EXHIBIT 3

ASSESSMENT OF TRACE METAL SOLUBILITY AND MOBILITY in Powder River Basin Coal Seams Upon Enhancing Methanogenesis

Prepared for BLM Branch of Solid Minerals, Wyoming State Office

G Ulrich and R DeBruyn
Luca Technologies, Inc.

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Purpose

Luca Technologies Inc. has developed technology for creation of biogenic gas in real time from in situ conversion of hydrocarbon substrates through the stimulation of native communities of microorganisms. This technology has been field-tested in a number of coal seams in Wyoming's Powder River Basin (PRB), and is now poised for large-scale commercial implementation in the PRB. Staff members of the Bureau of Land Management (BLM) have requested that Luca comment on the possibility that the operation of Luca's process could liberate trace elements from the coal. An unrelated study of the chemistry of coal cores taken from the Wyodak seam near the Black Thunder Mine in Campbell County detected the presence of metals in coal, which are deleterious to human health above low levels of concentration in groundwater, apparently bound into the coal by processes associated with groundwater flow and geochemistry. In response to BLM's inquiry and request that Luca review potential impacts for both the near term and the long term, Luca has prepared this report.

Summary and Conclusion

Luca's conclusion is that it is unlikely that trace metals will be released from the coals or become more concentrated in coals as a result of Luca enhancing methanogenesis. This conclusion is supported by laboratory studies, field data, and by considering that stimulating methanogenesis will not significantly alter the chemical environment relative to native conditions where substantial methanogenesis in the PRB has already occurred. In laboratory experiments, methanogenesis[1] supported by PRB coal did not result in the liberation of metals into PRB formation water. The lack of mobilization of metals from coal during methanogenesis implies that impacts to groundwater resources from the methanogenesis process are unlikely. This is an expected result from both geochemical and biological considerations. The native geochemical environment within the PRB coal seams is not conducive to the chemical liberation of the trace metals from the coals, and Luca's process does not change those conditions. In addition, since trace metal concentrations in PRB waters typically exceed concentrations required for supporting populations of microorganisms necessary for methanogenesis, trace metal augmentation is not part of Luca's process and there is no apparent need for microorganisms to obtain trace metals from those held in the coals. Therefore the uptake of these metals by microorganisms (for their growth and activity) should not result in the cycling and reconcentration of trace metals in PRB coal. In laboratory experiments, the dissolved concentration of some metals decreased, probably as a result of partitioning to coal surfaces. Trace metal adsorption to coals has also been reported in the literature, and likely plays a key role in maintaining low trace metal solubility in PRB waters, in conjunction with other factors usually required for methanogenesis, including near-neutral to slightly-alkaline pH and reducing conditions.

[1]Methanogenesis is the production of methane and carbon dioxide from complex hydrocarbon substrates by biological processes carried out by communities of microorganisms, including methanogens. These microbial communities produce methane only when conditions are anaerobic, or devoid of oxygen. Biogenic breakdown of hydrocarbons in aerobic environments on the earth's surface produce carbon dioxide, but not methane.

A comparison of field samples obtained by Luca with others obtained by USGS shows that metals concentrations in Luca's post-treatment water samples fall within the background concentration ranges for PRB coals from the broader USGS sample set. Concentrations of chloride, selenium, barium, arsenic, zinc, mercury, lead, copper cadmium and aluminum were all below EPA drinking water standards in all Luca samples. Concentrations of dissolved ferrous iron and manganese were consistent with the range of background concentrations for PRB waters, which often exceeded the MCL's. It is concluded that Luca's treatment of these wells did not result in changes to the measured inorganic water compositions relative to native PRB water compositions. The continuation of methanogenesis and Luca's stimulation thereof in PRB coals over what we consider to be the long term for commercial and regulatory planning (tens to hundreds of years) is unlikely to significantly alter trace metal solubility and cycling relative to the native methanogenic process that has already operated over a much longer time frame in the PRB.

Luca concludes it is unlikely that these trace elements will be released from coals acting as substrate for Luca's biogenic process. Important considerations are the technical aspects of the processes that could mobilize and cycle these metals, and the geochemical environment and the waters and the cells present in the coal seams. This position is supported by Luca laboratory studies, and by field data via samples taken by Luca and USGS. However, theoretical mechanisms by which anaerobic biodegradation could potentially increase dissolved trace metal concentrations exist, and hence periodic analysis of metals in a small number of post-treatment samples is suggested for continued confirmation.

Background

The distribution and mineral form of metals in coals are important considerations for evaluating metal mobility and cycling. Increased concentrations of trace metals of environmental concern in PRB Wyodak and Big George coals have been associated with clay partings and high ash zones. Increased concentrations at the base and top of the coal beds and in adjacent detrital rock have been attributed to detrital sedimentation (Stricker et. al., 2007) and increased groundwater transport (Drever et. al, 1977). Trace metals are also heterogeneously distributed in Black Warrior Basin coals of Alabama, and are associated with pyrite with increased abundance along faults, veins, and in directly adjacent coal (Diehl et al., 2004). These distributions are believed to have originated from deformation events leading to faulting that allowed the influx of metal-rich fluids. Metal sulfides (including pyritic) are predominant forms of metals in coals (Swaine and Goodarzi, 1995) and are often associated with increased trace metal concentrations in coals (Zhang et. al, 2007, Liu et. al, 2006, Diehl et. al, 2004). Some of the variables known to impact the solubility, mobility, and cycling of these metal species are discussed below.

A multitude of physiochemical factors regulate the solubility, cycling, and transport of metals as summarized thoroughly in Hullebush et. al, 2005. These include Eh, pH, ionic composition, the chemical form of the metal, adsorption, precipitation, and the formation of inorganic and organic complexes. Microbial activity can impact metal solubility and mobility directly wherein some metals are oxidized (including various iron and manganese minerals) generally in the presence of molecular oxygen, or reduced for energy gain by anaerobic microorganisms (including chromium reduction) (Hazen and Tabak, 2005). Microbial activities can also impact metal solubility indirectly through the alteration of the surrounding chemical conditions. Although the impact of these chemical and microbiological factors varies with specific metals, some generalities can be gleaned as discussed below in the context of metal cycling.

In the absence of oxygen and under more reducing conditions (lower Eh) that are typical in deep subsurface environments especially the methanogenic carbon-rich environments targeted by Luca, many metals are present as near insoluble forms including metal sulfides (Erses and Onay, 2003). In the absence of significant environmental changes including pH reduction or oxygen input, significant changes in the solubility of metal sulfides is unlikely given their stability under anoxic conditions. However, upon oxidation via natural weathering at redox interfaces including in shallow aquifers (Ulrich et al, 1998), or upon excavating anoxic sediments, rock, or coal, metal sulfides are readily oxidized often resulting in acid mine drainage or groundwater that can contain elevated metal concentrations (Ibeanusi and Wilde, 1998; Globitza, 2000; Cook and Fritz, 2001). The metal sulfide leaching process is catalyzed by a combination of aerobic iron and sulfur-oxidizing microorganisms coupled with abiotic oxidation leading to acidic conditions that further increase metal solubility (Aroklasamy and Dodge, 1989). Sulfate and dissolved iron concentrations derived from pyrite oxidation can be exceptionally high in these leachates.

Variables that can have strong impacts on the transport of solubilized metals include pH, pH buffering capacity, the Eh of the environment receiving acidic metal leachings, and hydrogen sulfide presence that is often attributed to microbial sulfate reduction (Cook and Fritz, 2001; Anderson et. al, 1991; Bozkurt et. al, 1999). At a pH >6, free metal cation concentrations are decreased due to increased adsorption, chelation by organic matter, or precipitation (Hullebush et. al, 2005). Where microbial sulfate reduction occurs in the receiving environment, many of the liberated metals can be re-precipitated as metal sulfides, thus completing a cycle of metal mobilization via oxidation, then reduction and precipitation upon entering reducing conditions.

Notable exceptions to the generalization that anaerobic conditions are associated with reduced metal solubility include increasing dissolved ferrous iron (Fe^{+2}) and dissolved manganese (Mn^{+2}) concentrations that can be associated with microbial reduction of nearly insoluble oxidized iron and manganese oxide minerals respectively (Crowe et al, 2006). The reduction of iron oxides can result in the release of arsenic adsorbed to the iron oxides (Stuben et al., 2003; Hullebush et. al, 2005). Upon reduction, including by a variety of anaerobic microorganisms and methanogenic consortia, more mobile As III is produced (Field et al., 2004). Similarly, laboratory experiments have demonstrated that cobalt, nickel, and aluminum can be released from the microbial reduction of iron oxides containing these metals (Zachara et. al, 2001; Quantin et. al, 2001). Iron reduction and the liberation of trace metals associated with iron oxides is unlikely to be significant in PRB coal seams due to the excess in carbon available to fuel biodegradation activities that deplete electron acceptors including iron oxides. Readily utilizable oxidized iron forms have likely been exhausted. For example, reactive iron oxides in peat sediments were shown to be limited to the upper 10-15 cm sediment interval and are depleted with depth where trace metals were largely associated with sulfides and organic phases (Koretsky et. al, 2006). The notion that iron oxides and iron reduction is unlikely in PRB coals is consistent with laboratory observations detailed below.

Results and Discussion

Laboratory Experiments.

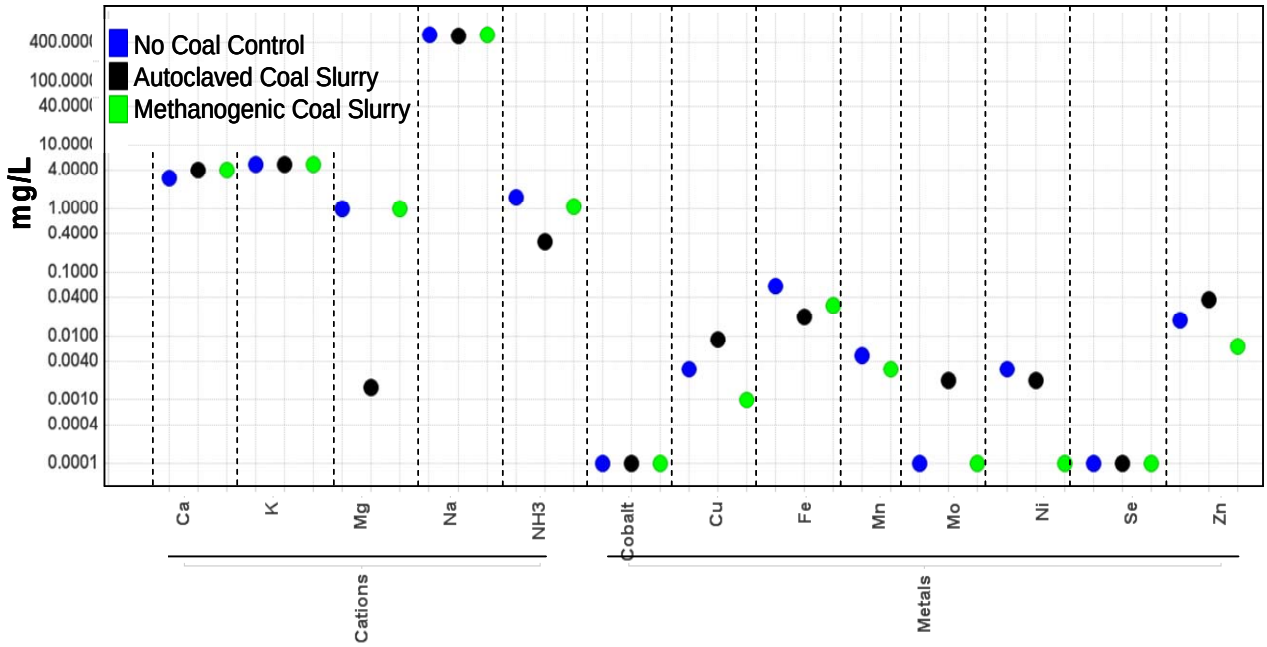
Several trace elements are components of cells, and are essential to cellular functions such as metabolism. They have long been recognized as effective stimuli of microbial activity in culture, and are included in medicinal preparations for humans such as multi-vitamins. In its studies of the functionalities of microbial consortia native to PRB coals, Luca has conducted many experiments utilizing amendment formulations which include many trace elements, although Luca does not employ trace metals in the amendment formulations utilized in the field in the PRB.

