Jackson Gulch Reservoir, Southwestern Colorado

Zebra and Quagga Mussel Colonization Potential, and Water-Quality Results, September 2008 - August 2009

Hydrological Studies Report 2010-05

Zebra mussel (*Dreissena polymorpha*)

Quagga mussel (*Dreissena rostriformis bugensis*)

Prepared in cooperation with
Mancos Water Conservancy District and
Southwestern Colorado Water Conservation District

Southwest Hydro-Logic

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Winfield G. Wright, *P.E., P.H.*

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CONVERSION FACTORS AND ABBREVIATIONS USED IN THIS REPORT

CONVERSION FACTORS:

Multiply	By	To obtain
cubic foot per second (cfs)	0.02832	cubic meter per second (m^3/sec)
foot (ft)	0.3048	meter (m)
gallon	3.78	liter (L)
inch	2.50	centimeter (cm)

Degrees Celsius (^oC) may be converted to degrees Fahrenheit (^oF) by using the following equation:

$$^oF = 9/5(^oC) + 32$$

ABBREVIATIONS:

The following terms and abbreviations may used in this report:

ft (feet)
mi^2 (square miles)
ft^3/sec (cubic feet per second)
gal/d (gallons per day)
inches per year (in/yr)
acre-feet per year (acre-ft/yr)
acre-feet per month (acre-ft/mo)
milligrams per liter (mg/L)
micrograms per liter (µg/L)
micrograms per liter (ug/L)
milliliter (mL)
millimeter (mm)
kilometer (km)
microsiemens per centimeter at 25 degrees Celsius (uS/cm@25^{o}C)

Southwest Hydro-Logic
265 Ridge Road
Durango, Colorado 81303
(970) 259-2851
(970) 749-3950
website: http://www.swhydrologic.com/
email: wgwright@frontier.net
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EXECUTIVE SUMMARY

According to generalized parameters for water-quality tolerances for zebra and quagga mussels (called *Dreissena* in this report), Jackson Gulch Reservoir would be vulnerable to colonization by *Dreissena*. Conversely, other data from Jackson Gulch Reservoir indicate that the reservoir is not vulnerable to infestation by *Dreissena*. For example, there are no snails or mollusks on the shoreline rocks at the reservoir, when other lakes in the region (Joe Moore Lake) have snail populations. Coal in bedrock (Dakota Formation of Cretaceous age) is exposed along the inlet canal to Jackson Gulch Reservoir, and there are mud flats comprised of weathered coal that contribute iron-colored water to the lake. Coal contributes carbon dioxide (CO_2) to the lake, and CO_2 concentrations are fatal for *Dreissena*. In the winter, the CO_2 is trapped under the ice, creating concentrations that are too high for *Dreissena* to tolerate.

While the water-quality conditions during the frozen winter period are unfavorable for colonization by zebra and quagga mussels, conditions in the upper level of the reservoir during March - August appear to be favorable for mussel colonization, with pH's ranging from 7.28 to 8.51, CO_2 concentrations ranging from 0 to 1.76, and calcium concentrations ranging from 27 to 34.5 mg/L.

Water-quality data were compiled from lakes and rivers in the U.S. where zebra and quagga mussels were reported. Compared with these other sites, Jackson Gulch has values for CO_2, pH, and CalSat Potential that indicate unfavorable conditions for *Dreissena*. For lakes across the U.S., positive CalSat Potential values exist for every lake where *Dreissena* has been reported. Lakes are vulnerable to *Dreissena* colonization for CalSat Potential greater than zero and pH greater than about 7.6. For Jackson Gulch Reservoir, the annual average for CalSat Potential and pH was -0.59 and 7.68, respectively. Jackson Gulch falls in the region of low vulnerability for *Dreissena* colonization.

Rank sum statistics were done comparing CalSat Potential at Jackson Gulch to sites across the U.S. where *Dreissena* adults or veligers were reported. There is a 4.4 percent probability of a positive *Dreissena* report at Jackson Gulch. However, it is doubtful that *Dreissena* could survive in Jackson Gulch at lower depths where the outlet structure is located given annual averages of 5.0 mg/L CO_2 and -0.59 CalSat Potential. The chances of *Dreissena* becoming established in Jackson Gulch are low.

