Memorandum

June 27, 2019

To: Dan Heilig, Wyoming Outdoor Council, Lander, WY

From: Harold Bergman, PhD, Professor Emeritus, University of Wyoming, Laramie, WY; and
Joseph Meyer, PhD, Chief Scientist, Applied Limnology Professionals LLC, Golden, CO

Regarding: Analysis of, and comments on, proposed WDEQ Wastewater Discharge Permit for Aethon Energy Operating, LLC – WY0002062 Renewal

We have reviewed a series of documents including WDEQ-WQD's proposed WYPDES discharge permit WY0002062 renewal for Aethon Energy Operating, LLC; Aethon's application for this permit renewal dated August 8, 2016; portions of Environmental Resources Management's (ERM's) Water Quality Compliance Analysis report to Aethon Energy dated April 23, 2018; and ERM's Modeling Study Addendum (undated). We also have reviewed and used a number of peer-reviewed publications on the chemistry of produced waters from oil and gas operations and the toxicity of these waters to aquatic biota, and we have cited these references, as appropriate, in the text below.

In the text that follows, we present our analyses, conclusions and positions related to water chemistry and aquatic toxicity of Aethon's produced water and WDEQ's proposed issuance of a discharge permit renewal for Aethon's discharge. We then present a number of major concerns and recommendations related to this proposed permit renewal.

Water Chemistry

Untreated Produced Water Discharge. The WDEQ's proposed discharge permit for Aethon Energy's proposed Moneta Divide oil and gas field would allow discharge of a maximum of 8.274 MGD[1] (million gallons per day) of oil and gas field produced water, with 2.436 MGD untreated and approximately 5.838 MGD treated by reverse osmosis. Without an accompanying discharge of treated water, 2.856 MGD of untreated water would be allowed. The only measured water quality data presented in the Aethon permit application or the WDEQ proposed discharge permit are in Table 2 of Aethon's application, for a water sample collected on 3/2/2017 from Outfall 006 (see Aethon's Table 2 untreated water chemistry). Thus, this water sample is a raw produced water sample (treated only with a skim pond at Outfall 006) from the "Central Facility separators." This set of water quality analyses is offered by Aethon in their application as "representative of the quality of water being proposed for discharge" (question 14 on page 5 of the Aethon application).

There are several major inadequacies in Aethon's Table 2 "representative" water quality analysis results. In particular, there are no measurements or possibly misleading values for the following important water quality parameters:

[1] For comparison, the treated wastewater discharge for representative Wyoming cities are as follows: Riverton = 1.9 MGD for ~11,000 people, Laramie = 4.5 MGD for ~32,000 people, and Casper = 10 MGD for ~58,000 people.

- Alkalinity and Bicarbonate ion concentration – Alkalinity and bicarbonate ion (HCO_3^-) measurements were not included in Aethon's Table 2 chemistry results. However, alkalinity (expressed as mg calcium carbonate/L) along with the reported pH of 7.31 (Table 2 from application) allows calculation of concentrations of bicarbonate, carbonate and hydroxide, that all contribute to total alkalinity. The bicarbonate ion (HCO_3^-) concentration is particularly important to know because bicarbonate is an important determinant for understanding and predicting toxicity to aquatic biota (see Aquatic Toxicity section, below). Because the Aethon Table 2 chemistry suffered from a very large charge imbalance (many fewer total negative charges than total positive charges per liter), and because the total charge of a water sample must be neutral, we were able to calculate the following estimate for the alkalinity and bicarbonate concentrations (assuming all of the deficiency of negative charges was due to alkalinity/bicarbonate): Alkalinity ~ 2,732 mg/L as $CaCO_3$; bicarbonate ~ 3,333 mg/L. These are quite high values not typical of most surface waters, but they are not uncommon for co-produced waters from deep oil and gas fields.
- Potassium (K^+) – No analyses of K^+ were included in Aethon's Table 2 chemistry results. However, based on a number of aquatic toxicity studies, K^+ can contribute more to aquatic toxicity than other constituents of typical saline produced waters when at similar concentrations (Mount et al., 1997). Thus, the K^+ concentration would be an important determinant for understanding and predicting toxicity of the produced waters to aquatic biota (see Aquatic Toxicity section, below). If K^+ was present in the Table 2 production water (which is highly likely) and its concentration had been reported, the estimated alkalinity and bicarbonate concentrations presented in the previous bullet would be even higher.
- Chloride (Cl^-) – The water chemistry for Aethon's "representative" discharge presented in Table 2 of Aethon's application shows a one-time analysis for chloride of 1840 mg/L. Yet the level allowed in WDEQ's proposed permit for an end-of-pipe chloride concentration is 2419 mg/L (based on an "historic effluent concentration" according to information in a footnote in WDEQ's proposed permit, though no supporting information is presented). And WDEQ-WQD's special end-of-pipe limit for chloride concentrations in oil and gas produced water discharges is 2000 mg/L (Chapter 2, Appendix H). But Appendix H also specifies that "[i]n no case shall any produced water discharge contain toxic materials in concentrations or combinations which are toxic to human, animal or aquatic life" (Appendix H(b)(i)). To assess the possibility of toxic effects on aquatic life, we need to consult Wyoming's water quality criteria for protection of aquatic life in receiving waters listed in WDEQ-WQD's Chapter 1 (Appendix B). Wyoming's aquatic life criteria for chloride are 860 mg Cl^-/L as an acute criterion (to protect for survival) and 230 mg Cl^-/L as a chronic criterion (to protect for reproduction and growth). These criteria are in agreement with EPA's recommended acute and chronic criteria listed in EPA's ambient water quality criteria document for chloride https://www.epa.gov/wqc/aquatic-life-ambient-water-quality-criteria-chloride-1988. Thus, to avoid adverse effects on fish and aquatic invertebrates, WDEQ's permitted end-of-pipe chloride discharge concentration of 2419 mg/L in the proposed permit would need to be diluted almost 3-fold to avoid in-stream acute effects (e.g., mortality of fish and aquatic invertebrates) and diluted more than 10-fold to avoid in-stream chronic effects (e.g., reproduction and growth of fish and aquatic invertebrates). Yet, no information is provided for dilution flow or water quality in Alkali or Badwater Creeks in

either Aethon's permit application or in WDEQ's proposed permit. (Also see comment on Alkali and Badwater Creeks, below.)