A) Stability of the solubility of trace elements during methanogenesis. In 2005, laboratory experiments were conducted to identify whether methanogenesis supported by PRB coal is associated with trace element liberation from coal into water. The partitioning of primary cations (Mg, Ca, and K), ammonium, and several trace metals (Co, Cu, Fe, Mn, Mo, Ni, Se, and Zn) between PRB water and coal was also evaluated. Sample collection, experiment preparation, and incubation were conducted under strict anaerobic conditions and at a temperature similar to in-situ conditions. The experimental

bottles consisted of five grams of ground coal and 15 ml of anoxic formation collected from the same well supplying core in 36 ml serum bottles sealed with stoppers. The headspace contained mainly nitrogen with 5% carbon dioxide to further replicate in-situ conditions including pH. It should be noted that grinding coal will expose coal surfaces that are unlikely to be in direct contact with groundwater flow in-situ. Thus, it is likely that these experimental conditions created the potential for increased trace metal contact and partitioning between water, cells, and coal relative to in-situ conditions.

Monarch coal and water experiments. The first set of experiments evaluated dissolved trace metals, major cations, and ammonium concentrations after methanogenesis occurred in coal slurries prepared with Monarch coal and water collected from the Western PRB. These data are compared with abiotic incubations that were autoclaved (120^0C, 15 minutes) to inhibit microbial activity and with no coal controls (Monarch water only). After methanogenesis occurred in methanogenic coal slurries, concentrations of major cations, trace elements, and ammonium were similar to autoclaved controls and no coal controls (Figure 1). Methanogenesis did not result in the liberation of metals, into formation water. Trace concentrations (ppb) of copper, molybdenum, and nickel were decreased in the methanogenic incubations suggesting microbial utilization although abiotic partitioning is also a possibility as detailed below.

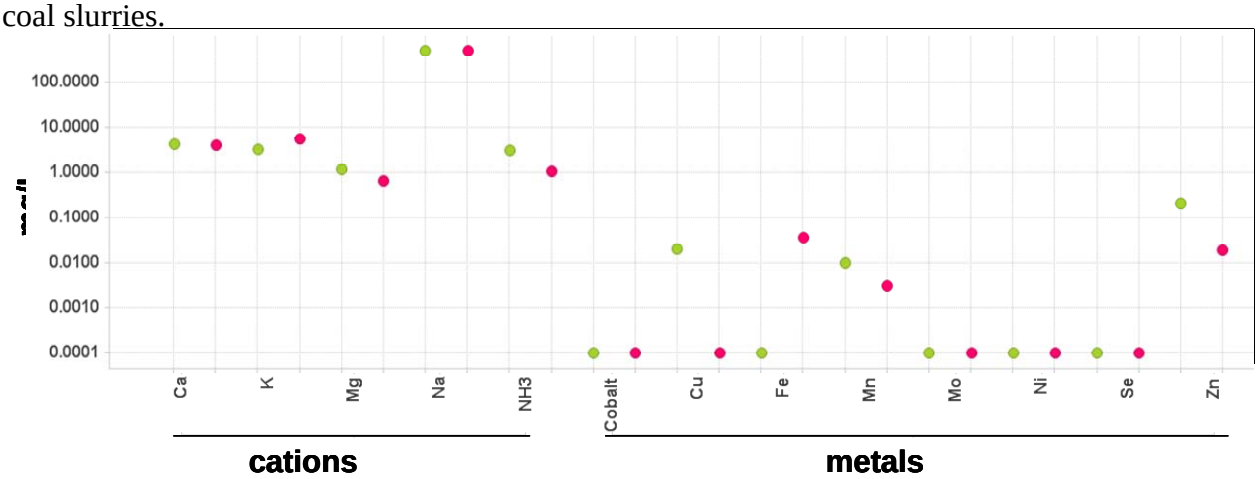
Figure 1. Comparison of inorganic water composition in water from Monarch methanogenic coal slurries, autoclaved controls, and no coal controls.



Carney coal and water experiments. Similar experiments were conducted with coal and water from the Carney seam from the Western PRB. The same constituents were analyzed immediately after preparing the slurries (To is the start of the experiment) and after methanogenesis supported on coal occurred (Tf is the last sample from the

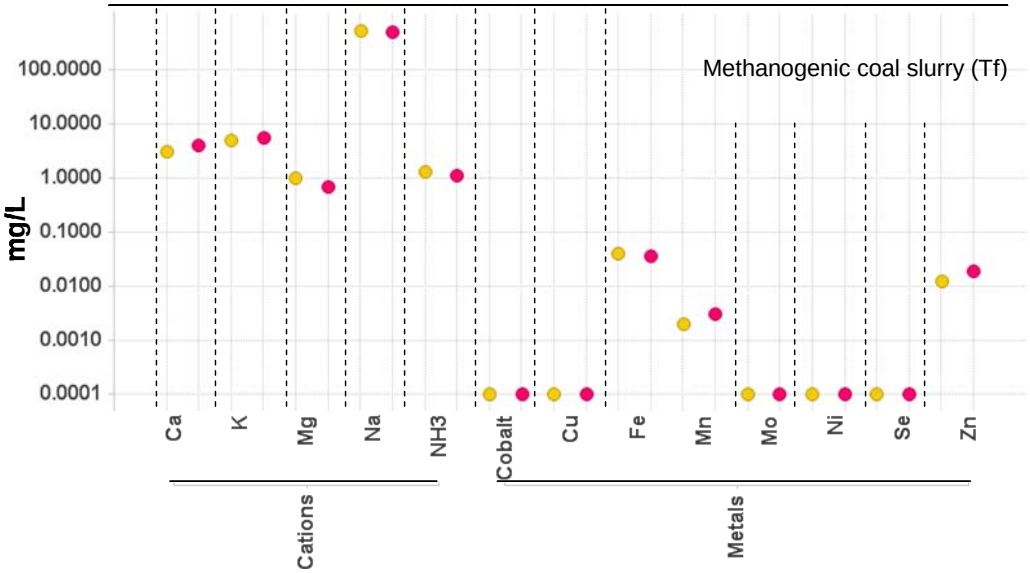
experiment). Results were compared with autoclaved controls. Concentrations of major cations, trace elements with the exception of iron, did not increase in the aqueous phase after methanogenesis occurred; again indicating that methanogenesis did not result in the liberation of elements from coal into formation water (Figure 2).

Figure 2. Comparison of initial and final water compositions from Carney methanogenic coal slurries.



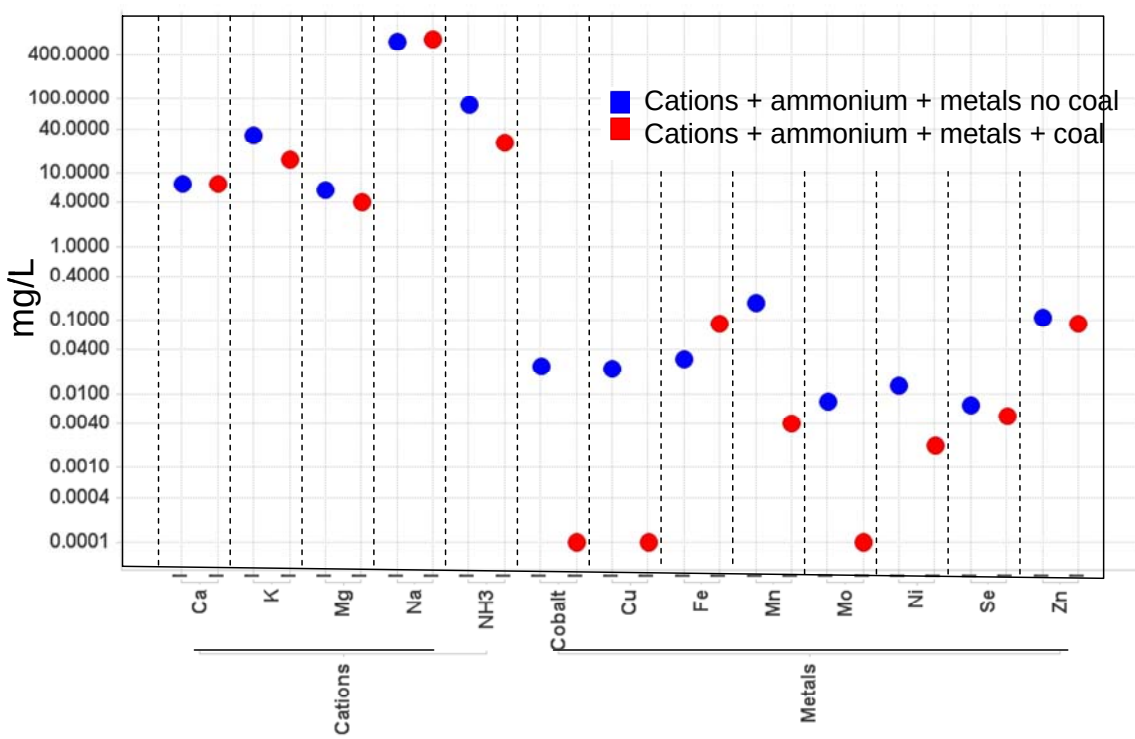
Increased dissolved iron (likely Fe^{+2}) is attributed to lab artifact via liberation from ground coal on the basis of a similar concentration in autoclaved controls at Tf (Figure 3) and the observation that the addition of chelators to coal slurries has resulted in the solubilization of significant iron concentrations (data not shown). The decreased concentration of copper, manganese, and zinc in Tf methanogenic coal slurries relative to initial concentrations (Figure 2) is likely due to the abiotic partitioning of these metals to ground coal on the basis of similar concentrations of all measured inorganics between Tf methanogenic coal slurries relative to autoclaved controls (Figure 3).

Figure 3. Comparison of final water compositions between methanogenic Carney coal slurries and autoclaved controls. Note, that iron concentrations were very similar between autoclaved and methanogenic slurries.



B) Partitioning of primary cations, trace metals, and ammonium between formation water and coal. A third laboratory experiment evaluated the partitioning of primary cations, several trace metals, and ammonium between formation water and coal. These compounds were added to coal slurries that were then gradually shaken to increase coal-water contact over a thirty two day period. For comparison, the same compounds were added to no coal controls. In this case, the PRB formation water used did not match the coal collection location. Because little methanogenesis occurred during this short period, changes in aqueous concentrations are likely not attributed to microbial activity. Figure 4 shows that the concentration of many of the compounds including ammonium, copper, manganese, molybdenum, nickel, and potassium were present at lower concentrations in the presence of coal. The loss of metals from solution is likely attributed to metal adsorption to coal surfaces. The efficient adsorption of metals (including Pb, Cr, Cd, Zn, Ni, Ca) to coals of various rank has been reported (Burns et. al, 1998) and increased for the lower rank coals tested. Metal binding was so efficient at a pH above approximately 5-6, that coals are considered as potential adsorbent material for waste water metal treatment.

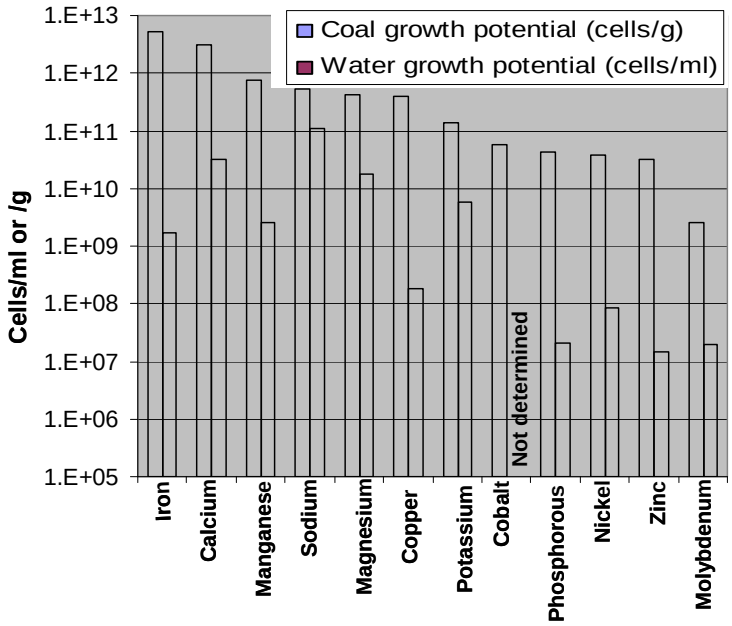
Figure 4. Comparison of water compositions between slurries with and without coal to evaluate metal partitioning to coal.



