming is already investing significant funds in efforts to enhance Colorado River flows. The State of Wyoming appropriated more than $1 million between 2014 and 2019 for cloud seeding in the Wind River Basin, as part of an effort to increase precipitation that might enhance flows to the Upper Colorado River system (Wyoming Water Development Commission, 2019). Wyoming was joined in funding this project by several in-state business and water supply entities, as well as urban water supply systems from lower basin states (including the Central Arizona Water Conservation District, the Colorado River Board of California - Six Agency Committee, and the

Southern Nevada Water Authority (Wyoming Water Development Commission, 2019).

The broad sectoral and geographic scope of the financial support for this cloud seeding venture reflects the recognition that water in Wyoming is vital to addressing water scarcity issues throughout the Colorado River Basin. As the Wyoming Water Development Commission's Report (2019) states:

> The Colorado River Basin Water Supply and Demand Study (2012) defined current and future imbalances in water supply and demand in the Colorado River Basin and the adjacent areas of the Basin States that receive Colorado River water for approximately the next 50 years, and developed and analyzed adaptation and mitigation strategies to resolve those imbalances (USBR). The watershed management concept in the study featured cloud seeding as … part of a larger strategy for flow augmentation in the Colorado River Basin.

In sum, the state of Wyoming, in partnership with businesses and water districts in the state, and with financial support from elsewhere throughout the Colorado River Basin, has been willing to invest significant resources in *cloud seeding* as a way to potentially find additional water to help meet Basin-wide needs. Such an investment by Wyoming is important evidence indicating that the prospect of potentially tapping the Madison Formation – with its large volume of high-quality water – can and should be considered as a valuable potential future source of water supply to assist the state in meeting both in-state needs and Colorado River Compact obligations.

6.3 Conclusions: Tapping the Madison Formation is Economically Practical

The discussion above provides several examples illustrating how valuable all of Wyoming's current and potential future water sources are for the state, and for all the other states in the Colorado River Basin. Any and all potential Wyoming sources of meaningful quantities of high-quality water must be considered as having significant economic value, regardless of whether or not they are currently tapped, or require a deep well to access. Given these very high economic water values, the Madison Formation must be recognized as an economically practical source of potential future drinking water supply. As such, the Aquifer Exemption should be denied.

7. Climate Change Implications for Water Management and Values

Aethon's argument does not recognize the critically important economic value perspectives that apply from appropriately expanding our temporal horizon by looking to the future and how key water-related conditions are changing. Criteria outlined in 40 CFR 146.4(b)(2) states that to exempt an aquifer, it must be demonstrated that "it *cannot now and* ***will not in the future*** *serve as a source of drinking water because it is situated at a depth or location which makes recovery*

of water for drinking water purposes economically or technologically impractical" (emphasis added).

Climate change is dramatically increasing the potential need for -- and economic "option value"[9] of -- preserving the Madison Formation as an aquifer that will in the future serve as an "economically practical" (if not essential) and technically feasible supply for drinking water and other critical purposes in the region. The Fourth National Climate Assessment (NCA4) report, issued by the U.S. Global Change Research Program (USGCRP, 2018), provides compelling information highlighting the role of our changing climate on the value and economic practicality of water sources such as the Madison Formation. This information is summarized below.

7.1 The Broad Scope of Climate Change Impacts

One of the top ten "Key Messages" from the Fourth National Climate Assessment, and widely supported by today's top scientists, is that our climate is in a process of changing in ways and at magnitudes that we do not yet fully comprehend*:*

> The climate change resulting from human-caused emissions of carbon dioxide will persist for decades to millennia. Self-reinforcing cycles within the climate system have the potential to accelerate human-induced change and even shift Earth's climate system into new states that are very different from those experienced in the recent past. Future changes outside the range projected by climate models cannot be ruled out, and due to their systematic tendency to underestimate temperature change during past warm periods, models may be more likely to understate than overestimate long-term future change (USGCRP, 2018, p. 102).

Climate change poses serious risks to Wyoming's and the nation's water resources (quality, quantity, and infrastructure). Climate change already is creating known changes as well as unknown changes due to tipping points and cascading events. What is known with a very high degree of confidence is that there may well be changes that reinforce the economic and technical practicality of tapping the Madison Formation for drinking water and other valuable uses in the future, and perhaps in the near-term.

7.2 Changes in Precipitation Patterns Impact Water Quality and Supply Quantity

Water is perhaps the first and most significant resource directly and indirectly impacted by the changing climate. As noted in the Fourth NCA (USGCRP, 2018; Loll et al., 2018, pp 147 -157):

[9] Option value is defined in the economics literature as the value (willingness to pay) for maintaining or preserving a public asset or service even if there is little or no likelihood of the individual actually ever using it. For example, individuals may place value on preserving a national park even if they are uncertain they will ever visit it. See, for example, Hanemann (1989)

- Earlier spring temperatures and later fall snowfall onset reduces the ability of the mountains to act as drinking water storage; reducing drinking water availability from surface waters in the Wind River and Colorado River Basins, which are primarily snow fed.

- More frequent intense precipitation events and fewer gentle rainfall events reduce water infiltration and increase turbidity and other pollutant loadings - i.e., decreasing water quantity and impacting water quality in surface waters and groundwaters. As such, many of the region's current water supply sources will ~~see~~ be more vulnerable to adverse impacts on water availability and water quality, heightening the regional communities' existing difficulties in meeting drought period demands, and treating water quality challenges to meet applicable drinking water standards.

- More precipitation falling as rain than snow, meaning less water storage in mountains for gradual release for downstream flows through summer and fall seasons. This results in lower instream flows, higher instream temperatures, reduced water quality (elevated concentrations of contaminants), reduced ecosystem services (e.g., as habitat for fish and other aquatic and riparian species), and less source water available to serve PWS needs.

- The potential for more frequent, severe, and/or prolonged droughts, such as already being experienced in the region.

Continuing and perhaps magnifying changes in climate change-driven precipitation patterns will have increasingly adverse impacts on the quantity of water available (especially in much of the western United States), as well as on the quality of our water resources.