- Sulfide – Hydrogen Sulfide (H_2S) – The WDEQ's water quality standard for H_2S is 2 μg/L. However, the reported measurement in Table 2 of Aethon's application is listed as <40 μg/L (presumably the detection limit for the analytical method used by Aethon), which does not provide assurance that the H_2S concentration meets the water quality standard. [Note that the Required Detection Limit shown in Table 2 for H_2S is 0.1 mg/L (100 μg/L), which is far too high for Aethon and WDEQ to determine whether the discharge meets the 2 μg/L standard; thus we assume that the 0.1 mg/L detection limit for H_2S shown in Aethon's Table 2 is an error].
- Benzene and BTEX – No analytical results are presented for Benzene or BTEX (Benzene, Toluene, Ethylbenzene, Xylene). This is a serious shortcoming, because many oil and gas produced waters can contain quite high concentrations of these very toxic compounds.
- Chemicals associated with treatment of oil and gas wells – These well treatment chemicals often associated with completion or maintenance of oil and gas wells (such as hydraulic fracturing or "fracking" chemicals) can be highly toxic, and may be present in "flow back" water or produced waters from unconventional well completions. Reported effects from these kinds of chemicals can include endocrine disruption with potential adverse human health or environmental effects (Kassotis et al., 2018), yet no information is presented in either Aethon's application or WDEQ's draft permit on presence or potential presence of these chemicals in existing or future discharges from the Aethon facilities.
- pH – The pH value reported by Aethon in Table 2 is 7.31, which is within the acceptable range of pH 6.5 to 9.0 at the outfall. However, we used the reported pH value and other chemistry from Table 2 along with our estimate of the alkalinity concentration in the discharge water from Outfall 006 to determine that, using the Windermere Humic Aqueous Model (WHAM) geochemical-speciation software (Lofts, 2012), the partial pressure of carbon dioxide (pCO_2) is highly over-saturated at the elevation of the Aethon facility (note that over-saturated CO_2 would be expected from a deep-water well). With Table 2 chemistry, including a calculated alkalinity of 2,732 mg $CaCO_3$/L (see above) and assuming a temperature of 25 ^oC, the dissolved concentration of CO_2 in Aethon's discharge would be approximately 193.6 mg/L, while the concentration of CO_2 in water in equilibrium with the atmosphere at Aethon's elevation and 25 ^oC would be 0.52 mg/L. Thus, 193.6/0.52 yields approximately 372-fold over-saturation of CO_2 at the outfall, given the water chemistry listed in Table 2.

  This means that CO_2 will de-gas from the discharge water as it flows downstream in Alkali Creek and Badwater Creek. As CO_2 de-gasses from the stream water, the CO_2 concentration will approach equilibrium with the atmosphere, the H^+ concentration in the water will decrease as a consequence, and thus the pH of the water will increase. The table below demonstrates that the WHAM-predicted pH of the full-strength produced water listed in Table 2 would reach as high as approximately 9.6 if the produced water fully equilibrated with the atmosphere and was not diluted by air-equilibrated water (i.e., the pH values listed in the "Full strength" column of the table, below, are approximately 9.6). That pH would violate the current Wyoming water quality standard (i.e., the pH would exceed the upper limit of pH 9) and would cause toxicity concerns for most fish species and other aquatic biota. Even if diluted to only $1/10^{th}$ of full-strength water (i.e., 1 part produced water diluted by 9 parts air-equilibrated water), the WHAM-predicted pH in equilibrium with the atmosphere would still be at or near 9 (i.e., pH 8.8-9.0 in the "1/10 Full strength" column, below). Thus, although a 10-fold dilution of the produced water might decrease its salinity to an acceptable concentration for aquatic life in Badwater Creek and/or after subsequent dilution on entry into Badwater Bay on Boysen Reservoir, pH should be recognized as a potentially more important driver for water quality in Badwater Creek and Badwater Bay than is salinity (which is what ERM's acceptable-discharge calculations were based on).

Summary of WHAM calculations with Table 2 water chemistry for full-strength untreated produced water and produced water diluted with distilled water to 1/2, 1/5, and 1/10 of full strength

	Equilibrium pH					
Temp. (C)	Full strength	1/2 Full strength	1/5 Full strength	1/10 Full strength	pCO_2 that produces pH 7.31 (atm CO2)	CO_2 super-saturation ratio
0	9.59	9.38	9.05	8.79	0.104	306
10	9.57	9.37	9.06	8.80	0.109	321
20	9.58	9.39	9.09	8.84	0.122	359
30	9.61	9.43	9.15	8.91	0.148	435
40	9.66	9.50	9.24	9.00	0.193	568

These results demonstrate that (1) the alkalinity of the produced waters released from Aethon's operations should not be ignored in a discharge permit, given the type of water chemistry listed in Table 2 in Aethon's permit application; and (2) the pH of this type of produced water at its point of release might be considerably lower than the pH at distances downstream in the receiving drainage, even with (and sometimes especially without) mixing of the produced water with other, air-equilibrated water. Because we are unaware of any measurements of pH and alkalinity in Alkali Creek, Badwater Creek and Badwater Bay that would indicate the extent of pH increase downstream from current discharge points for produced water from the Moneta Divide, we strongly recommend that, at a minimum, the temperature, pH, alkalinity and flow of Alkali Creek and Badwater Creek should be monitored at least monthly immediately upstream and downstream of Aethon's current discharges and also in Badwater Bay. That monitoring should begin at least one year before a final permit is signed, so preliminary knowledge of annual variations of temperature, pH, and alkalinity in Alkali Creek, Badwater Creek and Badwater Bay can be used to better establish acceptable dilution factors for untreated produced water discharged by Aethon. A plume of elevated pH entering Badwater Creek and Badwater Bay could easily degrade the quality of those waterbodies as a nursery for young fish.