C) Biological Demand for Trace Elements. The above laboratory results indicate that metals are not mobilized from coal during methanogenesis implying that impacts to

groundwater resources from the methanogenic process are unlikely. This is an expected result from geochemical and biological considerations. Trace metal requirements for microorganisms are very small. For example, an estimate of the quantity of inorganic elements required to support the growth of methanogenic consortia was made based on the elemental composition of methanogens (Scherer et al., 1983). Figure 5 illustrates the theoretical number of methanogen cells that could grow from either the elements in a Western PRB coal sample that has been used in lab testing and from the median concentration of elements in Eastern PRB waters measured in USGS samples collected throughout the basin (Rice et al, 2000). For reference, a total cell population of ~ 1 x 10^6 cells/ml water or g coal is often associated with active methanogenesis in PRB samples (lab and field). Thus, under methanogenic conditions, a driving force for methanogenic consortia to access and alter a significant percentage of trace metals from PRB coal for cell growth is not present. Similarly, the median concentration of inorganics including trace metals in PRB waters exceeds what is estimated to be required to grow methanogenic consortia. Cobalt was below detection in PRB waters preventing an estimation of methanogen growth potential for dissolved cobalt. Based on this analysis, trace metal concentrations in PRB waters typically exceed concentrations required for supporting populations of microorganisms necessary for methanogenesis, suggesting little or no apparent need from microorganisms to obtain their requirements for trace metals held in the coals. Therefore the uptake of metals by microorganisms involved in methanogenesis for cell growth should not result in the cycling and reconcentration of trace metals to PRB coal. This is in contrast to scenarios where trace metals could be mobilized under oxidizing conditions then precipitated under reducing conditions as described in the background section of this report. The aqueous solubility and transport of many trace metals would be anticipated to be low based on these early laboratory results and literature indicating the adsorption of trace metals to coals.

Figure 5. Estimates of the methanogen growth potential for inorganics in PRB waters and a PRB coal sample. Growth potential is calculated based on the quantity of these elements in methanogen cells. For comparison, approximately 10^6 cells/ml is often associated with active methanogenesis in PRB samples.



Field Results

Water samples were collected through 0.45 um filters, preserved with nitric acid, and analyzed for a suite of inorganic compounds from wells previously treated by Luca with amendments to stimulate methanogenesis. Five samples were collected from five Eastern PRB wells by an independent environmental consulting firm as instructed by BLM and analyzed for a more comprehensive suite of compounds relative to four western PRB wells sampled by Luca. The percentage of emplaced amended water pumped from the treated Eastern PRB wells prior to sample collection ranges from 0.4% to 300% of the emplaced treated water. One untreated Eastern PRB well was sampled for comparison. Appendix 1 contains plots of the data for each compound. Luca's samples are colored green for comparison with data in red for forty seven samples collected by the USGS (Rice et. al, 2000). Primary or secondary drinking EPA drinking water MCL's are colored red where applicable.

Concentrations of all elements analyzed in all of Luca's amended wells fall within the background concentration range for PRB values reported by the USGS. Concentrations of chloride, selenium, barium, arsenic, zinc, mercury, lead, copper, cadmium, and aluminum were below EPA drinking water standards in all of Luca's samples and USGS samples. Dissolved ferrous iron (Fe^{+2}) concentrations often exceed the 0.3 mg/L secondary drinking water standard for both Luca and USGS samples indicating that background concentrations of Fe^{+2} iron in PRB waters often exceed this MCL. The same is true for manganese but to a lesser extent.

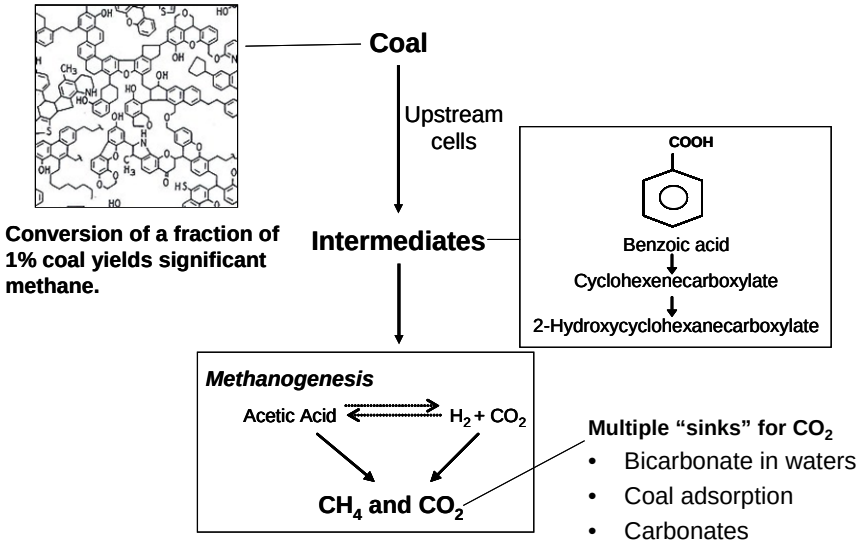
It is concluded that Luca's treatment of these wells did not result in changes to dissolved metal concentrations relative to native PRB water composition. These results are consistent with the laboratory results, that the chemical conditions required for methanogenesis (no oxygen and near neutral pH) increase the stability of most trace metals, and the fact that past native methanogenesis has not resulted in high trace metal concentrations,

Potential for long-term impacts

It is important to note that despite the abundance of research and literature detailing the role of microbial activities in metal mobility and cycling, such references on methanogenesis are scarce. To speculate on potential long-term impacts, the influence of the methanogenic process on factors that could impact metal solubility is considered.

The methanogenic biodegradation of coal is accomplished by a consortium of microorganisms including "upstream cells" that biodegrade coal compounds to intermediates and ultimately to acetate, carbon dioxide, and molecular hydrogen (Figure 6). Some methanogens in the PRB convert acetate to methane, while others convert

Figure 6. Simplified representation of the methanogenic process in PRB coals.



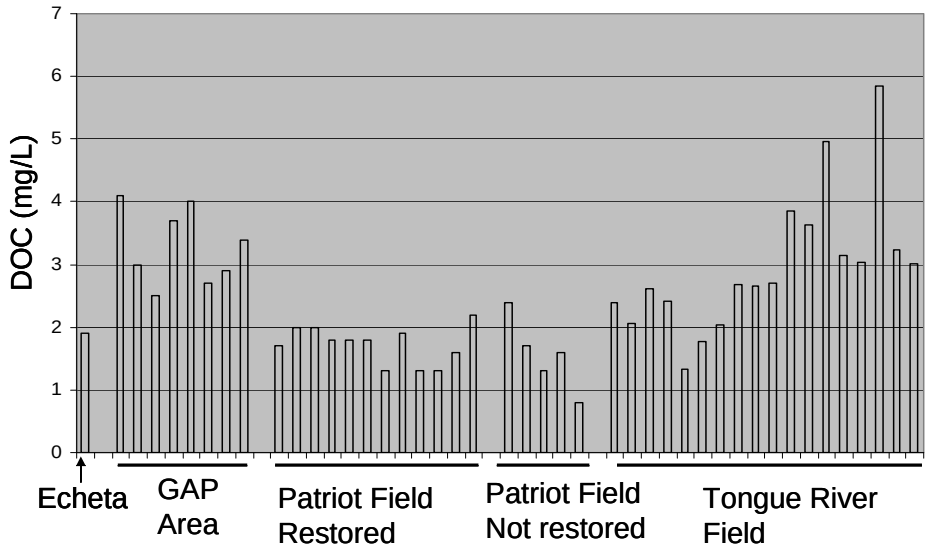
carbon dioxide and molecular hydrogen to methane. While some of the produced carbon dioxide is converted to methane by methanogens, both carbon dioxide and methane are final products of methanogenic biodegradation. The relatively high bicarbonate waters in the PRB are very likely derived from microbial sulfate reduction (Van Voast, 2003) and possibly methanogenesis. This bicarbonate in PRB waters, and likely carbonate minerals in the coals, provides pH buffering capacity in PRB coal seams with pH values typically slightly above neutrality as confirmed via limited in-situ pH measurements made by Luca. Thus, as for historical methanogenesis in the PRB, carbon dioxide production through methanogenesis over the long-term should not result in significantly lower pH which could increase metal solubility and mobilization. The importance of pH in governing metal solubility has been observed in waters from coals in Western Canada where the more buffered Horsehoe Canyon coals that exhibit signatures of methanogenesis (increased bicarbonate and isotopically lighter methane) contain decreased metal concentrations relative to more saline lower bicarbonate waters of the Mannville coals that do not show signatures of methanogenesis (Cheung et al., 2008). Further, stimulating coal biodegradation through methanogenesis would help maintain low Eh conditions. In the absence of coal biodegradation, the coals would be more susceptible to the infiltration of oxidized waters, increasing the potential for increased metal solubility and mobilization. Organic acid intermediates produced during methanogenic coal biodegradation that could reduce pH and complex metals in solution have been observed only at trace concentrations including post treatment.

The advancement of mining activities could in theory result in locally oxidizing conditions in the immediate vicinity of the mines and increase metal solubility and mobilization to down dip regions operated by Luca. Oxygen introduction is anticipated to be quite localized due to the high capacity of coals to bind oxygen (confirmed for PRB coal, data not shown). Stimulating methanogenesis should not decrease the pH buffering

capacity of the waters and is unlikely to diminish the inherent ability of coals to adsorb metals.

Because trace metals can be associated with dissolved organic carbon (DOC), DOC concentrations were compared between previously restored and non-restored wells within the Patriot project area (Figure 7). DOC concentrations in the restored waters fall within the range observed for the non-restored wells indicating that potential impacts of metal solubility or mobilization through changing DOC concentration are unlikely.

Figure 7. Comparison of dissolved organic carbon (DOC) concentrations between restored (treated) and non-restored wells within the South Pronghorn project area. DOC concentrations in other PRB non-restored waters are shown for comparison.



As trace metals are not lost upon biodegradation, the trace metal content of remaining non-biodegraded materials can increase. An extreme example is highly-biodegraded oils where greater than 50% of the initial mass of hydrocarbon can be biodegraded. A very different situation exists for coals. The biogenic conversion potential of coal is lower due to the lower hydrogen-to-carbon content of coal, and the greater complexity of the chemical structure of coal, which reduces its bioavailability to microorganisms. Even if a substantial percentage of the hydrogen in coal is eventually converted to methane, the actual original hydrogen content is a small portion of the coal's weight, and the stoichiometric extraction of associated carbon is a small portion of the original carbon in the coal. As a result, biogenesis of methane from coal will remove a small percentage of the original coal unit weight, and the relative concentration of trace elements in the coals should increase only by this percentage.