7.3. Our Deteriorating Water Infrastructure System is at Risk

Floods, wildfires, hurricanes and other extreme weather-related events are expected to see increased intensity as our climate continues to change. These extreme events – and the increased likelihood of multiple and cascading events -- are among the factors that will place our water infrastructure at increased risk in the years ahead. As the Fourth NCA observes:

> Infrastructure design, operation, financing principles and regulatory standards typically do not account for a changing climate. Current risk management does not typically consider the impact of compound extremes (co-occurrences of multiple events) and the risk of cascading infrastructure failure of the interconnected energy and water systems. Across the nation much of the water infrastructure is aging and in need of major capital investments. And failure in one system, for example energy, can lead to failures in others (e.g., water).
>
> … The risks associated with changing climate are compounded by inadequate attention

> to the state of water infrastructure and insufficient maintenance. Developing new water management and planning approaches may require updating the regulatory, legal and institutional structures that constrain innovation in water management, community planning and infrastructure design… (USGCRP, 2018, pp 147 -157).

7.3 Wildfire and Water Resources

The increased incidence and adverse impacts of high-intensity wildfires is already painfully evident in Wyoming and across all western US states.[10] Climate change plays a significant direct role in increasing the frequency and severity of these wildfire events.

The adverse impact of wildfires on water resources is well documented, including several research reports sponsored by the Water Research Foundation.[11] The loss of forested watersheds and the associated increase in post-burn erosion and sedimentation have significant adverse impact on source water quality, the timing of flows to downstream users, and reservoir water storage capacity. The Fourth NCA notes:

> Analyses estimated that the area burned by wildfire across the western United States from 1984 to 2015 was twice what would have burned had climate change not occurred. Wildfires around Los Angeles from 1990 to 2009 caused $3.1 billion in damages (unadjusted for inflation). Tree death in mid-elevation conifer forests doubled from 1955 to 2007 due, in part, to climate change (USGCRP, 2018, p.1104).

As wildfires continue to become more frequent and more intense, the impacts on our water resources are expected to grow continuously more severe. Accordingly, a water resource such as the Madison Formation – which is physically isolated from adverse impacts from wildfires – will become increasingly important as a highly valuable water supply option, deserving of prudent continuing protection.

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[10] *See, e.g.,* Bill Gabbert, "Mullen Fire Reaches Albany, Wyoming," *Wildfire Today* (October 8, 2020). The Mullen Fire burned over 176,000 acres in the Medicine Bow National Forest thirty-eight miles west of Laramie, Wyoming. Sixty-five structures were destroyed. The U.S. Forest Service has reported that it cost $41.2 million dollars. Assessing and addressing the damage will cost more. WyoFile. 2020. Aftermath. December 4, 2020.

[11] Water Research Foundation projects examining the impacts of wildfire on drinking water include: (1) Project 4482 -Effects of Wildfire on Drinking Water Utilities and Best Practices for Wildfire Risk Reduction and Mitigation; (2) Project 4529 -Wildfire Impacts on Water Supplies and Potential for Mitigation: Workshop Report; (3) Project 4524 -Impact of Wildfires on Source Water Quality and Implications for Water Treatment and Finished Water Quality; (4) Project 4590 -Wildfire Impacts on Drinking Water Treatment Process Performance: Development of Evaluation Protocols and Management Practices; and (5) Project 4636 -An Integrated Modeling and Decision Framework to Evaluate Adaptation Strategies for Sustainable Drinking Water Utility Management Under Drought and Climate Change. Access at: www.WaterRF.org.

7.4. Water Management for a Changing Climate

Ultimately, addressing the water-related challenges imposed by climate change requires changes in how we perceive and manage our water resources and associated infrastructure. This change in water resource management must include how we view and protect all available water resources, including deep aquifers such as the Madison Formation. As the Fourth NCA notes (USGCRP, 2018):

> Current water management and planning principles typically do not address risk that changes over time, leaving society exposed to more risk than anticipated… the gap between research and implementation -- especially in view of regulatory and institutional constraints, remain a challenge.
>
> … A central challenge to water planning and management is learning to plan for *plausible* future climate conditions that are wider in range than those experienced in the past. Doing so requires approaches that evaluate plans over many possible futures instead of just one, and is focused on managing variability, which is likely the dominant source of operational uncertainty for many water systems (Loll et al., 2018, p. 155).
>
> … Water for people and nature in the [Colorado River Basin states] has declined during droughts, due in part to human-caused climate change. Intensifying droughts and occasional large floods, combined with critical water demands from a growing population, deteriorating infrastructure, and groundwater depletion, suggest the need for flexible water management techniques that address changing risks over time, balancing declining supplies with greater demands (USGCRP, 2018, p.1102).

7.5 Conclusions

Climate change places increased pressure on our water resources in many critical ways. Our management of those water resources needs to evolve to address these mounting challenges. Climate change is adversely impacting and posing significant risks to water quality, water quantity, and water infrastructure. These compounding risks make the economic "option value" of preserving and protectively managing our remaining water resources all the more important. As noted in the Fourth National Climate Assessment report (USGCRP, 2018, p. 157):

> Developing new water management and planning approaches may require updating the regulatory, legal and institutional structures that constrain innovation in water management, community planning and infrastructure design [including]… continued collaboration on transboundary watershed coordination and agreements that facilitate more sustainable water management practices.

Recognizing the challenge that small communities face in planning for and adapting to the risks posed by climate change on water resources, the Fourth NCA states, "Developing and implementing new approaches pose special challenges for smaller, rural and other communities with limited financial and technical resources" (USGCRP, 2018). The potential for tapping the Madison Formation in support of developing a regional PWS to replace the series of small PWS serving the Wind River Basin is a technically and economically practical, feasible and affordable option to helping these communities weather the water-related challenges posed by climate change.

8. Produced Waters as a Valuable Resource, Rather than as a Waste

The produced water generated by Aethon's fracking activities is a valuable water asset, and it should not be discarded as a waste product (and certainly not discarded as a "waste" in a manner that poses a threat to the high-quality waters[12] of the valuable Madison Formation).

Water is a scarce and essential resource in the region and, thus, the produced water extracted as a byproduct of natural gas production has considerable value itself. It merely needs suitable treatment so that it can be applied to beneficial uses (especially in a state and region where high yields of high-quality water are a relative scarce commodity).

Produced water is a potentially marketable commodity that energy development companies may consider selling (i.e., as a form of fit-for-purpose water reuse), after treatment aligns its quality with the water's intended uses. As water becomes scarcer in a climate-impacted arid region such as Wyoming and the Colorado River Basin, the energy sector can potentially realize additional revenues and profits by adding the produced water it extracts to the mix of commodities it sells. As our regulatory and water rights institutions evolve to address the changing needs and circumstances associated with growing water scarcity and climate change, barriers to the appropriate reuse of produced waters will likely dissipate.