1.0 ZEBRA AND QUAGGA MUSSEL (*DREISSENA*) INVASION IN THE U.S.

In 1986, zebra mussels spread from Eurasia to the Great Lakes in contaminated ballast water. They quickly spread to the Mississippi River, its tributaries and inland lakes. Major changes will occur throughout the Colorado River system as a result of the Quagga mussel, initially discovered in Lake Mead in January 2007.

The mussels (called *Dreissena*) produce microscopic larvae that float freely in the water column, and thus can pass through screens installed to exclude them.

Zebra mussels (and their relative, the quagga mussel) are small clam-like mollusks with dark and light colored stripes. They smother aquatic organisms, such as crayfish and native clams and out-compete other organisms for food and aquatic habitat. These mussels damage equipment by attaching to boat motors or hard surfaces and clog water treatment facilities. They litter beaches with sharp, dangerous shells. They are filterers; therefore, the water may be less turbid, but they remove phytoplankton from the food web which are necessary for the survival of other aquatic organisms.

In 1988, zebra mussels spread from Eurasia to the Great Lakes in contaminated ballast water. They quickly spread to the Mississippi River, its tributaries and inland lakes (**Figure 1**). Zebra mussels have already cost the US billions of dollars a year in national control efforts.

In January 2007, the quagga mussel was discovered at Lake Mead. Zebra mussels were found at Pueblo Reservoir in January 2008. In June 2008, quagga mussels were found in Lake Powell, and in August adult mussels turned up in the Central Arizona Canal in north Scottsdale. The discoveries have generated instant concern, as the mussels can colonize water-supply systems and hydroelectric power plants to the point of disrupting operations.

A few important facts about the quagga mussel:[1]

- *Dreissena* mussels are an inedible shellfish native to the Dneiper River drainage in Ukraine. In the U.S., they were first found in the Great Lakes in 1988.
- *Dreissena* populations grow exponentially. A single mussel can produce 30,000 to 40,000 fertilized eggs in one breeding cycle, equating to almost one million eggs released per quagga per year. Their eggs can easily float downstream.
- *Dreissena* prefer standing water (reservoirs and lakes), but can survive in the moving water of rivers and canals for many days. This means that they can be transported easily from one location to another.
- *Dreissena* can survive in deep reservoirs and lakes.

Dreissena mussels have a limited range of conditions under which they can survive. One of the most important factors is calcium in water, which is necessary for *Dreissena* to build their calcium carbonate shells ($CaCO_3$). The pH values of water (acidic, neutral, or basic conditions) also are important. In order for them to survive, water-quality conditions must be suitable for development of the $CaCO_3$ shell.

Results from this study indicate that elevated carbon dioxide (CO_2) concentrations and a low CalSat Potential values are indicators of conditions that are unsuitable for *Dreissena* to survive.

[1]David Wegner, Glen Canyon Institute Newsletter, October 8, 2008.