In addition to the recommended field monitoring, Aethon should also be required to incorporate these pH and alkalinity concerns into ERM's model that was used to calculate acceptable discharge and dilution rates (which were based on salinity concerns in Aethon's permit application, not on pH and alkalinity concerns). And as an extension, all inputs of produced water to Badwater Creek from both the Aethon and the Burlington operations should be combined in those calculations, to produce a cumulative-effects analysis.

Treated produced water using reverse osmosis. The proposed WDEQ permit specifies that of the maximum of 8.274 MGD ultimately allowed under this proposed permit, 5.838 MGD must be treated with reverse osmosis (RO-treated). Yet, we could find no water chemistry analysis results for discharge from the existing Neptune Water Treatment Facility that uses reverse osmosis; only a process flow diagram is presented in Appendix C of the application, and no water chemistry results are presented in the application or the proposed permit for the water discharged from this Neptune Facility at Outfall 001. Though no water chemistry measurements were presented for outflow from the Neptune Facility RO-treated water in Aethon's application or WDEQ's proposed permit, ERM's consulting report to Aethon presents operator-guaranteed treated Neptune effluent concentrations for several key parameters, as follows (ERM report, page 155):

- TDS = 350 mg/L (ppm)
- Chloride = 150 mg/L
- Sulfate = 40 mg/L
- Oil & Grease = 10 mg/L

Additionally, Aethon's measured post-treatment pH averaged from 3 years of daily measurements was 7.47 (ERM report, page 155).

This lack of actual water chemistry is important, because dilution of produced water with RO-treated water will result in higher salinity and alkalinity and a different pH than if the produced water would be diluted with distilled water. This means that the pH estimates in the table above (which assumed dilution of produced water with distilled water) likely differ from pH estimates that would be based on dilution with RO-treated water. But without reliable chemistry of Aethon's RO-treated water, the extent of the likely underestimates of the equilibrium pH in Badwater Creek is unknown.

Alkali Creek and Badwater Creek. No water chemistry or flow information is presented for Alkali Creek or Badwater Creek above and below the Aethon produced water discharges, and no thorough analysis of potential effects of Aethon's discharge on aquatic biota can be completed without this information. Moreover, monthly water chemistry and flow data for Alkali and Badwater Creeks would be needed for at least a 1-year monitoring period to account for variations in chemistry and flow, due to differences in dilution flows and water quality especially during low-flow periods of an annual hydrologic cycle.

Aquatic Toxicity

Highly saline co-produced waters from oil and gas operations typically have very poor water quality with very high concentrations of total dissolved solids (TDS) and other constituents. Adverse effects of discharging these saline production waters on aquatic biota have been reported from as early as 1924 (Wiebe, Burr and Faubion, 1924; Clemens and Jones, 1954).

In a study conducted by researchers at the University of Wyoming (UW) from 1988-1990 (Boelter et al., 1992), toxicity tests with larval Fathead Minnows (*Pimephales promelas*) and a water flea (*Ceriodaphnia dubia*) were conducted on water samples collected from Salt Creek and the Powder River below the Salt Creek oil field near Kaycee, Wyoming. Boelter et al. (1992) reported significantly decreased survival and reproduction in 7-day toxicity tests with *C. dubia* and significantly decreased growth in 7-day tests with Fathead Minnow larvae, as compared with reference water samples collected upstream from produced water discharges from the Salt Creek oil field. These significant toxic effects were measured in ambient water samples collected as far as 124 km downstream from produced water discharges in the Salt Creek oil field, particularly during low-flow periods in Salt Creek and the Powder River. It is important to note that analyzed concentrations of alkalinity, sodium, chloride and bicarbonate in Salt Creek and the Powder River producing significant reductions in survival, reproduction and growth of aquatic test organisms in the Boelter et al. (1992) study were approximately one-half to as little as one-tenth the concentrations of these same parameters reported (sodium and chloride concentrations reported in Table 2 in the Aethon application) or calculated for Aethon's untreated produced water at Outfall 6 (calculated alkalinity and bicarbonate concentrations as presented in the Water Chemistry section, above).

In part as a response to EPA's new effluent biomonitoring requirements implemented in the 1980's as Whole Effluent Toxicity (WET) tests, the Gas Research Institute (GRI) funded a series of studies to develop models that could be used to predict the toxicity of produced waters of varying quality from oil and gas operations. These studies were initiated at the University of Wyoming and then continued by former UW graduate students in a series of collaborations that included UW, ENSR Corporation, USEPA, and others (Gulley et al., 1992; Mount et al., 1992; Mount et al., 1997; and Tietge et al., 1997). In this series of studies, almost 3000 toxicity tests were conducted to measure survival of Fathead Minnows and two species of water fleas (*C. dubia* and *Daphnia magna*) exposed to different ionic mixtures that spanned the range of water chemistries typical of produced waters from oil and gas operations. Results from these toxicity tests were incorporated into multivariate logistic regression models that predict the acute (i.e., short-term) survival of the three test species (48-hour survival for the water fleas, 96-hour survival for the Fathead Minnow) based on the major-ion concentrations typical of oil and gas produced waters. The best-fit models for survival of all three species are presented in Table 4 of the paper by Mount et al. (1997), entitled *Statistical Models to Predict the Toxicity of Major Ions to Ceriodaphnia dubia, Daphnia magna and Pimephales promelas (Fathead Minnows)*. The utility of these models for reliably predicting acute lethality of oil and gas produced waters as well as other saline waters is amply illustrated or cited by Mount et al. (1992), Mount et al. (1997) and Tietge et al. (1997) using comparisons of actual measured toxicity from published studies and predicted toxicity using these models.