Allowing the produced water to be considered as a "waste" -- and also enabling the gas company to dispose of that waste in a manner that puts an essential and valuable future water resource at risk -- reflects a clear misalignment of economic values. When demand increases again for natural gas (as it inevitably will in the future), then natural gas prices will rise. At that time, it will be economically feasible for the company to pay for suitable treatment and management of the produced water it generates, and still make an attractive profit from its gas operations (it may also make additional profit on selling its produced waters).

[12] Throughout this report, reference is made to the high quality of the waters in the Madison Formation. For example, Encana (2012) reported TDS at 1000 ug/L in the relevant portion of the aquifer that would be adversely impacted by the requested Aquifer Exemption. Other studies confirm the high quality of the resource, containing low TDS water in proximity to mountain uplifts resulting in secondary porosity and hydraulic conductivity. For example, Miller (1976) measured TDS in three Madison Formation wells ranging from 861 -1130 mg/L.

The productive reuse of produced waters is already recognized as a viable and important practice. Under the U.S. EPA's Water Reuse Action Plan (WRAP), there are two WRAP actions focusing on recycling of produced water:

- WRAP Action 2.3.3, with an EPA report available at: https://www.epa.gov/eg/final-report-oil-and-gas-extraction-wastewater-management), and

- WRAP Action 2.4.2, focusing on a New Mexico effort to evaluate recycling of produced water (https://nmpwrc.nmsu.edu/).

Wyoming is amongst the additional states in which produced water recycling is being seriously discussed, along with New Mexico and California (D. Smith, Assistant Director, Water Division, USEPA, Region 9, personal communication).

Produced water already is being recycled on the east side of San Joaquin Valley, near Bakersfield (CA), and applied to uses including food crop irrigation. The State of California has been leading an effort to further evaluate water quality/safety issues associated with crop irrigation, and it recently released a report finding that crop irrigation with produced waters is safe (California Regional Water Resource Control Board, 2021).

Providing Aethon with an Aquifer Exemption as a means of reducing their costs of production now, when natural gas is in relatively low demand and of low value -- and by doing so at the risk of fouling a highly valuable water supply natural asset -- does not make economic sense. It is economically justified to reject the request for an Aquifer Exemption.

9. Conclusions

Granting an Aquifer Exemption for disposal of oil and gas wastewater into the Madison Formation conflicts with the applicable regulatory criteria. Governing regulations preclude issuing an Aquifer Exemption if the aquifer has the potential to serve a source of drinking water, in a manner that is economically and technically practical. As demonstrated throughout this report, it is economically practical to preserve the Madison Formation as a future source of drinking water. It also is technologically practical to tap the Madison Formation for drinking water supply purposes. It makes compelling economic sense to preserve this natural asset for highly valuable future beneficial uses to meet anticipated near- and long-term future needs for the Wind River Basin, the State of Wyoming, and the entire Colorado River Basin.

In summary, Aethon Energy's request for an Aquifer Exemption for the Madison Formation should be denied for numerous reasons, based on the high value that the aquifer system holds as an economically and technologically practical source of drinking water in the future.

10. References

Adams, J. 2019. States sign agreement to help boost Lake Powell and Lake Mead New plan aims to protect water supply across the Southwest after years of drought. May 24, 2019. Accessed at: https://denverwatertap.org/2019/05/24/states-sign-agreement-to-help-boost-lake-powell-and-lake-mead/

BRS, Inc. 2003. Wind/Bighorn River Basin Plan, Final Report. Prepared for the Wyoming Water Development Commission. Prepared by BRS Inc., in Association With: MWH, Lidstone and Associates, Trihydro Corporation, Donnell and Allred Inc., Water Rights Services LLC. October 2003. Accessed at: https://waterplan.state.wy.us/plan/bighorn/finalrept/final_report.html

California Regional Water Quality Control Board. 2021. Food Safety Project White Paper on the Reuse of Oil Field Produced Water for Irrigation of Food Crops in Central Kern County, California. California Regional Water Quality Control Board (Central Valley Region). Written on Behalf of: Food Safety Expert Panel. January 28, 2021. Accessed February 2021 at: https://www.waterboards.ca.gov/centralvalley/water_issues/oil_fields/food_safety/data/white_paper/foodsafety_whitepaper.pdf

Code of Federal Regulations. 40 CFR 146.4(b)(2)

DeOreo, W. P. Mayer, B. Dziegielewski, J. Kiefer. 2019. Residential End Uses of Water – Executive Report 2. Water Research Foundation. Report 4309A. Accessed at: https://www.waterrf.org/resource/residential-end-uses-water-version-2-executive-report

DOWL. 2021. Accessed at: https://www.dowl.com/projects/big-horn-regional-water-supply/

Encana. 2012. Application for Aquifer Exemption, Before the Wyoming Oil and Gas Conservation Commission. Submitted November 19, 2012. P.2, Section 4.

Google. 2021. Populations of Communities in Wyoming. Accessed February 2021 at: https://www.google.com/search?q=population+of+lander+wyoming&rlz=1C5CHFA_enUS726US726&oq=Population+of+Lander&aqs=chrome.0.0j69i57j0j0i22i30l5.14917j0j15&sourceid=chrome&ie=UTF-8

Hanemann, W. M. 1989. Information and the concept of option value. Journal of Environmental Economics and Management, Volume 16, Issue 1, January 1989, Pages 23-37. Accessed at: https://www.sciencedirect.com/science/article/abs/pii/0095069689900429

Hartman, T. 2019. Confronting Colorado River challenges: Denver Water is joining other utilities and districts to address water shortages on the lifeblood for the southwest. February 12, 2019. Accessed at: https://denverwatertap.org/2019/02/12/confronting-colorado-river-challenges/

Henderson, J., & Raucher, R. S. (2019). *Water Utility Partnerships: Resource Guide and Toolbox (WRF-4750).* Denver: Water Research Foundation (with co-funding from AWWA and NACWA).