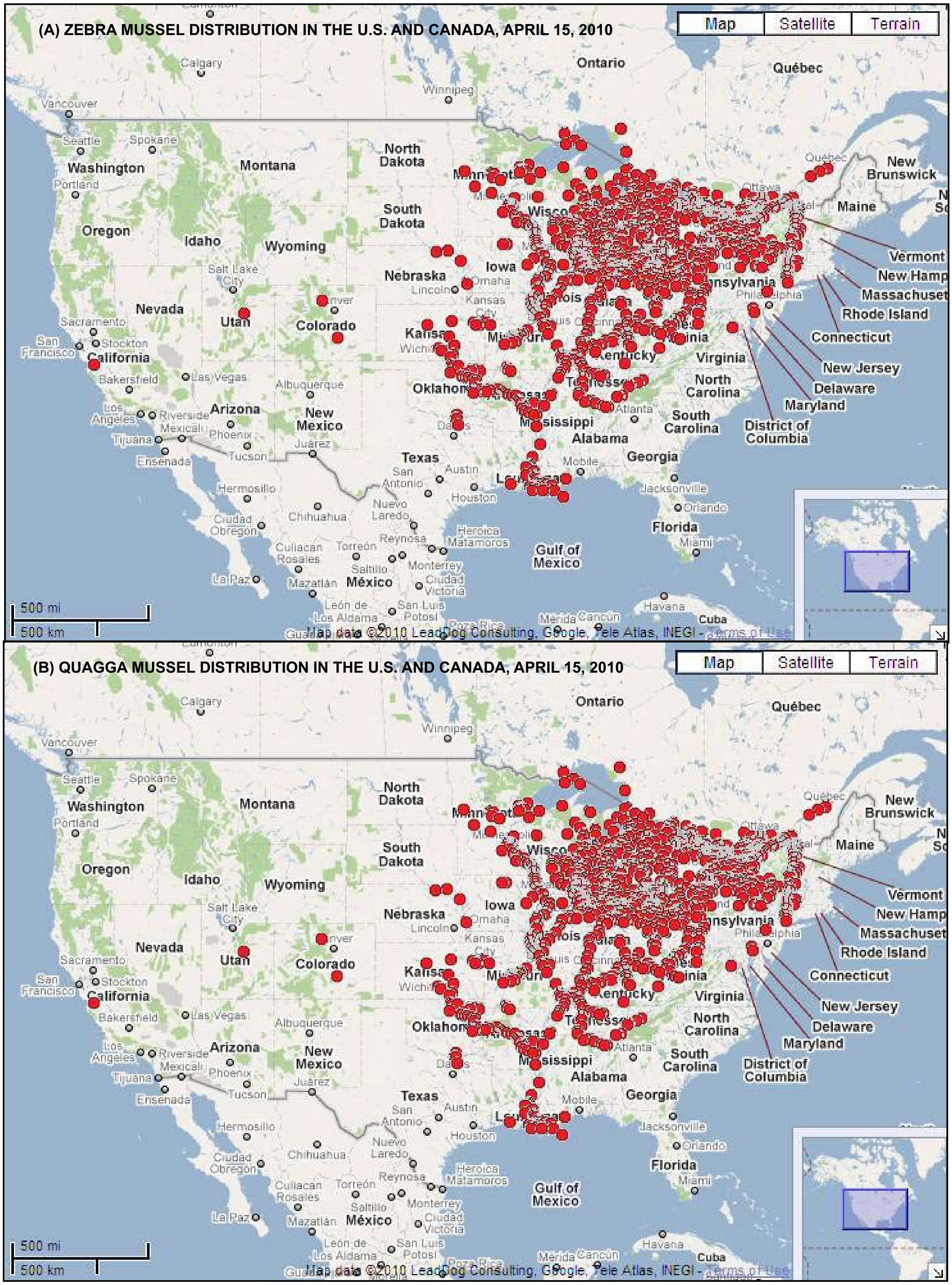


Figure 1. Distribution of zebra and quagga mussels in the U.S. and Canada, April 15, 2010 (http://nas.er.usgs.gov/).

2.0 *DREISSENA* COLONIZATION POTENTIAL: ENVIRONMENTAL TOLERANCES

The degree to which a body of water, and associated facilities, is at risk of becoming infested with Quagga or Zebra Mussels can be estimated by comparing the organisms known environmental tolerances to water-chemistry parameters of that body of water.

Driessena cannot survive in water with low CalSat Potential, low calcium concentrations, low pH values, and high carbon dioxide concentrations.

Zebra and quagga mussels have a limited range of conditions under which they can survive. One of the most important factors is calcium in water, which is necessary for *Dreissena* to build their calcium carbonate shells ($CaCO_3$). The pH values of water (acidic, neutral, or basic conditions) also are important. In order for them to survive, water-quality conditions must be suitable for development of the $CaCO_3$ shell. Conditions are not suitable where $CaCO_3$ can dissolve in water. The CalSat Potential (calcite saturation index) is a measure of the ability of $CaCO_3$ to dissolve into water or precipitate from water. Expressed as a dimensionless ratio, waters with CalSat Potential values near zero are at equilibrium. Waters with CalSat Potential values less than zero would dissolve $CaCO_3$. Waters with CalSat Potential values greater than zero are suitable for *Dreissena* to build their shells.