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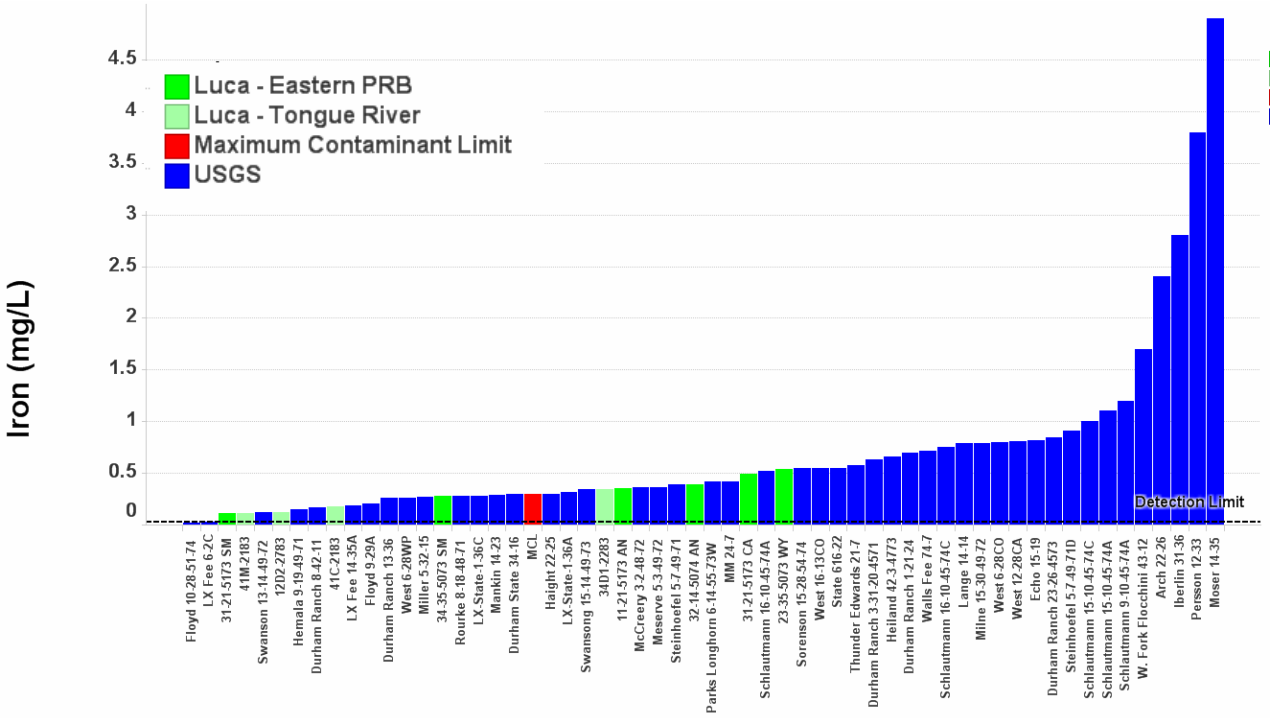
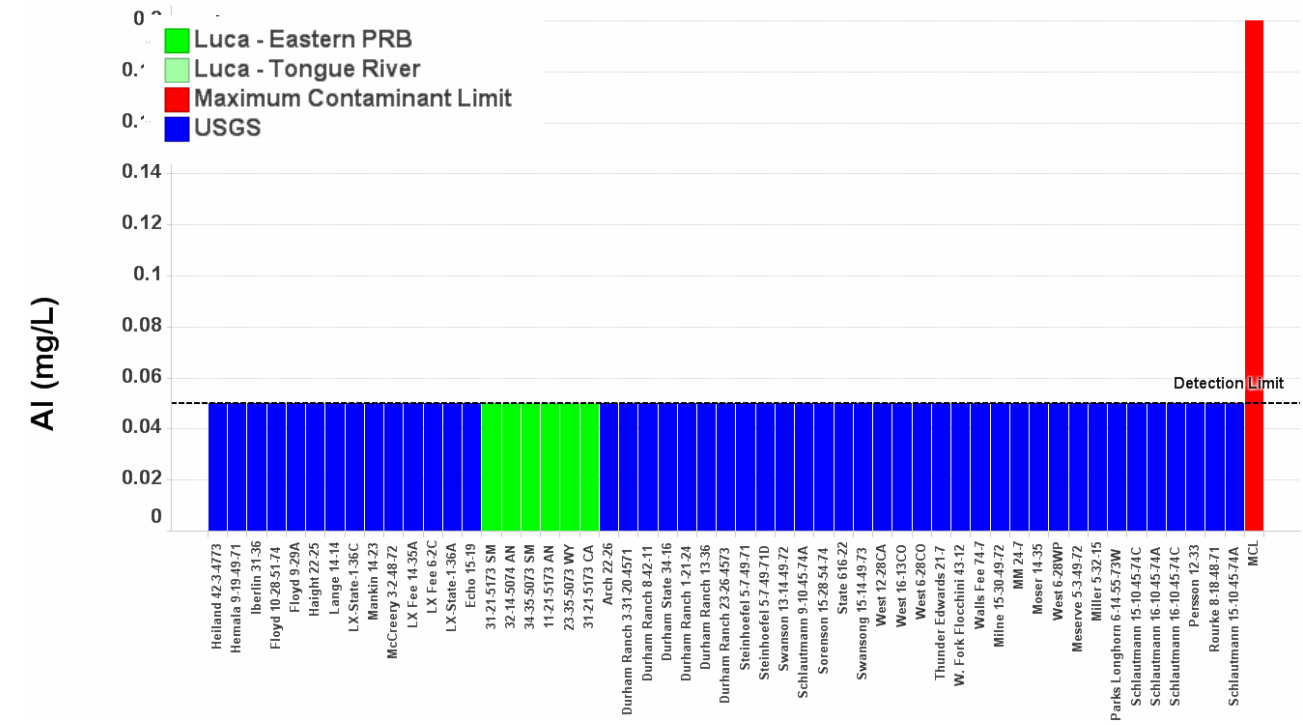
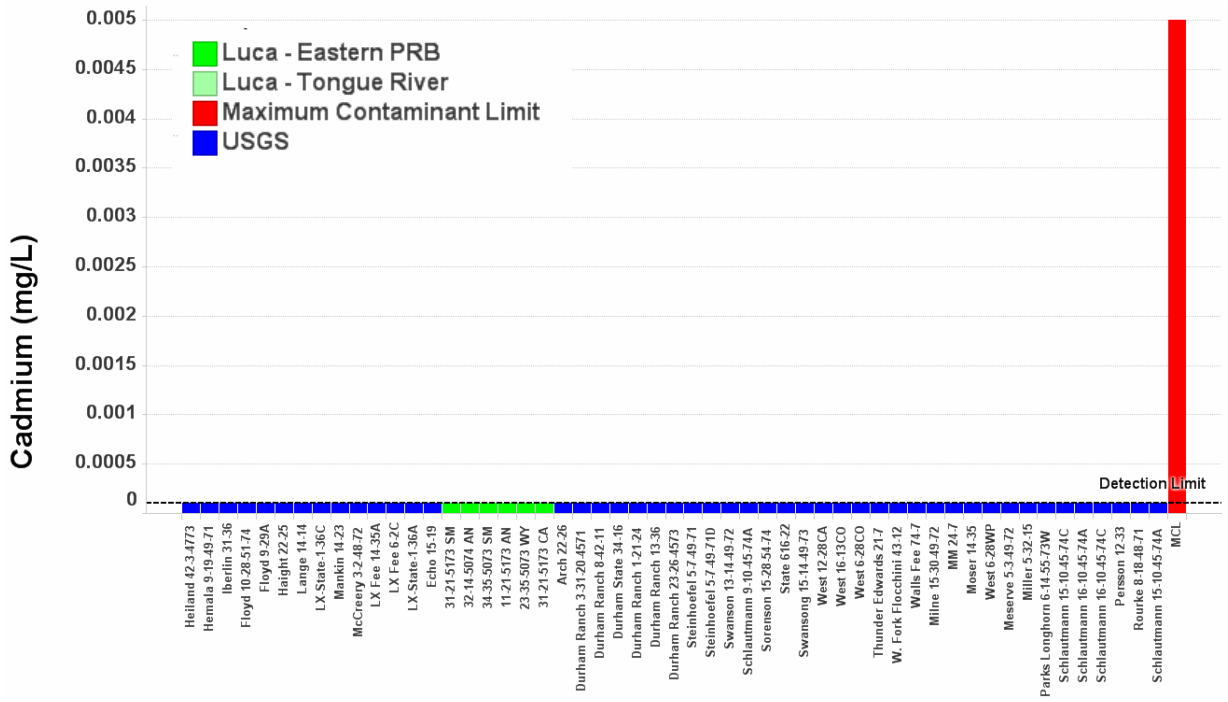
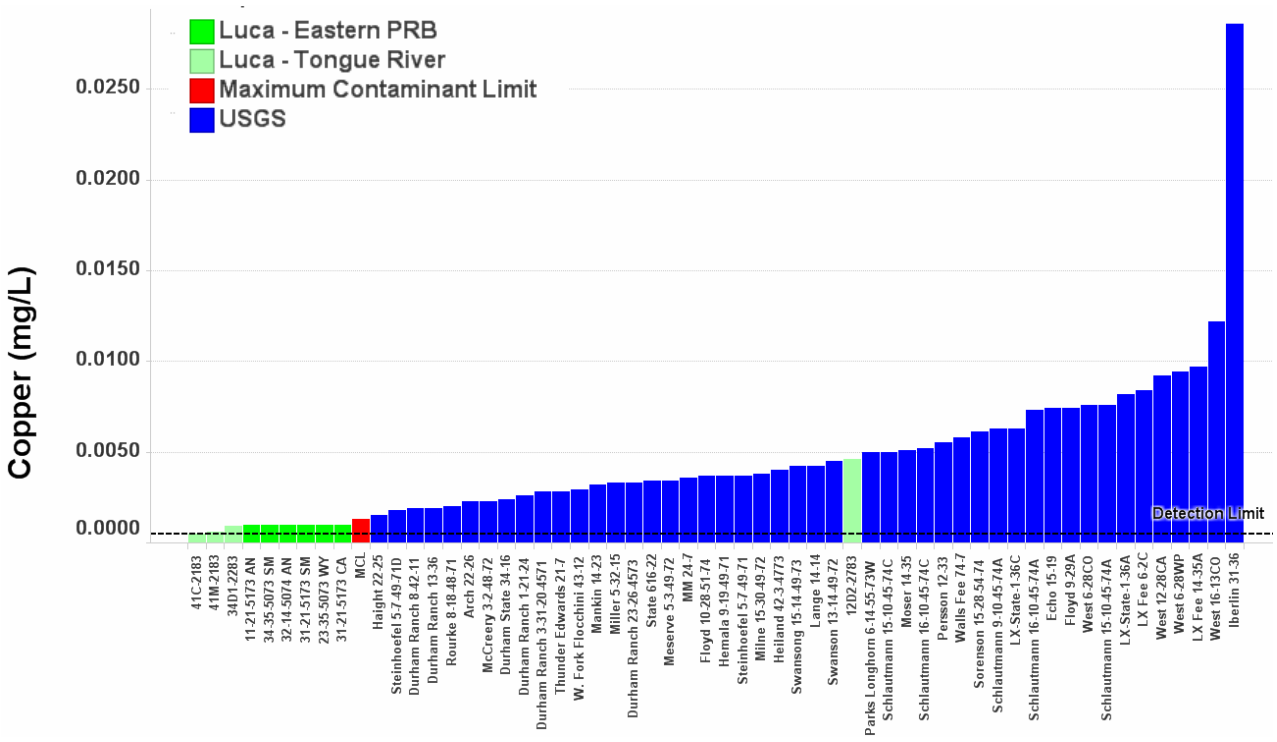
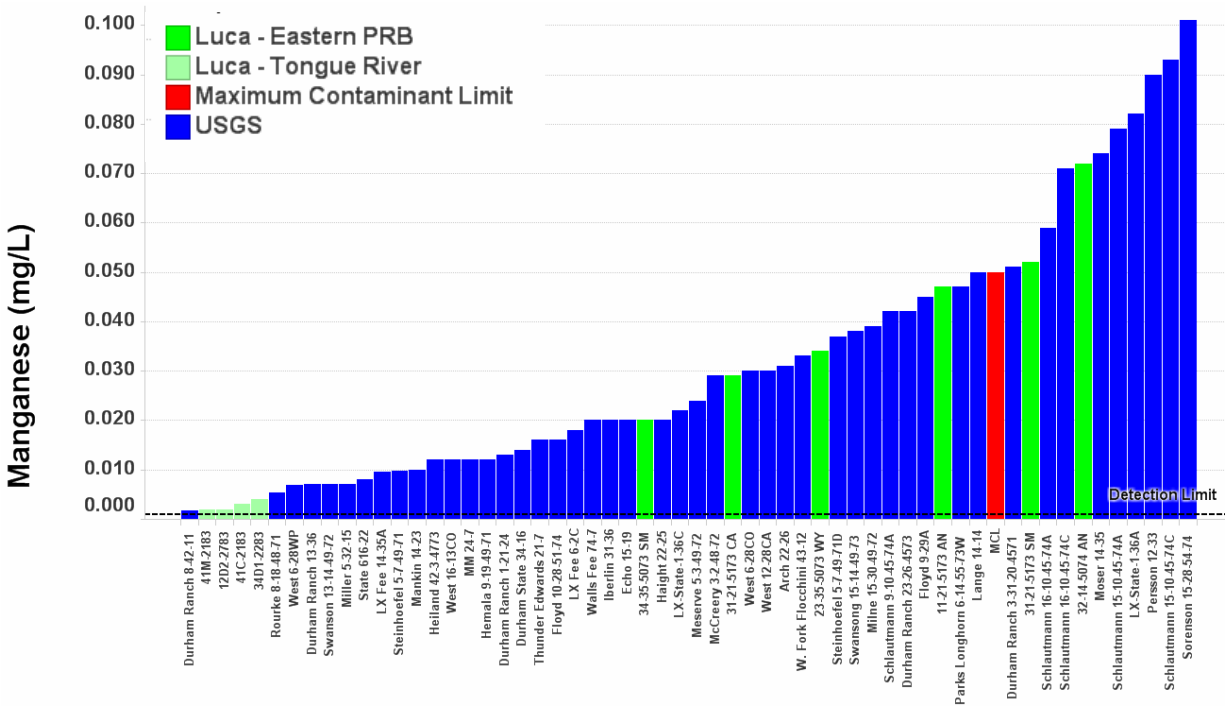
Appendix. Comparison of dissolved inorganics between water samples from wells previously amended by Luca to stimulate methanogenesis in the Eastern PRB (dark green) and Western PRB (light green) relative to samples collected by the USGS (blue). EPA's primary or secondary drinking water mcl's are colored red where applicable.