Howe, B. R. 2021. Wall Street Eyes Billions in the Colorado's Water. New York Times. Jan.3, 2021. Accessed at: https://Wall%20Street%20Eyes%20Billions%20in%20the%20Colorado%E2%80%99s%20Water%20-%20The%20New%20York%20Times.html

James Gores and Associates. 2010. Arapahoe Water Supply Level II Study. Prepared for Wyoming Water Development Commission, October. Accessed February 2021 at: http://library.wrds.uwyo.edu/wwdcrept/Arapahoe/Arapahoe-Water_Supply_Level_II_Study-Final_Report-2010.pdf

Lall, U., T. Johnson, P. Colohan, A. Aghakouchak, C. Brown, G. McCabe, R. Pulwarty, and A. Sankarasubramanian. 2018. Water. In Impacts, Risks, and Adaptation in the United States: Fourth National Climate Assessment, Volume II [Reidmiller, D.R., C.W. Avery, D.R. Easterling, K.E. Kunkel, K.L.M. Lewis, T.K. Maycock, and B.C. Stewart (eds.)]. U.S. Global Change Research Program, Washington, DC, USA, pp. 145–173. doi: 10.7930/NCA4.2018.CH3. Accessed January 2021 at: https://nca2018.globalchange.gov/chapter/water

Mayer, P. 2021. Personal Communication. President, Water Demand Management, Boulder, CO. Email of January 16, 2021.

Miller, W.R. 1976. Water in Carbonate Rocks of the Madison Group in Southeastern Montana - A Preliminary Evaluation, USGS WSP 2043

Percy, B.S. 2020. Appendix B: Economic Practicality of Potable Water Use Amsden and Madison Formations (submitted as part of Aethon's submittal to the Wyoming Oil and Gas Commission for an Aquifer Exemption). Signed August 12, 2021.

Raucher, R. S., Cromwell, J., Henderson, J., Wagner, C., Rubin, S., Goldstein, J., Kirsch, B. 2010. *Regional Solutions to Water Supply Provision.* Denver: AWWA Research Foundation. Retrieved from https://www.waterrf.org/research/projects/regional-solutions-water-supplyprovision

Raucher, R. and G. Tchobanoglous. 2014. Opportunities and Economics of Direct Potable Reuse. White Paper. WateReuse Research Foundation.

Richter, B. 2021. Western Slope needs to suspend irrigation to avert water shortage catastrophe. Denver Post. January 6, 2021. Accessed at: https://www.denverpost.com/2021/01/06/water-shortage-lake-powell-colorado-river-basin/

Rosenlund, J., 2018. Big Horn Regional Southern Supply Level II Study. Prepared for: Wyoming Water Development Commission. Prepared by Dowl. September 2018. Accessed at: http://wwdc.state.wy.us/

Smith, D. 2021. Personal communication. Deputy Director, Water Division, EPA Region 9. Email of January 16, 2021

US Environmental Protection Agency. 2021. Water Reuse Action Plan. Accessed at: https://www.epa.gov/waterreuse/wrap-action-activities-and-highlights

US Global Change Research Program. 2018. Impacts, Risks and Adaptations in the United States: Fourth National Climate Assessment. Washington, DC. 1515 pages. DOI 10.7930/NCA4.2018. Accessed at: https://nca2018.globalchange.gov/downloads/

Wireman, M, and S. Spencer. 2021. Technology Aspects – Drilling, constructing, developing and operating deep groundwater supply wells. Technical Memorandum. February 25, 2021.

Wyoming Water Development Commission. 2018. Public Water Supply Survey Report. Accessed at: https://wwdc.state.wy.us/watsys/2018/raterept.pdf

Wyoming Water Development Commission. 2019. Wyoming Water Development Commission Report to the Wyoming Legislature. Accessed at: https://wwdc.state.wy.us/legreport/2019/2019Rept.pdf

WyoFile. 2020. State gives Aethon OK to inject Moneta pollutants into aquifer. Nov. 12, 2020. Accessed at: https://www.wyofile.com/state-to-aethon-ok-to-inject-moneta-pollutants-into-aquifer/

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Dr. Raucher has more than 35 years of experience specializing in economics, water supply planning, Triple Bottom Line (TBL) analysis, valuing water supply reliability, affordability, risk management, strategic planning, and policy analysis related to water supply, water reuse, desalination, and stormwater. He is a noted expert on assessing the value of water reuse projects and water supply portfolio planning; affordability and customer assistance programs, planning under climate change and other large uncertainties, business case evaluation, asset management, and integrated resource management.

Education

Ph.D., Public Finance and Natural Resource Economics, University of Wisconsin, 1980

M.S., Econometrics, University of Wisconsin, 1978

B.A., Anthropology and Economics, State University of New York at Albany, 1976

Professional Experience

National Drinking Water Advisory Council (NDWAC), workgroup expert

National Research Council (NRC), Committee member/expert; co-author

Recipient of the 2016 Water Research Foundation *Pankaj Parekh Research Innovation Award* for lifetime achievements in applied water sector research.

Chapter author on how to analyze the range of possible water supply enhancement options, in AWWA's update of the *M50 Manual of Practice for Water Resources Planning* (Third Edition, Chapter 9, 2016)

Representative Projects

Triple Bottom Line and Fiscal Analysis of Water Reuse and Other IRP Options in the Chino Basin

Client: Inland Empire Utilities Agency (IEUA)

Dr. Raucher developed a TBL-based assessment of the integrated regional water supply portfolio that the IEUA and its partner agencies in the Chino Basin (located east of Los Angeles) compiled as an alternative to its prior portfolio of import- and local groundwater-reliant supply options. The analysis revealed large financial savings to the basin entities of pursuing additions of stormwater capture and recharge, groundwater desalination, potable reuse, and aquifer storage and recovery to their IRP. Social and environmental benefits included energy savings and associated reduced carbon footprint and air pollutant emissions, increased supply reliability locally and regionally, and surface and groundwater quality improvements.

Economic and TBL Framework for Water Reuse Projects

Client: WateReuse Research Foundation

Dr. Raucher served as PI creating a Triple Bottom Line (TBL) framework to help water agencies identify, estimate, and communicate the full range of benefits and costs associated with water reuse projects. Dr. Raucher examined the distinction between a financial accounting assessment of water reuse program cash flows (incurred costs compared to revenue streams) and an economic benefit-cost analysis that includes TBL values for community-wide beneficiaries (e.g., potable water system customers benefiting from deferred or avoided potable supply costs). The team developed a spreadsheet model and demonstrated the framework's applicability through case study applications. Case study applications included the Phoenix Water Department, Arizona; West and Central Basin Municipal Water District, California; Pinellas County, Florida; Santa Clara Valley Water District, California; and Las Vegas Valley Water District, Nevada.