In addition to the ability to predict the acute lethality of various major-ion mixtures in produced waters to these three species, the researchers were also able to rank the relative toxicity of various ion constituents in typical produced waters (Mount et al., 1997), as follows:

$$K^+ > HCO_3^- \sim Mg^{2+} > Cl^- > SO_4^{2+}$$

These researchers also noted that Na^+ and Ca^{2+} were not significant variables in any of the models.

It is important to note that, in spite of this knowledge about relative contributions of various major ions in produced waters to aquatic toxicity, Aethon's reported produced water chemistry (Table 2 in Aethon's application) does not include analyses for K^+ or HCO_3^-; nor does it include analysis results for alkalinity, which would allow calculation of the HCO_3^- concentration. We presume that this is possibly because WDEQ does not have a water quality standard and monitoring requirements for potassium, bicarbonate or alkalinity. We strongly recommend that any permit that WDEQ issues for the Aethon facility, or for any other discharge of untreated or treated well-field produced water, should include a monitoring requirement and water quality standards for potassium, bicarbonate and alkalinity.

Based on the utility and proven reliability of the Mount et al. (1997) multivariate logistic-regression models for accurately predicting toxicity of saline produced waters, we ran these models using input chemistry from Table 2 in Aethon's permit application, which Aethon claims to be "representative of the quality of water being proposed for discharge" (Aethon permit application). We then supplemented the water chemistry data in Table 2 with our approximations of alkalinity and bicarbonate concentration necessary to achieve charge balance in the Table 2 chemistry (see the Water Chemistry section, above). Results of these model runs are shown in the table below. Note that these model runs with the undiluted, full-strength Aethon produced water predict zero percent (0%) survival for 48-hour lethality tests with *C. dubia* and *Daphnia magna* and zero percent (0%) survival for 96-hour lethality tests with Fathead Minnows. We also ran these models assuming dilution of the Aethon produced water in a series of up to a 10-fold dilution with distilled water. As shown in the table below, it was necessary to dilute Aethon produced water 10-fold with distilled water to achieve close to 100% survival for the three test species.

Model-predicted acute toxicity of Aethon produced water at full strength and after dilution with distilled water, based on model calculations using final regression equations presented in Table 4 in Mount et al. (1997).

Sample of Aethon produced water represented in Table 2 of application (Full Strength or Diluted)	Predicted Survival		
	C. dubia **48-hour survival (%)**	***D. magna*** **48-hour survival (%)**	**FHM 96-hour survival (%)**
Table 2 chemistry	0.0	0.0	0.0
Table 2 diluted 2x w/ dH2O	0.0	2.7	2.2
Table 2 diluted 3x w/ dH2O	2.4	34.8	27.6
Table 2 diluted 4x w dH2O	33.6	70.3	61.1
Table 2 diluted 5x w/ dH2O	75.6	85.2	78.6
Table 2 diluted 10x w/ dH2O	99.1	97.2	95.3

C. dubia = *Ceriodaphnia dubia*
D. magna = *Daphnia magna*
FHM = Fathead Minnow
dH2O = Distilled water

Note that longer-term effects on reproduction of *Ceriodaphnia* and growth of Fathead Minnows would occur at even greater dilutions of Aethon produced water than shown in the above table for short-term lethality. Thus, adverse effects on aquatic invertebrate communities in Alkali Creek and adverse effects on fish and aquatic invertebrates in Badwater Creek would be expected if untreated produced waters are not adequately diluted with good-quality water.

In fact, given the normal low flow in Alkali Creek (Class 3B with protected uses including aquatic life other than fish), defined in the draft permit (Statement of Basis, page 9) as "a low-flow stream, generally flowing only in response to storm events, snowmelt, or man-made discharges," and given our evaluation of likely pH increases in excess of pH 9 due to CO_2 de-gassing and given the predicted lethality of undiluted or modestly diluted historical produced water discharges, we are highly confident that a chemical and biological survey of Alkali Creek below Aethon's discharge would show existing (and likely future) violations of Wyoming water quality standards as well as lack of support of designated uses for aquatic life. Moreover, because Badwater Creek (Class 2AB with protected uses including a cold-water fishery) is also a "relatively low-flow, perennial stream" (Draft Permit, Statement of Basis, page 9), and given our assessment of (1) likely elevated pH exceeding 9 due to CO_2 de-gassing and (2) predicted lethality (as well as adverse effects on reproduction and growth of aquatic biota) with insufficient dilution of produced water discharges, we are highly confident that a chemical and biological survey of Badwater Creek would show existing (and likely future) violations of Wyoming water quality standards and lack of support for designated uses for aquatic communities and fish for a considerable distance downstream from the confluence with Alkali Creek.

Major Concerns and Recommendations

- The draft permit renewal for WY0002060 should not be approved – The permit renewal application and the draft permit, together, are severely inadequate and missing crucial information that would allow for evaluation of potential violations of end-of-pipe discharge limits, in-stream water quality standards, and effects on aquatic biota as a consequence of the discharges allowed under the proposed permit.
- Monitoring data necessary for evaluation of the proposed permit renewal – At a minimum, the temperature, pH, TDS, chloride, alkalinity, and flow of Alkali Creek and Badwater Creek should be monitored at least monthly immediately upstream and downstream of Aethon's current discharge in Alkali and Badwater Creeks and also in Badwater Bay. That monitoring should begin at least one year before a final permit is signed by WDEQ, so knowledge of annual variations of flow, temperature, pH, TDS, chloride and alkalinity in Alkali Creek, Badwater Creek and Badwater Bay can be used to better establish acceptable dilution factors for untreated produced water discharged by Aethon.
- Predicted elevation of pH above the pH 9 Wyoming water quality standard – The chemistry of untreated produced water discharged by Aethon will worsen as it flows down Badwater Creek (i.e., the pH of the water will increase and might exceed the in-stream Wyoming water quality standard for pH if not diluted adequately), thus posing a hazard for aquatic life in Alkali Creek, Badwater Creek and Badwater Bay. If pH becomes elevated in Badwater Creek and approaches or exceeds the Wyoming water quality standard's upper pH level of 9, Aethon's hydrologic analysis should be repeated to take into account the potential for adverse water chemistry changes downstream in Badwater Creek as the untreated produced water equilibrates with the atmosphere.