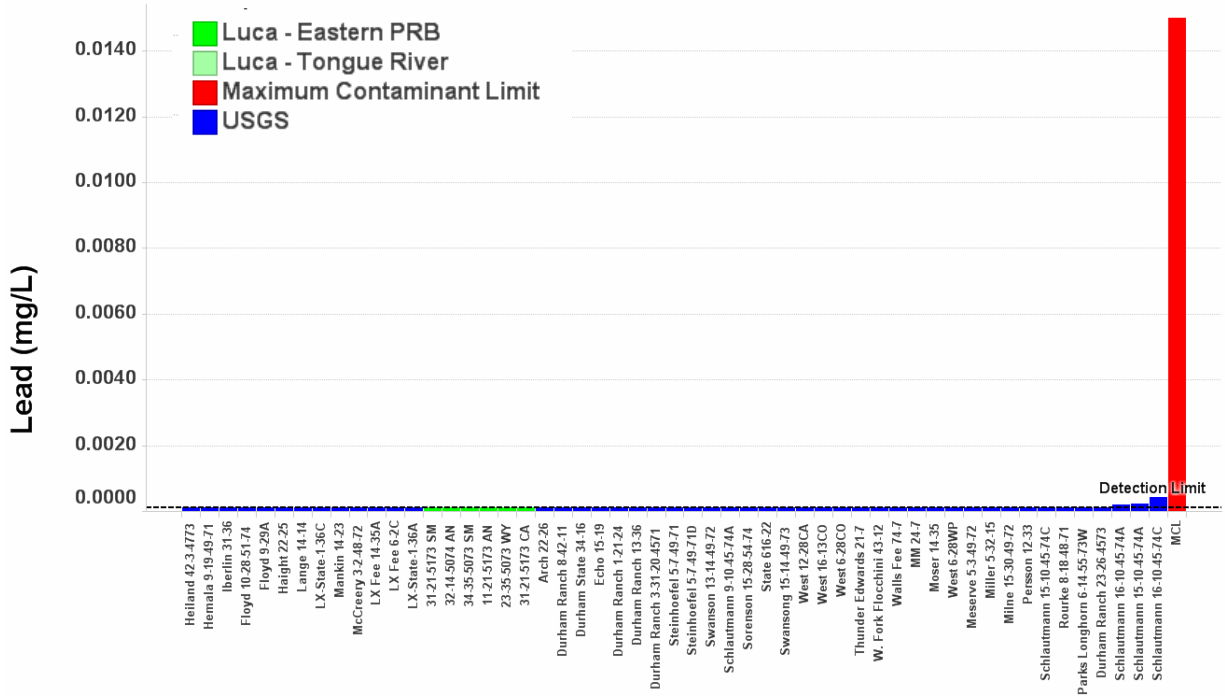


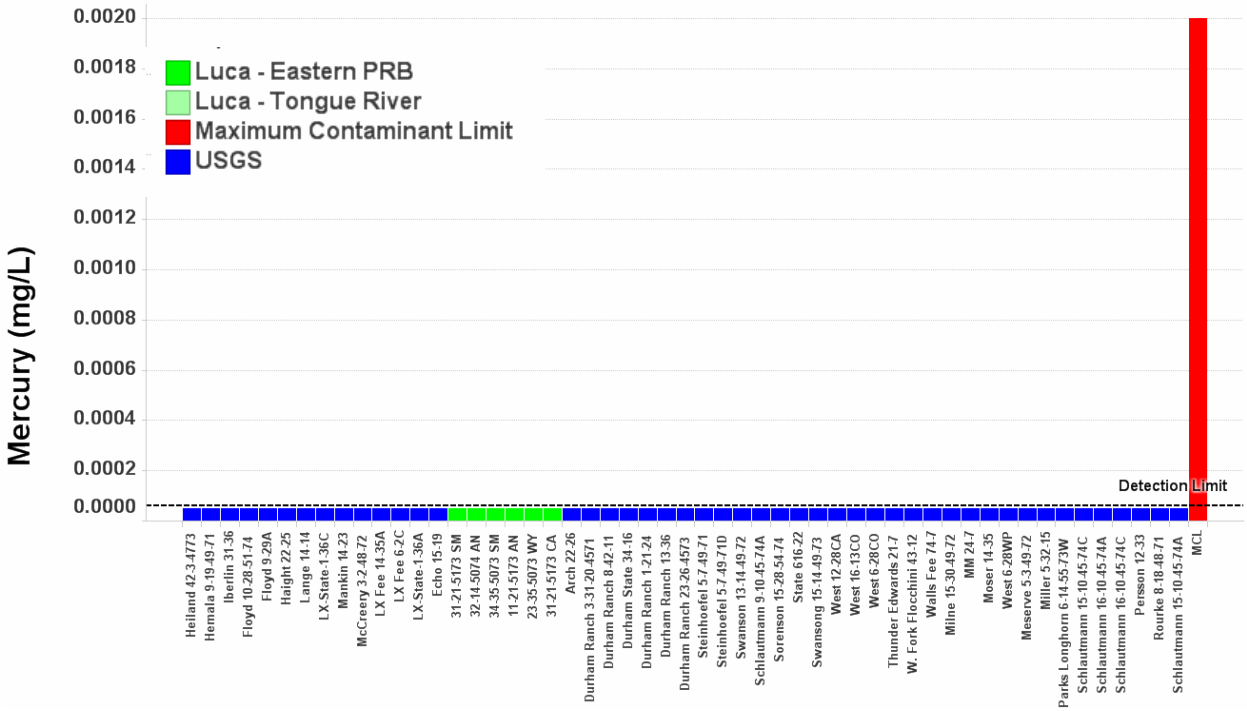


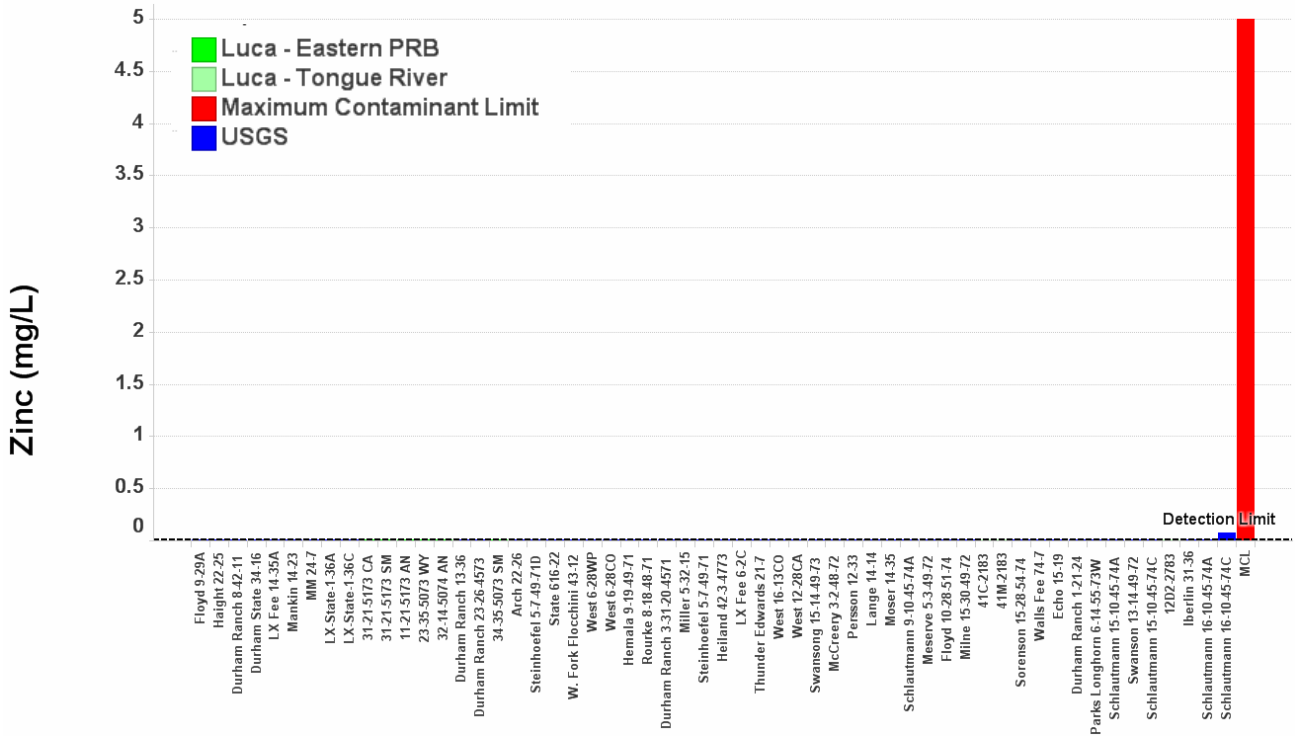

Cadmium (mg/L)
0.005
0.0045
0.004
0.0035
0.003
0.0025
0.002
0.0015
0.001
0.0005
0
Luca - Eastern PRB
Luca - Tongue River
Maximum Contaminant Limit
USGS
Detection Limit
Heiland 42-3-4773
Hemala 9-19-49-71
Iberlin 31-36
Floyd 10-28-51-74
Floyd 9-29A
Haight 22-25
Lange 14-14
LX-State-1-36C
Mankin 14-23
McCreery 3-2-48-72
LX Fee 14-35A
LX Fee 6-2C
LX-State-1-36A
Echo 15-19
31-21-5173 SM
32-14-5074 AN
34-35-5073 SM
11-21-5173 AN
23-35-5073 WY
31-21-5173 CA
Arch 22-26
Durham Ranch 3-31-20-4571
Durham Ranch 8-42-11
Durham State 34-16
Durham Ranch 1-21-24
Durham Ranch 13-36
Durham Ranch 23-26-4573
Steinhoefel 5-7-49-71
Steinhoefel 5-7-49-71D
Swanson 13-14-49-72
Schlautmann 9-10-45-74A
Sorenson 15-28-54-74
State 616-22
Swansong 15-14-49-73
West 12-28CA
West 16-13CO
West 6-28CO
Thunder Edwards 21-7
W. Fork Flocchini 43-12
Walls Fee 74-7
Milne 15-30-49-72
MM 24-7
Moser 14-35
West 6-28WP
Meserve 5-3-49-72
Miller 5-32-15
Parks Longhorn 6-14-55-73W
Schlautmann 15-10-45-74C
Schlautmann 16-10-45-74A
Schlautmann 16-10-45-74C
Persson 12-33
Rourke 8-18-48-71
Schlautmann 15-10-45-74A
MCL