The Value of Water Supply Reliability in the Residential Sector
Client: WateReuse Research Foundation

Dr. Raucher served as PI on this research project estimating the value of water supply reliability to residential customers that may face periodic water-use restrictions due to climate change and other potential causes of water supply shortages. The project entailed developing stated preference choice set experiments (conjoint analysis), using focus groups and pretesting, and then implementing an internet-based field survey of 2000 households within five utility service areas across the United States (including one community each in northern and southern California). This research provided empirically robust and credible estimates of household willingness-to-pay to avoid varying levels (severity, frequency, and duration) of future water supply shortfalls and water-use curtailments. The survey also elicited consumer preferences for alternative water supply sources (e.g., a general preference for conservation and expanded water recycling over water imports or desalination).

Integrated Resource Planning for Water Utilities with Nontraditional Source Water Options
Client: WateReuse Research Foundation

Dr. Raucher served as Principal Investigator examining different approaches to water utility integrated resource planning processes. He examined how nontraditional water resource options – such as water reuse, desalination, and stormwater capture – could be folded into the traditional integrated resource planning processes. His final report includes an overview of integrated resource planning objectives, steps, and processes; an evaluation of barriers and opportunities; case studies; and recommended approaches for integrating nontraditional supply options into the framework.

Economic Impact Analysis of Potential Water Shortages for a California Water Utility Service Area
Client: Confidential (Large Bay Area Water Utility)

Dr. Raucher and his colleagues provided an economic analysis of the *Consequences of Failure* (CoF) from a potential loss of transmission infrastructure for a major Bay Area water utility from a potential seismic event that disrupts the level of water service the utility can provide its customers. The analysis considered different service recovery timelines, using estimates of business sector resiliency to disruption, combined with data on economic activity by sector, to calculate the loss of business activity. This direct economic loss was entered into the IMPLAN model of regional economic activity in the county to estimate the potential indirect and induced loss of regional economic output, employment, labor earnings, tax revenues and other adverse regional economic impacts that can be avoided through the investments that avoid or limit the potential for future water supply disruptions and shortfalls. Key findings include a large loss of economic output from businesses totaling almost $2 billion under a 30-day return to service scenario and $3.5 billion under a 60-day return to service scenario. Loss of value for residential customers totals $1.3 billion under the 30-day scenario and $2.7 billion for the 60-day scenario.

City of Santa Cruz, Technical Lead supporting the Water Supply Advisory Committee (WSAC) with Adaptive Long-Term Water Supply Planning and Regional Collaboration
Client: City of Santa Cruz, CA; Santa Cruz Water Department (SCWD)

Dr. Raucher led the technical team guiding a City Council-appointed citizen's advisory committee (WSAC) and the City Water Department through a high-profile Integrated Water Resource Management (IWRM) planning process. The WSAC consisted of 14 citizens representing diverse stakeholder groups, charged with developing a long-term water supply plan for the City. Dr. Raucher and his team provided strategic planning, tutorials and training exercises, subject area expertise, technical analyses, and communication and facilitation skills that built a working understanding of the challenges and complexities of meeting long-term water supply

needs for the City and its regional neighbors, while accommodating critical instream flow, carbon footprint, and other environmental considerations.

Dr. Raucher and his team helped the City Water Department and WSAC develop a consensus in support for an Adaptive Long-Term Water Supply Plan that addresses large uncertainties related to climate, hydrology, regulatory mandates, water use efficiency and conservation, technical feasibility water quality, carbon footprint, critical instream flows for threatened salmonid species, and regional economic issues. Regional collaboration with Soquel Creek Water District and other neighboring systems were a focal point, including potential water quality and institutional barriers and opportunities.

Using Graywater and Stormwater to Enhance Local Water Supplies: Assessing Risks, Costs, and Benefits
Sponsor: National Academies of Sciences, Engineering and Medicine

As a committee member and co-author of the recent National Research Council report (July 2016), Dr. Raucher focused on the Triple Bottom Line economics and incentives related to implementing innovative stormwater management and graywater reuse strategies. His analysis examined the benefits, costs, and related incentive options for implementing GI and other stormwater management options across different scales (parcel, neighborhood, regional) and across the different regions of the United States.

Opportunities and Economics of Direct Potable Reuse (DPR)
Client: WateReuse Research Foundation

Dr. Raucher and co-author, Dr. George Tchobanoglous (UC Davis), prepared a 2014 white paper, *Opportunities and Economics for Direct Potable Reuse*. This white paper identifies the relevant treatment technologies for DPR, together with associated cost, energy use, and carbon footprint. This paper identified the direct benefits of DPR projects and the key issues and benefits for considering DPR projects relative to other water supply options. The paper also identifies the potential amount of water available for future DPR and IPR projects in California.

Water Resource Values and Costs for Alternative Water Supply Options
Client: El Paso Water Utilities (EPWU) Public Service Board

Dr. Raucher provided expert analyses in assessing the true economic cost of a wide range of options that El Paso considered to meet its growing water demands. In accordance with international treaty and interstate agreements, El Paso and its neighboring communities along the U.S.-Mexican border region are significantly reducing their historic reliance on groundwater sources depleted at rates far in excess of natural recharge. This created intense demands on the region's limited surface water resources. Dr. Raucher developed an economic evaluation so that EPWU could make objective, apples-to-apples comparisons of options to meet future demands. The analysis also explored the value of water resources in alternative uses (e.g., cropland irrigation), evaluated comparable water exchanges in terms of water rights acquisition prices in the region, and developed various financing options to make water rights acquisitions more attractive to potential sellers. A subsequent TBL analysis revealed the financial, social and environmental advantages of expanded reuse and groundwater desalting options relative to imported supplies.

Triple Bottom Line Analysis of Alternative Water Supply Options
Client: El Paso Water Utilities (EPWU) Public Service Board

Dr. Raucher led a sustainability-based Triple Bottom Line evaluation of short- and long-term water supply planning options for EPWU, to assess the comparative advantages and disadvantages of the potential expansion of various water supply sources and related treatment processes. The evaluations indicated that expanded groundwater desalting, and expanded water recycling treatment systems were investments that were well justified – compared to other alternatives -- in terms of financial, water supply reliability, social, and environmental considerations. The analysis by Dr. Raucher revealed the considerable TBL economic,

social, and environmental benefits of El Paso expanding it water reuse program as an alternative to tapping water rights acquired from agricultural communities across the region.