Averting such water chemistry changes might necessitate even greater dilution of the untreated produced water than the currently-planned-for salinity constraint in the Wind River downstream of Boysen Reservoir necessitates.

- Predicted toxicity of Aethon's untreated produced water – Based on a published model of the toxicity of saline oil and gas industry produced water to freshwater fish and invertebrates, Aethon's untreated produced water would have to be diluted at least 10-fold to avoid decreasing short-term survival of aquatic organisms; and it is likely that even more dilution would be needed to avoid longer-term, sublethal impairment (e.g., decreased growth and/or reproduction). Thus, averting such adverse effects in Alkali Creek, Badwater Creek and possibly in Badwater Bay might necessitate even greater dilution of the untreated production water than the currently-planned-for salinity constraint necessitates (which is based on projected salinity changes in the Wind River downstream of Boysen Reservoir).
- Contributions of potassium to the toxicity of Aethon's produced water discharge – The lack of an analysis for potassium in the water chemistry reported by Aethon means we have no way of knowing if the reportedly most-toxic major ion in the water (K^+) will be present at a high enough concentration to impair survival, growth, or reproduction of fish and other aquatic organisms.
- Inadequate hydrogen sulfide analyses in the permit application – The analytical method used for sulfides in the water chemistry reported by Aethon was not sensitive enough to determine whether the Wyoming water quality standard for sulfide will be exceeded and thus impair survival, growth, or reproduction of fish and other aquatic organisms.
- Cumulative effects of all discharges – Any analysis of the potential effects of Aethon's discharge of produced water should include the cumulative effects of all discharges into the Badwater Creek drainage (i.e., Aethon, Burlington, and any other discharges, current and future). And when evaluating the potential effects in the Wind River downstream of Boysen Reservoir, the cumulative effects of all discharges (current and future) in the entire Boysen Reservoir drainage should be considered.
- Toxicity testing requirements in the permit – To test whether Aethon's produced water discharges might adversely affect fish and/or other aquatic organisms in Alkali Creek, Badwater Creek and Badwater Bay, stricter toxicity testing requirements will be needed in a final discharge permit. Whole Effluent Toxicity (WET) tests should be required quarterly (rather than annually), include each outfall rather than a flow-weighted composite sample, include acute 48-hour lethality tests with *Daphnia magna* and acute 96-hour lethality tests with Fathead Minnows, and include chronic toxicity tests for 7-day larval Fathead Minnow growth and 7-day *Ceriodaphnia magna* reproduction (this *Ceriodaphnia* chronic test is now not included in the draft permit but would be important in evaluating potential effects of the discharge in Alkali Creek and Badwater Creek). Additionally, WDEQ should require Aethon to conduct a preliminary toxicity study before the discharge permit is finalized, to ensure the required dilution of untreated produced water is sufficient to avoid long-term toxicity downstream. To evaluate the possible effects of pH shifts to greater than pH 9 due to CO_2 de-gassing, these tests should include testing of both "fresh" untreated produced water and "aged" untreated produced water, with the length of the "aging" determined by the longest projected transit time for water between its discharge into Alkali Creek and its entry into Badwater Bay.

<u>**References Cited**</u>

Boelter, A.M., F.N. Lamming, A.M. Farag and **H.L. Bergman.** 1992. Environmental effects of saline oil-field discharges on surface waters. *Environ. Toxicol. Chem.* **11**:1187–1195.

Clemens, H.P. and **W.H. Jones.** 1954. Toxicity of brine water from oil wells. *Trans. Am. Fish. Soc.* **84:**97- 109.

Gulley, D.D., D.R. Mount, J.R. Hockett and H.L. Bergman. 1992. A statistical model to predict toxicity of saline produced waters to freshwater organisms. In J.P. Ray and F.R. Engelhardt, eds., *Produced Water: Technological/Environmental Issues and Solutions.* Plenum, New York, NY, USA, pp. 89–96.

Kassotis, C.D., D.C. Vu, P.H. Vo, C.H. Lin, J.N. Cornelius-Green, S. Patton and S.C. Nagel. 2018. Endocrine-disrupting activities and organic contaminants associated with oil and gas operations in Wyoming groundwater. *Arch. Of Environ. Contam. And Toxicol.* **75**: 247-258.

Lofts, S. 2012. User's Guide to WHAM7: Windermere Humic Aqueous Model, Version 7. Centre for Ecology and Hydrology, Natural Environment Research Council, UK.

Mount, D.R., K.R. Drottar, D.D. Gulley, J.P. Fillo and **P.E. O'Neil.** 1992. Use of laboratory toxicity data for evaluating the environmental acceptability of produced water discharge to surface waters. In J.P. Ray and F.R. Engelhardt, eds., *Produced Water: Technological/Environmental Issues and Solutions.* Plenum, New York, NY, USA, pp. 175–185.

Mount, D.R., D.D. Gulley, J.R. Hockett, T.D. Garrison and **J.M. Evans.** 1997. Statistical models to predict the toxicity of major ions to *Ceriodaphnia dubia, Daphnia magna* and *Pimephales promelas* (fathead minnows). *Environ. Toxicol. Chem.* **16**:2009–2019.