In general, lakes that are vulnerable to *Dreissena* colonization have pH values greater than about 7.6 and CalSat Potential greater than zero. Lakes that are vulnerable to *Dreissena* colonization have calcium values greater than about 30 mg/L and CalSat Potential values greater than zero. For sites with relatively low calcium values and high CalSat Potential, there is still potential for colonization because *Dreissena* can survive in water with calcium concentrations as low as 15 mg/L. Lakes are vulnerable to *Dreissena* colonization for CO_2 concentrations less than about 2.0 mg/L and hardness concentrations greater than about 100 mg/L as $CaCO_3$.

Table 1. Water-quality limitations for survival of Zebra and Quagga Mussels

Parameter	Range	Can Veligers or Adult *Dreissena* Survive?
CalSat Potential (calcite saturation index)	less than zero	Veligers, no. Adults, no.
	near zero	Veligers, uncertain. Adults, possible.
	greater than zero	Veligers, yes. Adults, yes.
Calcium	less than 15 mg/L	Veligers, no. Adults, yes if CalSat Potential remains greater than zero.
	16 - 30 mg/L	Veligers, no if CalSat Potential remains less than zero. Adults, no if CalSat Potential remains less than zero.
	greater than 30 mg/L	Veligers, yes if CalSat Potential remains greater than zero. Adults, yes if CalSat Potential remains greater than zero.
pH	less than 7.0	Veligers, no. Adults, no.
	7.1 - 7.6	Veligers, no. Adults, uncertain if CalSat Potential remains greater than zero.
	7.6 - 9.0	Veligers, yes if CalSat Potential is greater than zero. Adults, yes if CalSat Potential is greater than zero.
	greater than 9.0	Veligers, no. Adults, no.
Carbon Dioxide (CO_2)	less than 2 mg/L	Veligers, yes. Adults, yes.
	2 - 6 mg/L	Veligers, no. Adults, unlikely in lakes, possibly in rivers.
	greater than 6 mg/L	Veligers, no. Adults, no.

3.0 INTENSIFIED FIELD STUDY AT JACKSON GULCH RESERVOIR, SOUTHWESTERN COLORADO

The Mancos Water Conservancy District takes a pro-active approach to the threat posed by zebra and quagga mussels.

Seasonal water-quality data were collected at Jackson Gulch Reservoir to determine the potential for zebra or quagga mussel colonization potential. Field and laboratory parameters were measured six times from September 2008 through August 2009.

During 2008-09, water-quality samples were collected six times from Jackson Gulch Reservoir, located in Montezuma County, Colorado, near the headwaters of the Mancos River basin. Field water-quality parameters (pH, specific conductance, water temperature, and dissolved oxygen) were measured in the lake every five feet at the deepest point in the reservoir using a YSI ProSeries™ lake profiler. Water-quality samples were collected at the upper, middle, and lower levels of the reservoir using a Teflon™ Kemmerer sampler. During the winter, the reservoir was frozen, and a hole was bored into the ice in order to measure field parameters and collect water-quality samples. Samples were filtered using a 0.45 μm (micrometer) disposable filter into polyethylene bottles, and were preserved with nitric acid for cation analyses. Samples for anion analyses were unpreserved. Samples for alkalinity and acidity were collected in glass bottles. Alkalinity titrations (for determination of HCO_3^- concentrations) and acidity titrations (for determination of CO_2 concentrations) were chilled and performed within 24 hours of sample collection. Cations (calcium, magnesium, sodium), anions (chloride, sulfate, fluoride), and nutrients (nitrate, ammonia) were determined by spectrophotometry and colorimetry.

Alkalinity titrations were performed by incremental addition of a weak acid (0.016 normal sulfuric acid) to 100 mL (milliliters) of sample water. Alkalinity was determined by the amount of acid added to create an inflection point of the titration curve near pH 4.5. Acidity titrations were performed by incremental addition of a strong base (0.05 normal sodium hydroxide) to 100 mL of sample water in a glass bottle while the opening was sealed with Parafilm™ to prevent the escape of CO_2. Acidity was calculated by the amount of base added to create an inflection point of the titration curve near pH 8.3. If no inflection point was noticeable, acidity was determined using the amount of base added to a fixed-end point of pH 8.3. Water-quality data for Jackson Gulch Reservoir are tabulated in ***APPENDIX A1***.