Deploying a Risk Management Framework for Water Assets, Including a TBL Assessment of the full Consequences of Failure
Client: Water Research Foundation

For WRF project 4451, Dr. Raucher served as PI developing and applying a risk management framework for water utility assets. A key component of the risk management framework was the development and integration of a Triple Bottom Line (TBL) assessment of the full Consequence of Failure (CoF) costs associated with flooding and other adverse outcomes associated with pipe breaks and other buried infrastructure failures. Risk management approaches and enhanced business case evaluations were developed. The risk management applications illustrate how using CoF information, along with probability of failure insights, can help justify access to capital improvement plan and operations budgets for targeted resiliency- or robustness-enhancing programs and other risk management activities.

Developing Economic and Financial Analysis Guidelines for Water Supply, Wastewater, and Other Sanitation Components of Urban Development Projects.
Client: Asian Development Bank,

Dr. Raucher developed guidelines for the financial and economic analysis of sanitation components (water supply, wastewater, solid waste, drainage improvement, and flood protection) of urban development projects. The project entailed providing technical guidance and case illustrations for the application of management issues including demand forecasting, financial management, cost recovery, and sustainability evaluations. The guidelines also address the issues of measuring benefits and costs of infrastructure investments that are designed to protect and enhance public health, safety, and environmental conditions.

Value of Water Supply Reliability in the Commercial, Industrial, and Institutional (CII) Sectors
Client: WateReuse Research Foundation

Dr. Raucher served as Principal Investigator (PI) examining the value of water supply reliability for key customer classes in the CII sectors. Utility managers and others recognize that water supply reliability is highly valued by their communities, including residential, agricultural, business, and other CII customers. However, there has been limited suitable CII customer valuation data that had made these reliability benefits difficult to quantify in a meaningful and credible manner. The project reviewed water-use data collected for CII customers, and identified key CII subsectors by overlaying water use data with data on local economic output by subsector. Businesses in key CII subsectors were interviewed in order to understand potential impacts on economic output and employment from water-use curtailment scenarios. This information is designed to be used for multiple purposes, such as evaluating the added value of projects that increase the reliability of a community's water supply for key businesses. By examining the value of water supply reliability in important commercial and industrial sectors, this study provides a useful basis for determining how much "value added" is provided by potential investments in water rights banking, water reuse, and other projects that enhance overall water supply reliability.

Triple Bottom Line (TBL) Analysis of Green Infrastructure for Stormwater Management
Client: Philadelphia Water Department

Dr. Raucher led a pioneering TBL analysis of a series of "green" alternatives for stormwater management measures. The TBL analysis revealed significant co-benefits and related opportunities to incentivize the use of GI on public and private spaces in lieu of an exclusive reliance on traditional "gray" infrastructure approaches. This TBL analysis was instrumental in enabling the City of Philadelphia's to convince the US EPA Enforcement program to include green infrastructure as a significant portion of the approved compliance plan for the City's Combined Sewer Overflow Consent Decree.

Evaluating Long- and Short-term Water Sector Planning under Climate Change
Client: WateReuse Research Foundation

Dr. Raucher served as PI evaluating how water resource professionals, including managers of water or wastewater utilities, can best include climate change considerations in their ongoing planning and decision-making processes. The focus was on providing pragmatic guidance to assist managers in identifying key vulnerabilities, and how to effectively operationalize an adaptive management approach for managing their climate-related risks. The report includes pragmatic guidance, as well as technical background chapters on key issues such as climate change modeling and downscaling, and three detailed case studies of three different regions. The use of nontraditional water supply options (including water reuse, desal, stormwater capture, and conservation) serve as focal points as no/low regrets options to enhance flexibility, diversify portfolios, and provide greater supply reliability and resilience in the face of uncertain but potentially significant climate change risks.

The Value of Water, and the Role of Water Values in Water Supply Management
Client: Water Research Foundation

Dr. Raucher was PI on this project that examined the value of water in its many applications (including instream and extractive uses). This research describes a range of value concepts and measures that apply to water resources and water service provision, demonstrates how to estimate the value of water, and how it can be incorporated into the planning and management functions of water utilities and other water resource management agencies. Water valuation is being explored for a broad range of water uses and settings, including (1) conjunctive use values using reclaimed water; (2) commercial, industrial, and institutional (CII) values for reuse water applied to industrial proposes; (3) instream uses for ecological purposes, hydropower generation, and recreation; and (4) extractive use values for agricultural, industrial, and municipal (residential) users. Cases were developed to help illustrate relevant concepts, valuation methods, and the practical application of empirical findings to relevant water management issues. (2004)

Challenges, Practical Approaches, and Opportunities for Pricing Reuse Water
Client: Water Research Foundation (WRF)

For WRF project 4662, Dr. Raucher served as PI developing a report examining the challenges and effective strategies for allocating water reuse costs, and effective strategies for assessing the beneficial value reuse projects may provide and using a “beneficiary pays” cost of service for reuse, and developing rates and related revenues to support full cost recovery. The project included an informative survey of a diverse array of utility participants (17 reuse utilities drawn from across the U.S., and including 2 from Australia), and developing 10 in-depth utility case studies.

Affordability Assessment Toolkit for Water, Wastewater, and Stormwater Management
Clients: Water Environment Federation, AWWA, and the US Conference of Mayors

Dr. Raucher and Janet Clements examined how stormwater, wastewater and water supply regulatory mandates and infrastructure renewal needs are creating considerable fiscal pressures on utilities and affordability issues for the communities they serve. Dr. Raucher and Ms. Clements led an assessment -- and developed a toolkit for utility practitioners -- of how to measure and reflect the affordability of these services, in the context of a utility’s socioeconomic diversity and economic realities. They contrasted these approaches to the standard U.S. Environmental Protection Agency metrics.

National Drinking Water Advisory Council (NDWAC): Benefits, Costs, and Affordability Workgroups. Dr. Raucher served as AWWA-nominated member of three NDWAC workgroups and contributed recommendations to how to more meaningfully evaluate affordability. He also served on NDWAC

workgroups recommending approaches for improved estimation of the benefits and costs of drinking water regulations.

Selected Publications

"Alternatives Analysis" (Chapter 9). 2017. *M50: Water Resource Planning*. Third Edition. American Water Works Association, Manual M50. Denver, CO.