Tietge, J.E., J.R. Hockett and **J.M. Evans.** 1997. Major ion toxicity of six produced waters to three freshwater species: Application of ion toxicity models and TIE procedures. *Environ. Toxicol. Chem.* **16**:2002–2008.

Wiebe, A.H., J.G. Burr and **H.E. Faubion.** 1924. The problem of stream pollution in Texas with special reference to salt water from the oil fields. *Trans. Am. Fish. Soc.* **64:**231-85.

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EDUCATION
Eastern Michigan University Biology B.A., 1968
Eastern Michigan University Biology M.S., 1971
Michigan State University Fisheries Biology Ph.D., 1973

PROFESSIONAL POSITIONS
2011-2013 Department Head, Department of Zoology and Physiology, University of Wyoming
1995-2016 J.E. Warren Distinguished Professor of Energy and Environment, University of Wyoming
1998-2008 Director, William D. Ruckelshaus Institute and Helga Otto Haub School of
  Environment and Natural Resources, University of Wyoming
1988 Visiting Scientist, U.S. Environmental Protection Agency, Duluth, Minnesota
1986-1987 Acting Director, Wyoming Water Research Center, University of Wyoming
1984-2016 Professor, Department of Zoology and Physiology, University of Wyoming (Retired 2016)
1984-1999 Director, Red Buttes Environmental Biology Laboratory, University of Wyoming
1975-1984 Asst. & Assoc. Professor, Dept. of Zoology and Physiology, University of Wyoming

PROFESSIONAL AWARDS AND DISTINCTIONS (Selected)
Founder's Award, Society of Environmental Toxicology and Chemistry, 2018
Distinguished Faculty Graduate Mentor Award, University of Wyoming, 2014
Extraordinary Merit in Advising, Arts & Sciences College, University of Wyoming, 2014
Elected Fellow, American Association for the Advancement of Science, 1995
George Duke Humphrey Distinguished Faculty Award, University of Wyoming, 1995
Conservation Educator of the Year, Wyoming Wildlife Federation, 1986
President of the Society of Environmental Toxicology and Chemistry, 1984-85
President of the Water Quality Section, American Fisheries Society, 1982-83
Editorial Board, Environmental Toxicology and Chemistry, 1981-84
EPA Doctoral Traineeship, Michigan State University, 1971-73

STATE, NATIONAL AND INTERNATIONAL ADVISORY & REVIEW PANELS (Selected)
Wyoming Environmental Quality Council, 1983-95; Chairman, 1985-87
National Research Council - National Academy of Sciences Committees/Board
  Ecological Risk Assessment, 1986-87
  Animals as Monitors of Environmental Hazards, 1987-91
  NRC Board of Agriculture and Natural Resources, 2009-2016
Environmental Protection Agency, ORD, Peer Review Panels/Review Committees
  Exploratory Grants Program, Environmental Biology Panel, 1986-96
  National Acid Precipitation Assessment Program, Aquatic Effects Program, Panel Chair, 1987
  Graduate Fellowship Review Panel, 1995-98, 2009-12
  Environmental Protection Agency, Science Advisory Panel for Pesticides (FIFRA), 1984-87
  Science and Technology Achievement Awards, 1986-87
  Water Quality Standards Research Review, 1986
  Ecological Risk Assessment Research Review, 1986
  Environmental Protection Agency, Board of Scientific Councilors, 1996-97
The Royal Society (London), Surface Water Acidification Program Review Panel, 1990
Private Sector Board and Advisory Positions
  PacifiCorp, Inc., Environmental Forum, Portland, OR, 2000-04
  Wyoming Outdoor Council Board, Lander, WY, 2009-2015; 2017-present

SELECTED RELEVANT PUBLICATIONS (Selected from over 100 publications)

Johnson, E.O., B.D. Cherrington and H.L. Bergman. 201_. Assessment of endocrine disrupting compounds in Wyoming surface waters. Environ. Toxicol. Chem. (In Preparation).

Firkus, T., F.J. Rahel, H.L. Bergman and B.D. Cherrington. 2017. Warmed winter water temperatures alter reproduction in two fish species from the South Platte River, Colorado. Environmental Management 61(4) https://doi.org/10.1007/s00267-017-0954-9.

Pham, D.T., H.M. Nguyen, T.Boivin, A. Zajacova, S.V. Huzurbazar and H.L. Bergman. 2015. Predictors for dioxin accumulation in residents living in Da Nang and Bien Hoa, Vietnam, many years after Agent Orange use. Chemosphere 118:277-283.

Godwin, B.L., S.E. Albeke, H.L. Bergman, A. Walters and M. Ben-David. 2015. Density of river otters (*Lontra canadensis*) in relation to energy development in the Green River Basin, Wyoming. Science of the Total Environment 532: 780-790.

Wood, C.M., H.L. Bergman, A. Bianchini, P. Laurent, J. Maina, O.E. Johannsson, L. Bianchini, C. Chevalier, G.D. Kavembe, M.B. Papah and R.O. Ojoo. 2012. Transepithelial potential in the Magadi tilapia, a fish in extreme alkalinity. J. Comp. Phyiol. B 182: 247-258.

Bergman, H.L. (ed.). 2009. Research and Development Concerning Coalbed Natural Gas. Final Report to the NETL, U.S. Department of Energy, Ruckelshaus Institute of Environment and Natural Resources, University of Wyoming, Laramie, Wyoming. 177pp.

Bergman, H.L., A.M. Boelter, and K.S. Parady (eds.). 2008. Research needs and management strategies for pallid sturgeon recovery. Final Report to the U.S. Army Corp of Engineers, Ruckelshaus Institute of Environment and Natural Resources, University of Wyoming, Laramie, Wyoming. 36pp. + App.

Bergman, H.L. (ed.). 2005. Water Production from Coalbed Methane Development: A Summary of Quantity, Quality and Management Options. Ruckelshaus Institute of Environment and Natural Resources, University of Wyoming, Laramie, Wyoming. 64 pp. + App.