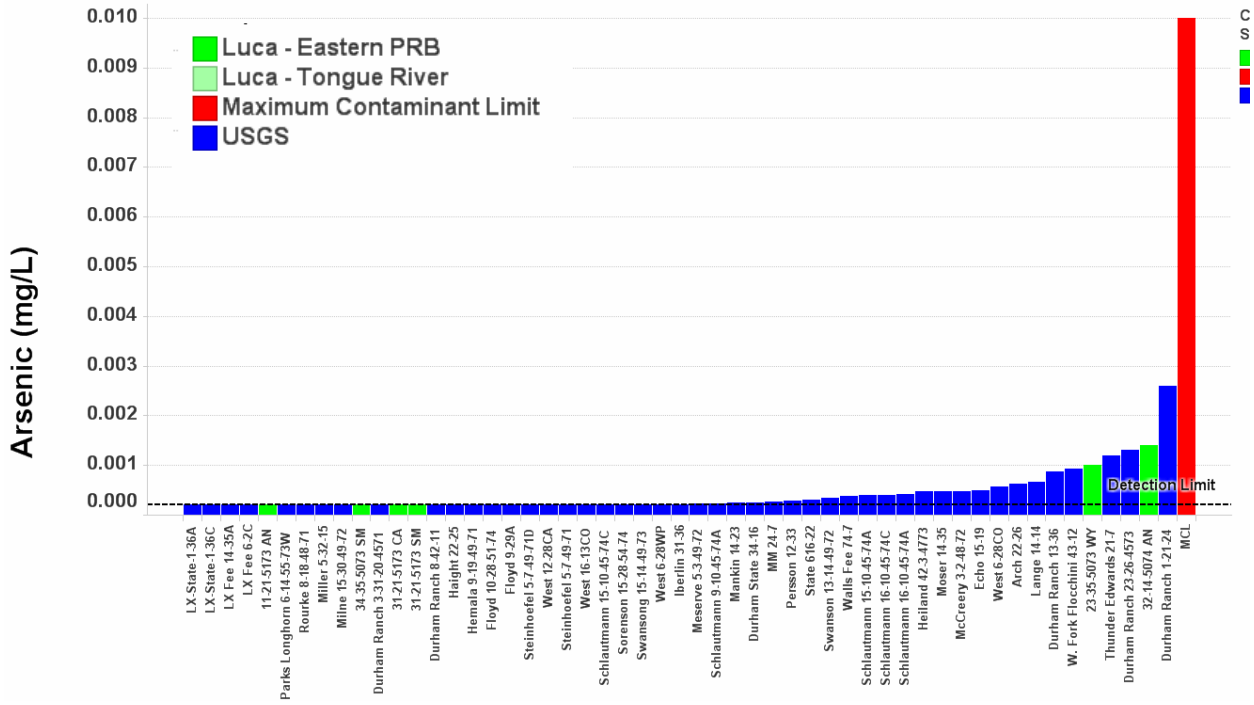

Copper (mg/L)
0.0250
0.0200
0.0150
0.0100
0.0050
0.0000
Luca - Eastern PRB
Luca - Tongue River
Maximum Contaminant Limit
USGS
Detection Limit
41C-2183
41M-2183
34D1-2283
11-21-5173 AN
34-35-5073 SM
32-14-5074 AN
31-21-5173 SM
23-35-5073 WY
31-21-5173 CA
MCL
Haight 22-25
Steinhoefel 5-7-49-71D
Durham Ranch 8-42-11
Durham Ranch 13-36
Rourke 8-18-48-71
Arch 22-26
McCreery 3-2-48-72
Durham State 34-16
Durham Ranch 1-21-24
Durham Ranch 3-31-20-4571
Thunder Edwards 21-7
W. Fork Flocchini 43-12
Mankin 14-23
Miller 5-32-15
Durham Ranch 23-26-4573
State 616-22
Meserve 5-3-49-72
MM 24-7
Floyd 10-28-51-74
Hemala 9-19-49-71
Steinhoefel 5-7-49-71
Milne 15-30-49-72
Heiland 42-3-4773
Swansong 15-14-49-73
Lange 14-14
Swanson 13-14-49-72
12D2-2783
Parks Longhorn 6-14-55-73W
Schlautmann 15-10-45-74C
Moser 14-35
Schlautmann 16-10-45-74C
Persson 12-33
Walls Fee 74-7
Sorenson 15-28-54-74
Schlautmann 9-10-45-74A
LX-State-1-36C
Schlautmann 16-10-45-74A
Echo 15-19
Floyd 9-29A
West 6-28CO
Schlautmann 15-10-45-74A
LX-State-1-36A
LX Fee 6-2C
West 12-28CA
West 6-28WP
LX Fee 14-35A
West 16-13CO
Iberlin 31-36

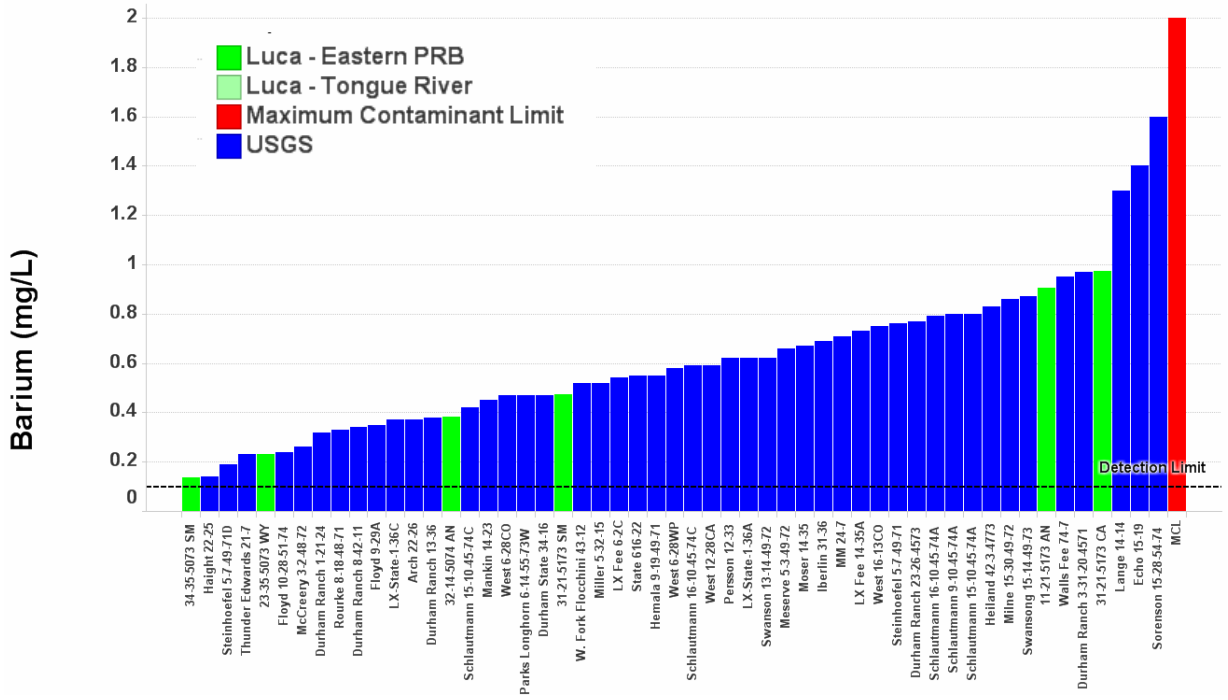

Manganese (mg/L)
0.100
0.090
0.080
0.070
0.060
0.050
0.040
0.030
0.020
0.010
0.000
Luca - Eastern PRB
Luca - Tongue River
Maximum Contaminant Limit
USGS
Detection Limit
Durham Ranch 8-42-11
41M-2183
12D2-2783
41C-2183
34D1-2283
Rourke 8-18-48-71
West 6-28WP
Durham Ranch 13-36
Swanson 13-14-49-72
Miller 5-32-15
State 616-22
LX Fee 14-35A
Steinhoefel 5-7-49-71
Mankin 14-23
Heiland 42-3-4773
West 16-13CO
MM 24-7
Hemala 9-19-49-71
Durham Ranch 1-21-24
Durham State 34-16
Thunder Edwards 21-7
Floyd 10-28-51-74
LX Fee 6-2C
Walls Fee 74-7
Iberlin 31-36
Echo 15-19
34-35-5073 SM
Haight 22-25
LX-State-1-36C
Meserve 5-3-49-72
McCreery 3-2-48-72
31-21-5173 CA
West 6-28CO
West 12-28CA
Arch 22-26
W. Fork Flocchini 43-12
23-35-5073 WY
Steinhoefel 5-7-49-71D
Swansong 15-14-49-73
Milne 15-30-49-72
Schlautmann 9-10-45-74A
Durham Ranch 23-26-4573
Floyd 9-29A
11-21-5173 AN
Parks Longhorn 6-14-55-73W
Lange 14-14
MCL
Durham Ranch 3-31-20-4571
31-21-5173 SM
Schlautmann 16-10-45-74A
Schlautmann 16-10-45-74C
32-14-5074 AN
Moser 14-35
Schlautmann 15-10-45-74A
LX-State-1-36A
Persson 12-33
Schlautmann 15-10-45-74C
Sorenson 15-28-54-74

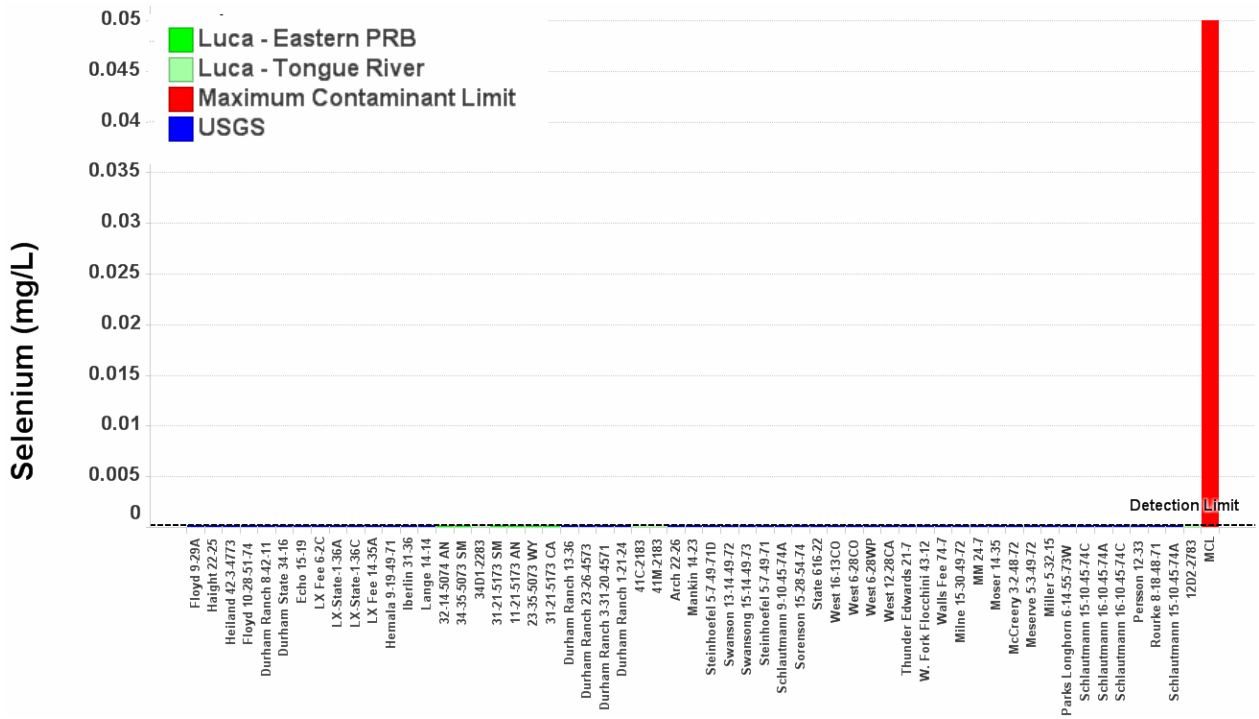

Lead (mg/L)
0.0140
0.0120
0.0100
0.0080
0.0060
0.0040
0.0020
0.0000
Luca - Eastern PRB
Luca - Tongue River
Maximum Contaminant Limit
USGS
Detection Limit
Heiland 42-3-4773
Hemala 9-19-49-71
Iberlin 31-36
Floyd 10-28-51-74
Floyd 9-29A
Haight 22-25
Lange 14-14
LX-State-1-36C
Mankin 14-23
McCreery 3-2-48-72
LX Fee 14-35A
LX Fee 6-2C
LX-State-1-36A
31-21-5173 SM
32-14-5074 AN
34-35-5073 SM
11-21-5173 AN
23-35-5073 WY
31-21-5173 CA
Arch 22-26
Durham Ranch 8-42-11
Durham State 34-16
Echo 15-19
Durham Ranch 1-21-24
Durham Ranch 13-36
Durham Ranch 3-31-20-4571
Steinhoefel 5-7-49-71
Steinhoefel 5-7-49-71D
Swanson 13-14-49-72
Schlautmann 9-10-45-74A
Sorenson 15-28-54-74
State 616-22
Swansong 15-14-49-73
West 12-28CA
West 16-13CO
West 6-28CO
Thunder Edwards 21-7
W. Fork Flocchini 43-12
Walls Fee 74-7
MM 24-7
Moser 14-35
West 6-28WP
Meserve 5-3-49-72
Miller 5-32-15
Milne 15-30-49-72
Persson 12-33
Schlautmann 15-10-45-74C
Rourke 8-18-48-71
Parks Longhorn 6-14-55-73W
Durham Ranch 23-26-4573
Schlautmann 16-10-45-74A
Schlautmann 15-10-45-74A
Schlautmann 16-10-45-74C
MCL