Effective Rate Approval Process Communication Strategies. 2016. With J. Mastracchio, J, R. Giardina, K. Raucher, et al. WRF project 4455. Denver, CO.

Using Graywater and Stormwater to Enhance Local Water Supplies: An Assessment of Risks, Costs and Benefits. 2016. Principal author of chapters 7 and 9. National Academies of Sciences, Engineering and Medicine (NAS). Washington, DC. National Academies Press.

The Value of Water Supply Reliability in the Commercial, Industrial and Institutional (CII) Sectors. 2015. Principal Investigator R.S. Raucher, with J. Henderson, J. Clements, Michael Duckworth, Jack C. Kiefer, Ben Dziegielewski and other contributing authors and project team members. WateReuse Research Foundation. Alexandria, VA.

The Opportunities and Economics for Direct Potable Reuse. 2014. With G. Tchobanoglous. WateReuse Research Foundation. November.

Desalination Concentrate Management Policy Analysis for the Arid West. 2014. with E.G. Archuleta, J. Clements, and M. Mickley. 2014. WateReuse Research Foundation, Alexandria, VA.

"Water Reuse Key to Utility Planning," with K. Raucher. 2013. *World Water: Water Reuse & Desalination* 4(3):25–27.

The Value of Water Supply Reliability in the Residential Sector. 2013. with J. Clements, C. Donovan, D. Chapman, R. Bishop, E. Horsch, G. Johns, M. Hanemann, S. Rodkin, and J. Garrett (contributing authors and project team members). WateReuse Research Foundation. Alexandria, VA.

"Optimizing Reliability: Portfolio Modeling of Contract Types for Retail Water Providers," with R. Kidson, B. Haddad, H. Zheng, and S. Kasower. 2013. *Water Resources Management* 27(9):3209–3225.

"Benefit-Cost Analysis for Drinking Water Standards: Efficiency, Equity, and Affordability Considerations in Small Communities," with S.J. Rubin, D. Crawford-Brown, and M.M. Lawson. 2011. *Journal of Benefit-Cost Analysis* 2(1): Article 4. DOI: 10.2202/2152-2812.1004.

"No Doubt About Climate Change and Its Implications for Water Suppliers," 2007. with J. Cromwell and J.B. Smith. *Journal AWWA* 99(9):112-117.

"Extending the Integrated Resource Planning Process to Include Water Reuse and other Nontraditional Water Sources," 2007. with J. Whitcomb, G. Fiske, J. Henderson, K. Hallett, and C. Kenney. WateReuse Research Foundation (Alexandria, VA), with funding support from the California State Water Resources Control Board, and U.S. Bureau of Reclamation.

"The Future of Water Desalination and Reuse: Factoring Climate Change and Other Issues into the Equation," 2007. with K. Hallett, J. Smith, and J. Cromwell. *The Environmental Benchmarker & Strategist*. Spring.

An Economic Framework for Evaluating the Benefits and Costs of Water Reuse, 2006. with K. Darr, J. Henderson, R. Linsky, J. Rice, B. Sheikh, and C. Wagner. Final Project Report and User Guidance. 03-006-02. WateReuse Foundation, Alexandria, VA.

"Intersubject Variability of Risk from Perchlorate in Community Water Supplies," with D. Crawford-Brown and M. Harrod. 2006. *Environmental Health Perspectives* 114(7):975-979.

The Value of Water: Concepts, Estimates, and Applications for Water Managers, with R. Linsky, E. Means, B. Hurd, J. Goldstein, A. Huber-Lee, and M. Renwick et al. 2005. Awwa Research Foundation, Denver, CO.

"The Value of Water: What It Means, Why It's Important, and How Water Utility Managers Can Use It." 2005. *Journal AWWA* 97(4):90-98.

"Water Utility Customer Attitudes and Values: Insights from Recent AwwaRF-Sponsored Research." 2005. *Drinking Water Research* 15(3): May/June.

Conventional and Unconventional Approaches to Water Service Provision, with M.L. Hagenstad, J. Cotruvo, R. Narasimhan, K. Martin, H. Arora, R. Regunathan, J.A. Drago, and F. Pontius. 2004. Awwa Research Foundation and American Water Works Association, Denver, CO.

"Economics of Conjunctive Use of Groundwater and Surface Water," with E.G. Reichard. 2004. *Water Resource Issues, Challenges and Opportunities*, R. Lawford (ed.). American Geophysical Union, Washington, DC.

Water Reuse Economic Framework: Workshop Report 2004. 2004. WateReuse Foundation and National Water Research Institute, Alexandria, VA.

"Benefit-Cost Analysis and Drinking Water Regulation." 2003. *Drinking Water Regulation and Health*, F.W. Pontius (ed.). ISBN: 0-471-41554-5. John Wiley and Sons, New York.

"Blending Science with Policy: Precautionary Assumptions and Their Impact on Benefit-Cost Analyses and Drinking Water Standards." 2003. *Critical Issues for Setting Regulatory Standards (second edition)*. Compiled and published by National Rural Water Association, Duncan, OK.

Additional information available upon request

KAREN S. RAUCHER

COMMUNICATION

POLICY STRATEGIST

Education

Master of Environmental Policy, *Yale School of Forestry and Environmental Studies,* 1983.
Short Course Certificate in Facilitation and Mediation, *Yale School of Organization and Management,* 1982.
Bachelor of Arts Honor, Independent Studies: Environmental Economics, *University of Oregon Honors College*, 1979.

Selected Experience

- ***Communication Policy Strategist, Raucher LLC. 2019 - Current***
  Ms. Raucher is an expert in developing communication strategies that build community understanding, trust, and support for adaptation to complex, highly uncertain futures. Karen has extensive experience building measurable changes using strategic communication plans that use an understanding of audience needs and risk communication strategies to build messages that resonate and affect values, beliefs, attitudes, and behaviors. Karen has a passion for using cutting-edge communication research to support the appropriate use of data and knowledge in personal and public complex, and highly uncertain decision processes -- including public health, climate change adaptation, sustainable and resilient long-term planning, managing contaminants of emerging concern, and environmental policy and rulemaking.
- ***Communication Policy Strategist, Corona Environmental Consulting. 2016 - 2019***
- ***Senior Associate, Abt Associates/Stratus Consulting. 1999–2016***
- ***At Risk Youth Program Director, Casey Middle School. 1997 - 1999***
- ***Policy Analyst, Environmental Protection Agency, Office of Policy, Planning, and Analysis. 1983–1986***

Recent Projects

Trending in an Instant: A Guide to the Use of Risk Communication Best Practices in Social Media for Water Professionals.