Google Earth, 2010

Figure 2. 3D perspective of Jackson Gulch Reservoir (looking northwest), southwestern Colorado, and photos of coal-related features.

4.0 JACKSON GULCH RESERVOIR: WATER-QUALITY RESULTS

Water-quality conditions changed throughout the year, and differences were most pronounced during winter under the ice.

While calcium concentrations and pH values appear to be favorable for *Dreissena* survival, the CalSat Potential and CO_2 values are not favorable.

Water-quality data from six sampling events during 2008-09 are tabulated in ***APPENDIX A1***. Calcium concentrations ranged from 28.4 to 36 mg/L, with an average of 30.2 mg/L. The pH values ranged from 6.93 to 8.51, with an average of 7.68. According to generalized parameters for water-quality tolerances for *Dreissena*,[1] Jackson Gulch Reservoir would be vulnerable to colonization by zebra and quagga mussels. Conversely, other data from Jackson Gulch Reservoir indicate that the reservoir is not vulnerable to infestation by zebra and quagga mussels. For example, there are no snails or mollusks on the shoreline rocks at the reservoir, when other lakes in the region (for example, Joe Moore Lake) have snail populations. Coal in bedrock (Dakota Formation of Cretaceous age) is exposed along the inlet canal to Jackson Gulch Reservoir (***FIGURE 2***), and there are mud flats comprised of weathered coal that contribute iron-colored water to the lake (***FIGURE 2***).

During February 2009 when the reservoir was covered with ice, water temperatures were consistent, ranging from 2.9 to 3.5^{o}C throughout the entire depth of the lake (***FIGURE 3***), and pH values also were relatively consistent ranging from 6.93 to 7.05, indicating very little or no stratification of water quality under the ice. CO_2 determined from acidity titrations ranged from 6.34 to 14.8 mg/L, with higher concentrations at the bottom of the lake (***FIGURE 3***). It is suspected that the coal contributes CO_2 to the water column, and the ice cover prevents the CO_2 from degassing, thereby retaining high dissolved CO_2 concentrations.

During the March 2009 sampling event, the ice had melted slightly around the edges of the lake. This melting and exposure of lake water to atmosphere was sufficient for the CO_2 to escape from being trapped under the ice, and CO_2 concentrations decreased dramatically, ranging from 0 to 5.98 mg/L in the upper to lower levels, respectively (***FIGURE 3***). pH values ranged from 8.7 to 7.48 in the upper to lower levels, respectively (***FIGURE 3***). Higher solute concentrations were observed during the February and March events than were observed during the other sampling events, possibly due to groundwater inflows and low water levels in the reservoir.

While the water-quality conditions during the frozen winter period are unfavorable for colonization by zebra and quagga mussels, conditions in the upper part of the reservoir during March - August appear to be favorable for mussel colonization, with pH's ranging from 7.28 to 8.51 and calcium concentrations ranging from 27 to 34.5 mg/L. The reservoir developed typical stratified conditions with warm water temperatures near the surface during May and July (***FIGURE 3***). Dissolved-oxygen concentrations were low near the bottom of the reservoir during August and September, typically due to algal growth settling to the bottom and creating anoxic conditions from decomposition.

For most of the year, dissolved CO_2 and CalSat Potential showed unfavorable conditions for *Dreissena* colonization. During September 2008 through February 2009, CO_2 concentrations were high, indicating unsuitable conditions for *Dreissena* survival. During May to August 2009, CO2 concentrations were low at the surface of the lake; however, the middle and lower depths of the reservoir experienced much higher CO_2 concentrations, ranging from 3.5 to 7.9 mg/L (***FIGURE 3***).

During September 2008, the CalSat Potential values were less than zero, ranging from -0.24 to -1.3. During February 2009, the CalSat Potential values were less than zero, indicating unsuitable conditions for *Dreissena* survival (***FIGURE 3***). From March to July, the CalSat Potential was greater than zero at the surface of the reservoir; however, CalSat Potential remained less than zero at the middle and lower depths for the entire year (***FIGURE 3***). The outlet structure from the reservoir is located in the lower depth of the reservoir (***FIGURE 3***).