Lease, H.M., J.A. Hansen, H.L. Bergman and J.S. Meyer. 2003. Structural changes in gills of Lost River suckers exposed to elevated pH and ammonia concentrations. Comp. Biochem. Phys. Part C, 134: 491-500.

Bergman, A.N., P. Laurent, G. Otiang'a-Owiti, H.L. Bergman, P.J. Walsh, P.W. Wilson, and C.M. Wood. 2003. Physiological adaptations of the gut in the Lake Magadi tilapia, *Alcolapia grahami*, in an alkaline- and saline-adapted teleost fish. Comp. Biochem. Phys. Part A, 136. 701-715.

DiToro, D.M., H.E. Allen, H.L. Bergman, J.S. Meyer, P.R. Paquin and R.C. Santore. 2001. Biotic ligand model of the acute toxicity of metals. 1. Technical basis. Environ. Toxicol. Chem. 20:2383-2396.

Hansen, J.A., D.F. Woodward, E.E. Little, A.J. DeLonay and H.L. Bergman. 1999. Behavioral avoidance: Possible mechanism for explaining abundance and distribution of trout species in a metals-impacted river. Environ. Toxicol. Chem. 18: 126-130.

MacRae, R.K., D.E. Smith, N. Swoboda-Colberg, J.S. Meyer and H.L. Bergman. 1999. Copper binding affinity of rainbow trout (*Oncorhynchus mykiss*) and brook trout (*Salvelinus fontinalis*) gills: Implications for assessing bioavailable metal. Environ. Toxicol. Chem. 18:1180-1189.

Meyer, J.S., R.C. Santore, J.P. Bobbitt, L.D. DeBrey, C.J. Boese, P.R. Paquin, H.E. Allen, H.L. Bergman and D.M. DiToro. 1999. Binding of nickel and copper to fish gills predicts toxicity when water hardness varies, but free-ion activity does not. Environ. Sci. Technol. 33:913-916.

Bergman, H.L. and E.J. Dorward-King. (eds.). 1997. Reassessment of Metals Criteria for Aquatic Life Protection: Priorities for Research and Implementation. SETAC Press, Pensacola, FL. 114 pp.

Boelter, A.M., F.N. Lamming, A.M. Farag, and H.L. Bergman. 1992. Environmental effects of saline oil-field discharges on surface waters. Environ. Toxicol. Chem. 11:1187-1195.

Gulley, D.D., D.R. Mount, J.R. Hockett and H.L. Bergman. 1992. A statistical model to predict toxicity of saline produced waters to freshwater organisms. pp 89-96 In: J.P. Ray and F.R. Engelhardt (eds.). Produced Water: Technological/Environmental Issues and Solutions. Plenum Press, New York.

Bergman, H.L., R.A. Kimerle and A.W. Maki (eds.). 1986. Environmental Hazard Assessment of Effluents. Pergamon Press, Elmsford, N.Y. 366 pp.

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EDUCATION
Lehigh University, Chemical Engineering B.S., 1973
University of Wyoming, Zoology and Physiology Ph.D., 1986

PROFESSIONAL POSITIONS

2016-Present	Chief Scientist, Applied Limnology Professionals LLC, Golden, CO
2012-Present	Affiliated Faculty Member, Department of Chemistry and Geochemistry, Colorado School of Mines, Golden, CO
2007-2016	Technical Expert and Principal Scientist, Arcadis, Lakewood, Colorado
2005-2007	Professor, Department of Zoology and Physiology, University of Wyoming
1999-2005	Associate Professor, Department of Zoology and Physiology, University of Wyoming
1999 2004	Director, Red Buttes Environmental Biology Laboratory, University of Wyoming
1994-1999	Assistant Professor, Department of Zoology and Physiology, University of Wyoming
1991-1993	Coordinator, Wastewater Utilization Graduate Program, Humboldt State University, Arcata, CA
1990-1993	Lecturer, Department of Fisheries, Humboldt State University, Arcata, CA
1989-1990	Postdoctoral Researcher, University of Wyoming-National Park Service Research Center, University of Wyoming
1988-1989	Postdoctoral Researcher, Lake Research Laboratory, Swiss Federal Institute for Water Resources and Water Pollution Control (EAWAG/ETH), Kastanienbaum, Switzerland
1987-1988	NATO Postdoctoral Research Fellow, Lake Research Laboratory, Swiss Federal Institute for Water Resources and Water Pollution Control (EAWAG/ETH), Kastanienbaum, Switzerland
1987	Research Scientist, Department of Zoology and Physiology, University of Wyoming
1986	Graduate Research and Teaching Assistant, Department of Zoology and Physiology, University of Wyoming
1980-1983	Associate Scientist, Western Aquatics, Inc., Laramie, WY [part-time]
1976-1985	Research Scientist, Department of Zoology and Physiology, University of Wyoming
1972	Student Participant, NASA Summer Institute for Biomedical Engineering, Howard University and Goddard Space Flight Center, Greenbelt, MD

PROFESSIONAL AWARDS AND DISTINCTIONS (Selected)
Fellow of Society of Environmental Toxicology and Chemistry, 2018-Present
President of Rocky Mountain Chapter of Society of Environmental Toxicology and Chemistry, 2004-2005
Member of Editorial Board, *Environmental Toxicology and Chemistry*, 1997-2000
Member of Board of Directors of Rocky Mountain Association of Environmental Professionals, 1983-1984

STATE, NATIONAL AND INTERNATIONAL ADVISORY & REVIEW PANELS (Selected)
U.S. Environmental Protection Agency: Member, Aquatic Life Criteria Consultative Panel of the Science Advisory Board of the U.S. Environmental Protection Agency. 2005.
U.S. Environmental Protection Agency: Member, Health and Ecological Effects Subcommittee of the Advisory Council on Clean Air Compliance Analysis of the Science Advisory Board (SAB) of the U.S. Environmental Protection Agency. 1998-2002.
Environment Canada: Member, Environmental Resource Group for the Assessment of Chloramine under the Canadian Environmental Protection Act. 1996-1999.
U.S. Environmental Protection Agency: Member, Advisory Council on Clean Air Compliance Analysis Physical Effects Review Subcommittee of the Science Advisory Board of the U.S. Environmental Protection Agency. 1994-1997.
U.S. Department of Energy: Review of documents addressing damages and benefits of various fuel cycles. 1992-1993.