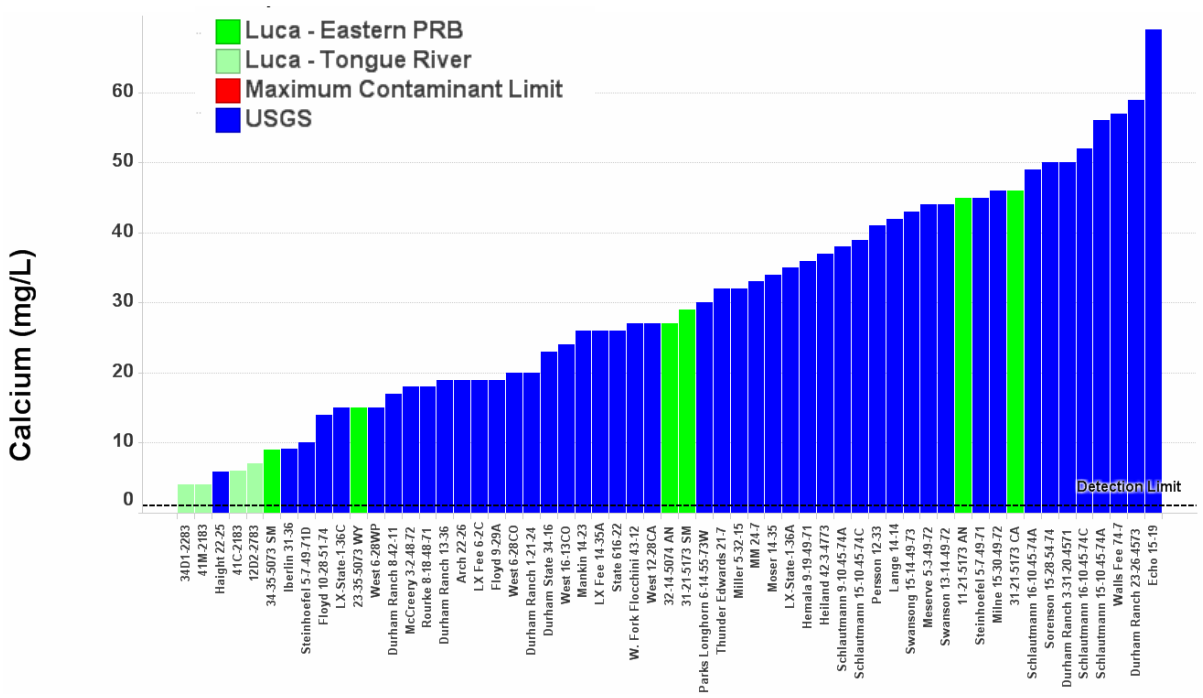

Mercury (mg/L)
0.0020
0.0018
0.0016
0.0014
0.0012
0.0010
0.0008
0.0006
0.0004
0.0002
0.0000
Luca - Eastern PRB
Luca - Tongue River
Maximum Contaminant Limit
USGS
Detection Limit
Heiland 42-3 4773
Hemala 9-19-49-71
Iberlin 31-36
Floyd 10-28-51-74
Floyd 9-29A
Haight 22-25
Lange 14-14
LX-State-1-36C
Mankin 14-23
McCreery 3-2-48-72
LX Fee 14-35A
LX Fee 6-2C
LX-State-1-36A
Echo 15-19
31-21-5173 SM
32-14-5074 AN
34-35-5073 SM
11-21-5173 AN
23-35-5073 WY
31-21-5173 CA
Arch 22-26
Durham Ranch 3-31-20-4571
Durham Ranch 8-42-11
Durham State 34-16
Durham Ranch 1-21-24
Durham Ranch 13-36
Durham Ranch 23-26-4573
Steinhoefel 5-7-49-71
Steinhoefel 5-7-49-71D
Swanson 13-14-49-72
Schlautmann 9-10-45-74A
Sorenson 15-28-54-74
State 616-22
Swansong 15-14-49-73
West 12-28CA
West 16-13CO
West 6-28CO
Thunder Edwards 21-7
W. Fork Flocchini 43-12
Walls Fee 74-7
Milne 15-30-49-72
MM 24-7
Moser 14-35
West 6-28WP
Meserve 5-3-49-72
Miller 5-32-15
Parks Longhorn 6-14-55-73W
Schlautmann 15-10-45-74C
Schlautmann 16-10-45-74A
Schlautmann 16-10-45-74C
Persson 12-33
Rourke 8-18-48-71
Schlautmann 15-10-45-74A
MCL

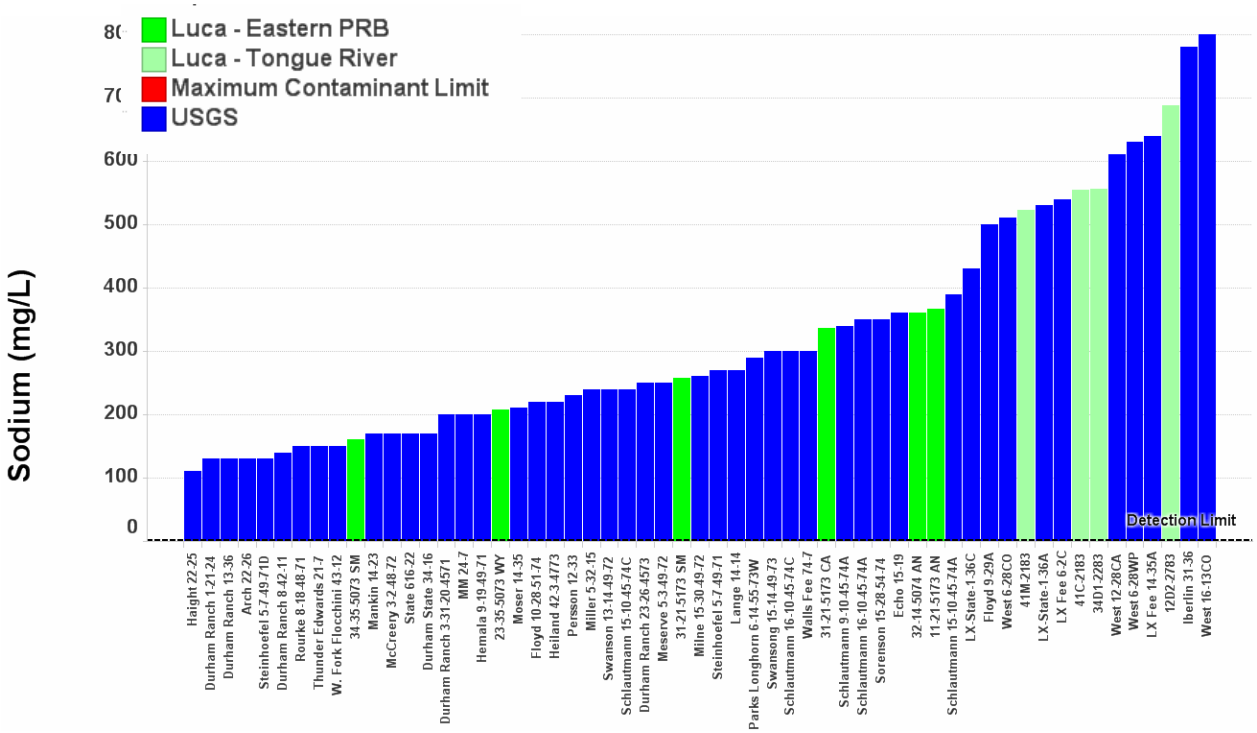

Zinc (mg/L)
5
4.5
4
3.5
3
2.5
2
1.5
1
0.5
0
Luca - Eastern PRB
Luca - Tongue River
Maximum Contaminant Limit
USGS
Detection Limit
Floyd 9-29A
Haight 22-25
Durham Ranch 8-42-11
Durham State 34-16
LX Fee 14-35A
Mankin 14-23
MM 24-7
LX-State-1-36A
LX-State-1-36C
31-21-5173 CA
31-21-5173 SM
11-21-5173 AN
23-35-5073 WY
32-14-5074 AN
Durham Ranch 13-36
Durham Ranch 23-26-4573
34-35-5073 SM
Arch 22-26
Steinhoefel 5-7-49-71D
State 616-22
W. Fork Flocchini 43-12
West 6-28WP
West 6-28CO
Hemala 9-19-49-71
Rourke 8-18-48-71
Durham Ranch 3-31-20-4571
Miller 5-32-15
Steinhoefel 5-7-49-71
Heiland 42-3-4773
LX Fee 6-2C
Thunder Edwards 21-7
West 16-13CO
West 12-28CA
Swansong 15-14-49-73
McCreery 3-2-48-72
Persson 12-33
Lange 14-14
Moser 14-35
Schlautmann 9-10-45-74A
Meserve 5-3-49-72
Floyd 10-28-51-74
Milne 15-30-49-72
41C-2183
41M-2183
Sorenson 15-28-54-74
Walls Fee 74-7
Echo 15-19
Durham Ranch 1-21-24
Parks Longhorn 6-14-55-73W
Schlautmann 15-10-45-74A
Swanson 13-14-49-72
Schlautmann 15-10-45-74C
12D2-2783
Iberlin 31-36
Schlautmann 16-10-45-74A
Schlautmann 16-10-45-74C
MCL

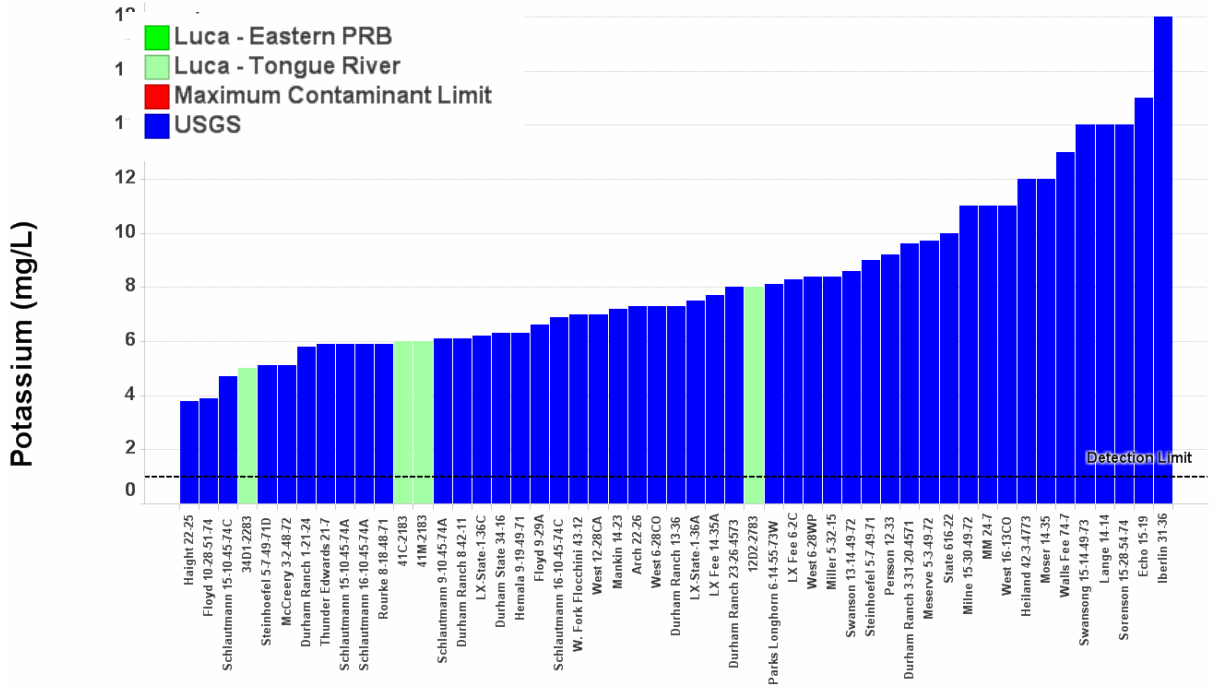

Arsenic (mg/L)
0.010
0.009
0.008
0.007
0.006
0.005
0.004
0.003
0.002
0.001
0.000
Luca - Eastern PRB
Luca - Tongue River
Maximum Contaminant Limit
USGS
Detection Limit
LX-State-1-36A
LX-State-1-36C
LX Fee 14-35A
LX Fee 6-2C
11-21-51/3 AN
Parks Longhorn 6-14-55-73W
Rourke 8-18-48-71
Miller 5-32-15
Milne 15-30-49-72
34-35-50/3 SM
Durham Ranch 3-31-20-45/1
31-21-51/3 CA
31-21-51/3 SM
Durham Ranch 8-42-11
Haight 22-25
Hemala 9-19-49-71
Floyd 10-28-51-74
Floyd 9-29A
Steinhoefel 5-7-49-71D
West 12-28CA
Steinhoefel 5-7-49-71
West 16-13CO
Schlautmann 15-10-45-74C
Sorenson 15-28-54-74
Swansong 15-14-49-73
West 6-28WP
Iberlin 31-36
Meserve 5-3-49-72
Schlautmann 9-10-45-74A
Mankin 14-23
Durham State 34-16
MM 24-7
Persson 12-33
State 616-22
Swanson 13-14-49-72
Walls Fee 74-7
Schlautmann 15-10-45-74A
Schlautmann 16-10-45-74C
Schlautmann 16-10-45-74A
Heiland 42-3-47/3
Moser 14-35
McCreery 3-2-48-72
Echo 15-19
West 6-28CO
Arch 22-26
Lange 14-14
Durham Ranch 13-36
W. Fork Flocchini 43-12
23-35-50/3 WY
Thunder Edwards 21-7
Durham Ranch 23-26-45/3
32-14-50/4 AN
Durham Ranch 1-21-24
MCL