During March 2009, the inlet canal was sampled, indicating a pH value of 6.22. Snowmelt runoff near the northeast corner of the lake had a pH value of 6.50. For both sites, CO_2 concentrations were high and CalSat Potential values were less than zero (***APPENDIX A1***).

[1] O'Neill, C.R., Jr., 2001, Zebra mussel--Impacts and Control: Cornell Cooperative Extension Information Bulletin 238.

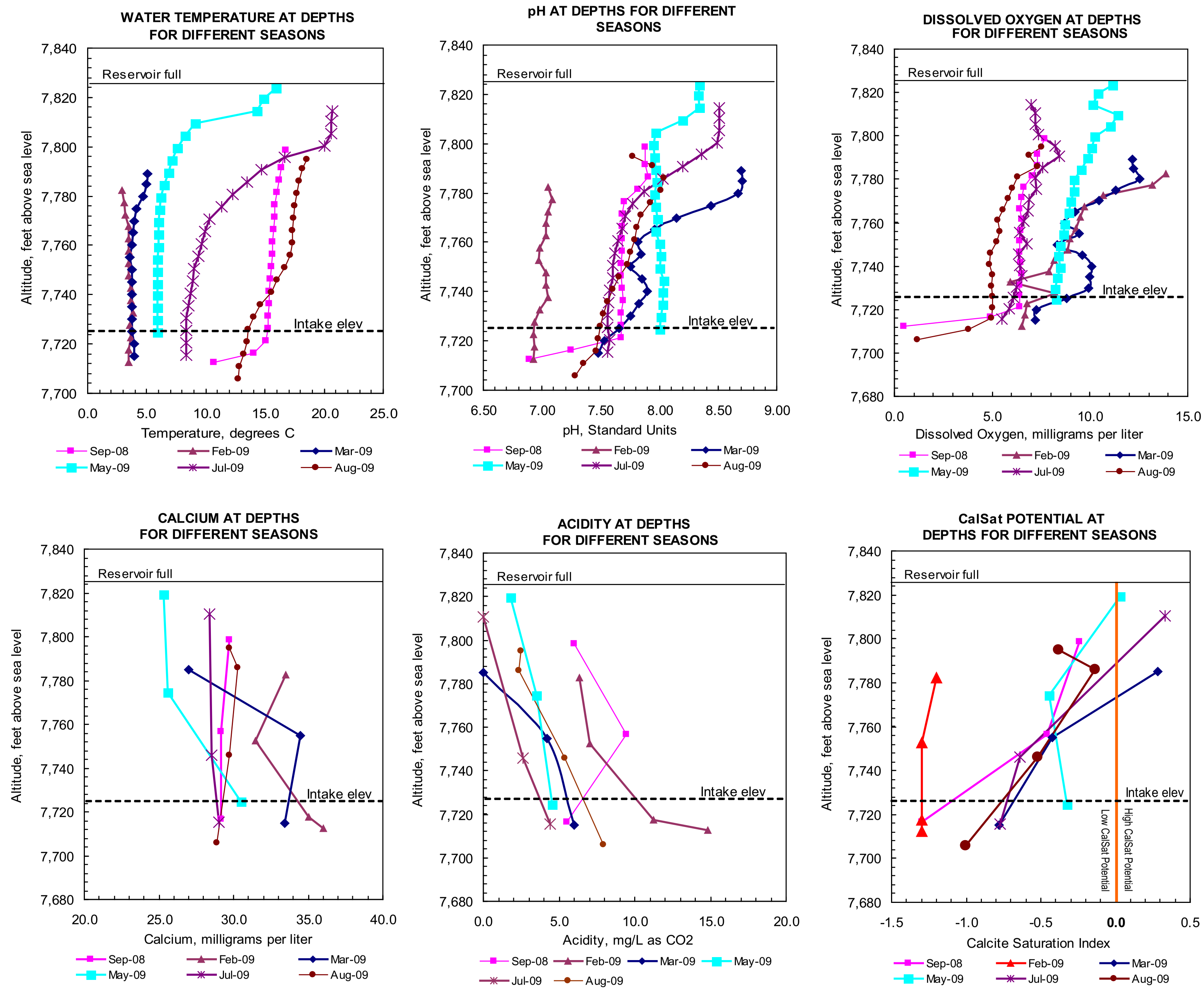


Figure 3. Variation of field and laboratory parameters in Jackson Gulch Reservoir at depths during different seasons.