SELECTED RELEVANT PUBLICATIONS (Selected from 100 publications)

Meyer, J.S. and D.K. DeForest. 2018. Protectiveness of copper water quality criteria against impairment of behavior and chemo/mechanosensory responses: An update. *Environmental Toxicology and Chemistry* 37:1260-1279.

Traudt, E.M., J.F. Ranville and J.S. Meyer. 2017. Acute toxicity of ternary Cd-Cu-Ni and Cd-Ni-Zn mixtures to *Daphnia magna*: Dominant metal pairs change along a concentration gradient. *Environmental Science and Technology* 51:4471-4481.

Müller, B., J.S. Meyer and R. Gächter. 2016. Alkalinity regulation in calcium carbonate-buffered lakes. *Limnology and Oceanography* 61:341-352.

Traudt, E.M., J.F. Ranville, S.A. Smith and J.S. Meyer. 2016. A test of the additivity of acute toxicity of binary-metal mixtures of Ni with Cd, Cu, and Zn to *Daphnia magna*, using the inflection point of the concentration-response curves. *Environmental Toxicology and Chemistry* 35:1843-1851.

Farley, K.J. and J.S. Meyer. 2015. Metal mixtures modeling evaluation: 3. Lessons learned and steps forward. *Environmental Toxicology and Chemistry* 34:821-832.

Farley, K.J., J.S. Meyer, L.S. Balistrieri, Y. Iwasaki, M. Kamo, S. Lofts, C.A. Mebane, W. Naito, A.C. Ryan, R.C. Santore and E. Tipping. 2015. Metal mixtures modeling evaluation: 2. Comparison of four modeling approaches. *Environmental Toxicology and Chemistry* 34:741-753.

Meyer, J.S., K.J. Farley and E.R. Garman. 2015. Metal mixtures modeling evaluation: 1. Technical background. *Environmental Toxicology and Chemistry* 34:726-740.

Meyer, J.S., J.F. Ranville, M. Pontasch, J.W. Gorsuch and W.J. Adams. 2015. Acute toxicity of binary and ternary mixtures of Cd, Cu, and Zn to *Daphnia magna*. *Environmental Toxicology and Chemistry* 34:799-808.

Fulton, B.A. and J.S. Meyer. 2014. Development of a regression model to predict copper toxicity to *Daphnia magna* and site-specific copper criteria across multiple surface-water drainages in an arid landscape. *Environmental Toxicology and Chemistry* 33:1865-1873.

Meyer, J.S. and GG. Pyle. 2013. Effects of anthropogenic chemicals on chemosensation and behavior in fish: Organismal, ecological, and regulatory implications. *Fisheries* 38:283-284.

Meyer, J.S., S.J. Clearwater, T.A. Doser, M.J. Rogaczewski and J.A. Hansen. 2007. *Effects of Water Chemistry on the Bioavailability and Toxicity of Waterborne Cadmium, Copper, Nickel, Lead, and Zinc to Freshwater Organisms*. SETAC Press, Pensacola, Florida, USA.

Meyer, J.S., W.J. Adams, K.V. Brix, S.N. Luoma, D.R. Mount, W.A. Stubblefield and C.M. Wood (eds.). 2005. *Toxicity of Dietborne Metals to Aquatic Organisms*. SETAC Press, Pensacola, Florida, USA.

Meyer, J.S. and J.A. Hansen. 2002. Subchronic toxicity of low dissolved oxygen concentrations, elevated pH, and elevated ammonia concentrations to Lost River suckers. *Transactions of the American Fisheries Society* 131:656-666.

Dare, M.R., W.A. Hubert and J.S. Meyer. 2001. Influence of stream flow on hydrogen sulfide concentrations and distributions of two trout species in a Rocky Mountains tailwater. *North American Journal of Fisheries Management* 21:971-975.

Di Toro, D.M., H.E. Allen, H.L. Bergman, J.S. Meyer, P.R. Paquin and R.C. Santore. 2001. Biotic ligand model of the acute toxicity of metals. 1. Technical basis. *Environmental Toxicology and Chemistry* 20:2383-2396.

Goldstein, J.N., W.A. Hubert, D.F. Woodward, A.M. Farag and J.S. Meyer. 2001. Naturalized salmonid populations occur in the presence of elevated trace element concentrations and temperatures in the Firehole River, Yellowstone National Park, Wyoming. *Environmental Toxicology and Chemistry* 20:2342-2352.

Santore, R.C., D.M. Di Toro, P.R. Paquin, H.E. Allen and J.S. Meyer. 2001. Biotic ligand model of the acute toxicity of metals. 2. Application to acute copper toxicity in freshwater fish and *Daphnia*. *Environmental Toxicology and Chemistry* 20:2397-2402.

Meyer, J.S., D.A. Sanchez, J.A. Brookman, D.B. McWhorter and H.L. Bergman. 1985. Chemistry and aquatic toxicity of raw oil shale leachates from Piceance Basin, Colorado. *Environmental Toxicology and Chemistry* 4:559-572.

Woodward, D.F., R.G. Riley, M.G. Henry, J.S. Meyer and T.R. Garland. 1985. Leaching of retorted oil shale: Assessing the toxicity to Colorado squawfish, fathead minnows, and two food-chain organisms. *Transactions of the American Fisheries Society* 114:887-894.