Client: American Water Works Association
Ms. Raucher is the risk communication content expert on this guide to water professionals on how to apply risk communication best practices to social media, both proactively and reactively. The Guide provides water professionals with an overview of how to use social media to build the utility's reputation as the *Trusted Source* for water information. The Guide also provides users with a checklist of things to think about and consider doing if they face a negative media event.

Raucher LLC
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Capacity Charge Customer Assistance Program Development

Client: King County, Department of Natural Resources and Parks (DNRP), Seattle, Washington

Ms. Raucher led King County DNRP through a collaborative process and an economic analysis to identify fiscally responsible opportunities that will provide customer assistance to those enrolled in the King County Capacity Charge Wastewater fee (currently about $15,000 per wastewater system hook-up). The project resulted in the King County Council's unanimous passage of four highly diverse affordability support programs that will bring *meaningful* support to seniors, the young, and those with both long-term and short-term financial challenges.

Building Resilience to A Changing Climate: A Technical Training in Water Utility Decision Support

Client: US Environmental Protection Agency and the Water Utility Climate Alliance

Ms. Raucher was a key trainer for the EPA/WUCA-sponsored training for water resource professionals designed to support the integration of climate science and new decision support and communication tools into comprehensive water resource planning. Karen supported the development and delivery of training on how to address the communication challenges created by the Wicked attributes of climate change, and how to use risk communication best practices and neurological insights to build the knowledge base decision makers need to appropriately use information with large levels of scientific complexity and high uncertainty.

Santa Cruz Water Supply Advisory Committee (WSAC): Adaptive Long-Term Planning Facilitation and Training

Client: City of Santa Cruz, Santa Cruz Water Department, California

Ms. Raucher co-led the technical team guiding a City Council-appointed citizens committee through a high-profile Integrated Resource Planning process. The committee consisted of 14 citizens representing diverse stakeholder groups. Ms. Raucher developed and led a series of tutorials and training exercises that built understanding in lay audiences of the primary issues and challenges facing water supply planning, including climate change; supporting the Committee's ability to reach consensus for an Adaptive Long-Term Water Supply Plan. Karen and Raucher LLC are currently continuing this work by bringing in Casey Brown, University of Massachusetts, to conduct a bottom-up decision-scaling stress test of the City's adaptive management plan to identify triggers and tipping points. The stress text includes an examination of community objectives to ensure the selected approach can be supported by community values.

Reaching Hard-to-Reach Customers

Client: Water Research Foundation (WRF)

Ms. Raucher developed guidance for water utilities on how to approach the challenge of identifying and developing financial assistance programs for customers who do not directly receive a water utility bill; i.e., the "hard to reach." The final report provides the water industry with a summary of a broad range of hard-to-reach affordability challenges and includes a business process and a set of communication strategies utilities can apply to both identify the need for and respond with effective provision of targeted assistance. The guidance in this document was used as a template for the successful collaborative process used in the selection of King County (WA) Capacity Charge assistance programs.

Cyanotoxin Risk Communication Guidance and Toolkit

Client: Water Research Foundation

Ms. Raucher led a collaborative process of water utility, public health and regulatory agency members in the development of a toolkit states and communities can use to share information about the risks of cyanotoxin in drinking water clearly and accurately. The toolkit and communication approach supports the ability of the public to make appropriate health decisions for themselves and their families.

Embracing Uncertainty: A Case Study Examination of How Climate Change is Shifting Water Utility Planning

Clients: Water Utility Climate Alliance, the American Water Works Association, the Water Research Foundation, and the Association of Metropolitan Water Agencies

Ms. Raucher and her team interviewed more than 35 water utilities around the world to identify how community water providers across the globe are changing their decision-making processes due to their need to plan for the unprecedented levels and layers of uncertainty associated with climate change. One of the major findings of this study is the need for water utilities to understand their communities' unique water drivers (e.g., does the community want unfettered economic growth, in which case supply reliability is crucial, or does the community fear that an increase in water supply will lead to unwanted growth?). As part of this study, Karen reviewed the primary decision models being used -- including optimization, scenario planning, and robust decision making - and summarized insights from users as to the pragmatic pros and cons of each approach under large uncertainty.

Affordability and the Value of Water in Northeast Ohio

Client: Northeast Ohio Regional Sewer District (NEORSD), Cleveland, Ohio.

Ms. Raucher worked with the NEORSD utility to increase their understanding of the relationship between their customers' values for water, wastewater rates, and a community-wide definition of affordability. This research identified primary messages the agency can use to build community understanding of their combined sewer overflow (CSO) Consent Decree. Karen's audience segmentation analysis provides NEORSD with insights into the value-rates-affordability nexus for large groups of customer/audience segments, rather than the mythical average customer. For example, the study found that over one-third of customers do not believe there is anything NEORSD can do to improve water quality in the region, identifying a significant messaging opportunity.

Water Professional Use of Highly Uncertain Climate Change Information

Client: Water Research Foundation

Ms. Raucher designed and implemented, with her team, a survey of water professionals that identifies their ability to gather, use, and share data with the new kinds and magnitudes of uncertainty being used in a wide range of planning activities from infrastructure and financial management to long-term supply and demand analysis. The survey also captured the need, across business functions, for training and education.

Effective Climate Communication for Water Utility Stakeholders

Clients: Water Research Foundation, AWWA, AMWA

Ms. Raucher was the lead researcher on this project, which focused on providing pragmatic insights to water utilities on how to communicate climate change to a wide range of audiences, including internal staff, customers, Governing Board members, the media, and special interest groups. Ms. Raucher and her team (including Dr. Tony Leiserowitz, Yale Climate Change Communication project) designed and conducted a state-of-the-art nationally representative public survey. Karen and her team then analyzed the findings to identify -- based on attitudes, beliefs, values and actions -- how Americans are segmented in their reactions to messages concerning community water and climate change. This report also includes a message-mapping tool that utilities can use to develop powerful, connecting, long-term communication strategies.

Speaking and Facilitation

Ms. Raucher is a respected and engaging speaker and facilitator. She has shared her research at a wide range of research conferences and has successfully facilitated a large number of workshops and collaborative processes.