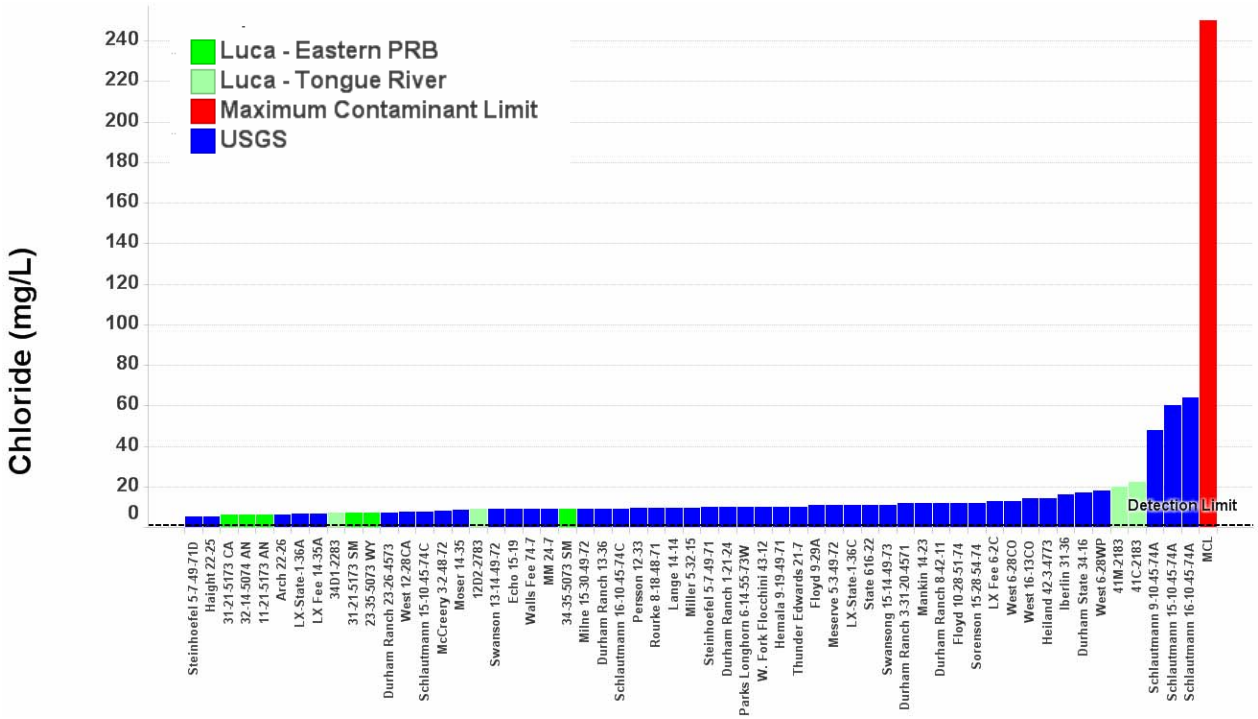

Barium (mg/L)
2
1.8
1.6
1.4
1.2
1
0.8
0.6
0.4
0.2
0
Luca - Eastern PRB
Luca - Tongue River
Maximum Contaminant Limit
USGS
Detection Limit
34-35-50/3 SM
Haight 22-25
Steinhoefel 5-7-49-71D
Thunder Edwards 21-7
23-35-50/3 WY
Floyd 10-28-51-74
McCreery 3-2-48-72
Durham Ranch 1-21-24
Rourke 8-18-48-71
Durham Ranch 8-42-11
Floyd 9-29A
LX-State-1-36C
Arch 22-26
Durham Ranch 13-36
32-14-50/4 AN
Schlautmann 15-10-45-74C
Mankin 14-23
West 6-28CO
Parks Longhorn 6-14-55-73W
Durham State 34-16
31-21-51/3 SM
W. Fork Flocchini 43-12
Miller 5-32-15
LX Fee 6-2C
State 616-22
Hemala 9-19-49-71
West 6-28WP
Schlautmann 16-10-45-74C
West 12-28CA
Persson 12-33
LX-State-1-36A
Swanson 13-14-49-72
Meserve 5-3-49-72
Moser 14-35
Iberlin 31-36
MM 24-7
LX Fee 14-35A
West 16-13CO
Steinhoefel 5-7-49-71
Durham Ranch 23-26-45/3
Schlautmann 16-10-45-74A
Schlautmann 9-10-45-74A
Schlautmann 15-10-45-74A
Heiland 42-3-47/3
Milne 15-30-49-72
Swansong 15-14-49-73
11-21-51/3 AN
Walls Fee 74-7
Durham Ranch 3-31-20-45/1
31-21-51/3 CA
Lange 14-14
Echo 15-19
Sorenson 15-28-54-74
MCL


Selenium (mg/L)
0.05
0.045
0.04
0.035
0.03
0.025
0.02
0.015
0.01
0.005
0
Luca - Eastern PRB
Luca - Tongue River
Maximum Contaminant Limit
USGS
Detection Limit
Floyd 9-29A
Haight 22-25
Heiland 42-3-4773
Floyd 10-28-51-74
Durham Ranch 8-42-11
Durham State 34-16
Echo 15-19
LX Fee 6-2C
LX State-1-36A
LX State-1-36C
LX Fee 14-35A
Hemala 9-19-49-71
Iberlin 31-36
Lange 14-14
32-14-5074 AN
34-35-5073 SM
34D1-2283
31-21-5173 SM
11-21-5173 AN
23-35-5073 WY
31-21-5173 CA
Durham Ranch 13-36
Durham Ranch 23-26-4573
Durham Ranch 3-31-20-4571
Durham Ranch 1-21-24
41C-2183
41M-2183
Arch 22-26
Mankin 14-23
Steinhoefel 5-7-49-71D
Swanson 13-14-49-72
Swansong 15-14-49-73
Steinhoefel 5-7-49-71
Schlautmann 9-10-45-74A
Sorenson 15-28-54-74
State 616-22
West 16-13CO
West 6-28CO
West 6-28WP
West 12-28CA
Thunder Edwards 21-7
W. Fork Flocchini 43-12
Walls Fee 74-7
Milne 15-30-49-72
MM 24-7
Moser 14-35
McCreery 3-2-48-72
Meserve 5-3-49-72
Miller 5-32-15
Parks Longhorn 6-14-55-73W
Schlautmann 15-10-45-74C
Schlautmann 16-10-45-74A
Schlautmann 16-10-45-74C
Persson 12-33
Rourke 8-18-48-71
Schlautmann 15-10-45-74A
12D2-2783
MCL


Calcium (mg/L)
60
50
40
30
20
10
0
Luca - Eastern PRB
Luca - Tongue River
Maximum Contaminant Limit
USGS
Detection Limit
34D1-2283
41M-2183
Haight 22-25
41C-2183
12D2-2783
34-35-5073 SM
Iberlin 31-36
Steinhoefel 5-7-49-71D
Floyd 10-28-51-74
LX State-1-36C
23-35-5073 WY
West 6-28WP
Durham Ranch 8-42-11
McCreery 3-2-48-72
Rourke 8-18-48-71
Durham Ranch 13-36
Arch 22-26
LX Fee 6-2C
Floyd 9-29A
West 6-28CO
Durham Ranch 1-21-24
Durham State 34-16
West 16-13CO
Mankin 14-23
LX Fee 14-35A
State 616-22
W. Fork Flocchini 43-12
West 12-28CA
32-14-5074 AN
31-21-5173 SM
Parks Longhorn 6-14-55-73W
Thunder Edwards 21-7
Miller 5-32-15
MM 24-7
Moser 14-35
LX State-1-36A
Hemala 9-19-49-71
Heiland 42-3-4773
Schlautmann 9-10-45-74A
Schlautmann 15-10-45-74C
Persson 12-33
Lange 14-14
Swansong 15-14-49-73
Meserve 5-3-49-72
Swanson 13-14-49-72
11-21-5173 AN
Steinhoefel 5-7-49-71
Milne 15-30-49-72
31-21-5173 CA
Schlautmann 16-10-45-74A
Sorenson 15-28-54-74
Durham Ranch 3-31-20-4571
Schlautmann 16-10-45-74C
Schlautmann 15-10-45-74A
Walls Fee 74-7
Durham Ranch 23-26-4573
Echo 15-19


Luca - Eastern PRB
Luca - Tongue River
Maximum Contaminant Limit
USGS
Sodium (mg/L)
600
500
400
300
200
100
0
Detection Limit
Haight 22-25
Durham Ranch 1-21-24
Durham Ranch 13-36
Arch 22-26
Steinhoefel 5-7-49-71D
Durham Ranch 8-42-11
Rourke 8-18-48-71
Thunder Edwards 21-7
W. Fork Flocchini 43-12
34-35-5073 SM
Mankin 14-23
McCreery 3-2-48-72
State 616-22
Durham State 34-16
Durham Ranch 3-31-20-4571
MM 24-7
Hemala 9-19-49-71
23-35-5073 WY
Moser 14-35
Floyd 10-28-51-74
Heiland 42-3-4773
Persson 12-33
Miller 5-32-15
Swanson 13-14-49-72
Schlautmann 15-10-45-74C
Durham Ranch 23-26-4573
Meserve 5-3-49-72
31-21-5173 SM
Milne 15-30-49-72
Steinhoefel 5-7-49-71
Lange 14-14
Parks Longhorn 6-14-55-73W
Swansong 15-14-49-73
Schlautmann 16-10-45-74C
Walls Fee 74-7
31-21-5173 CA
Schlautmann 9-10-45-74A
Schlautmann 16-10-45-74A
Sorenson 15-28-54-74
Echo 15-19
32-14-5074 AN
11-21-5173 AN
Schlautmann 15-10-45-74A
LX-State-1-36C
Floyd 9-29A
West 6-28CO
41M-2183
LX-State-1-36A
LX Fee 6-2C
41C-2183
34D1-2283
West 12-28CA
West 6-28WP
LX Fee 14-35A
12D2-2783
Iberlin 31-36
West 16-13CO


Luca - Eastern PRB
Luca - Tongue River
Maximum Contaminant Limit
USGS
Potassium (mg/L)
12
10
8
6
4
2
0
Detection Limit
Haight 22-25
Floyd 10-28-51-74
Schlautmann 15-10-45-74C
34D1-2283
Steinhoefel 5-7-49-71D
McCreery 3-2-48-72
Durham Ranch 1-21-24
Thunder Edwards 21-7
Schlautmann 15-10-45-74A
Schlautmann 16-10-45-74A
Rourke 8-18-48-71
41C-2183
41M-2183
Schlautmann 9-10-45-74A
Durham Ranch 8-42-11
LX-State-1-36C
Durham State 34-16
Hemala 9-19-49-71
Floyd 9-29A
Schlautmann 16-10-45-74C
W. Fork Flocchini 43-12
West 12-28CA
Mankin 14-23
Arch 22-26
West 6-28CO
Durham Ranch 13-36
LX-State-1-36A
LX Fee 14-35A
Durham Ranch 23-26-4573
12D2-2783
Parks Longhorn 6-14-55-73W
LX Fee 6-2C
West 6-28WP
Miller 5-32-15
Swanson 13-14-49-72
Steinhoefel 5-7-49-71
Persson 12-33
Durham Ranch 3-31-20-4571
Meserve 5-3-49-72
State 616-22
Milne 15-30-49-72
MM 24-7
West 16-13CO
Heiland 42-3-4773
Moser 14-35
Walls Fee 74-7
Swansong 15-14-49-73
Lange 14-14
Sorenson 15-28-54-74
Echo 15-19
Iberlin 31-36


Chloride (mg/L)
240
220
200
180
160
140
120
100
80
60
40
20
0
Luca - Eastern PRB
Luca - Tongue River
Maximum Contaminant Limit
USGS
Detection Limit
Steinhoefel 5-7 49-71D
Haight 22-25
31-21-5173 CA
32-14-5074 AN
11-21-5173 AN
Arch 22-26
LX-State-1-36A
LX Fee 14-35A
34D1-2283
31-21-5173 SM
23-35-5073 WY
Durham Ranch 23-26-4573
West 12-28CA
Schlautmann 15-10-45-74C
McCreery 3-2-48-72
Moser 14-35
12D2-2783
Swanson 13-14-49-72
Echo 15-19
Walls Fee 74-7
MM 24-7
34-35-5073 SM
Milne 15-30-49-72
Durham Ranch 13-36
Schlautmann 16-10-45-74C
Persson 12-33
Rourke 8-18-48-71
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Hemala 9-19-49-71
Thunder Edwards 21-7
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Meserve 5-3-49-72
LX-State-1-36C
State 616-22
Swansong 15-14-49-73
Durham Ranch 3-31-20-4571
Mankin 14-23
Durham Ranch 8-42-11
Floyd 10-28-51-74
Sorenson 15-28-54-74
LX Fee 6-2C
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Heiland 42-3-4773
Iberlin 31-36
Durham State 34-16
West 6-28WP
41M-2183
41C-2183
Schlautmann 9-10-45-74A
Schlautmann 15-10-45-74A
Schlautmann 16-10-45-74A
MCL