5.0 JACKSON GULCH RESERVOIR: SEASONAL WATER-QUALITY

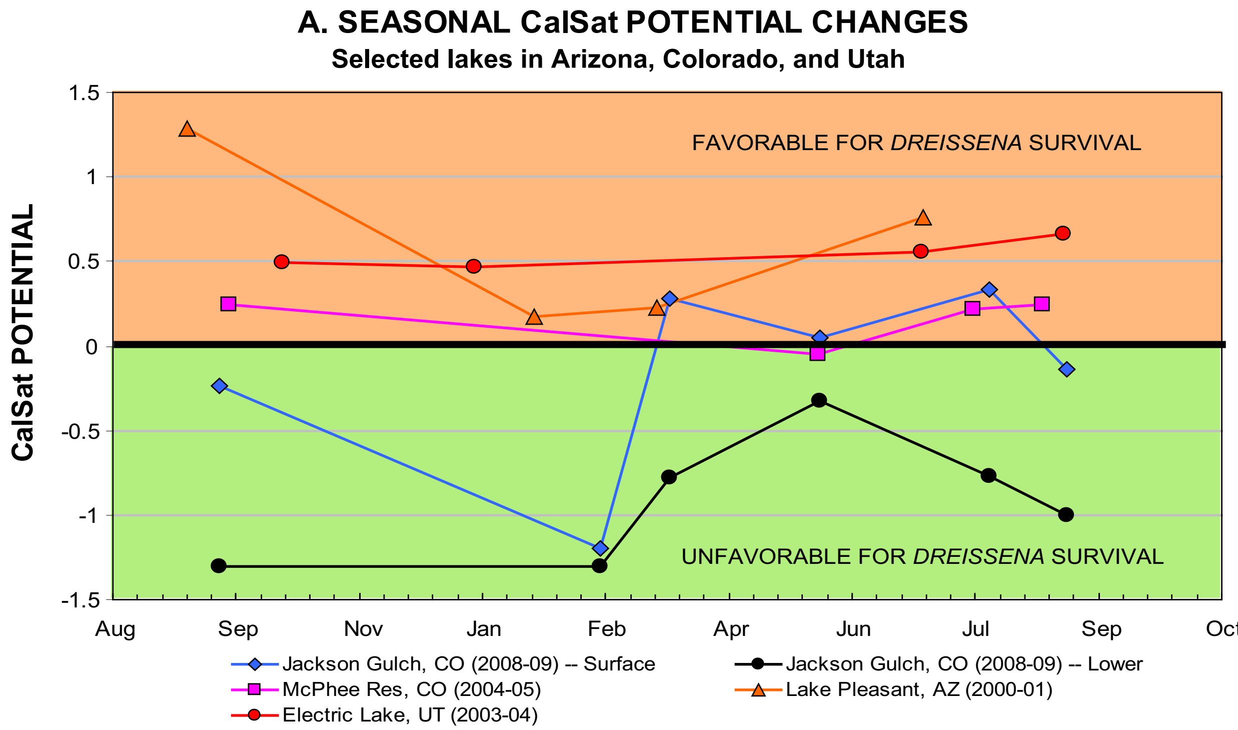
CalSat Potential and pH values of lakes vary throughout the year. Some lakes have favorable conditions all year. Jackson Gulch has unfavorable conditions for part of the year.

Conditions at the surface vary from unfavorable for *Dreissena* in the winter to favorable for *Dreissena* in the early summer. Conditions in the lower reservoir (where the intake is located) remain unfavorable for *Dreissena* throughout the year. In order for *Dreissena* to survive, conditions need to be favorable all year.

Seasonal variations of water-quality parameters are important for *Dreissena* colonization potential. Water-quality samples collected during the winter can be different than samples collected during the summer. The most critical time periods for survival of *Dreissena* may be during the winter when ice covers a lake.

In Jackson Gulch Reservoir during February 2009, the CalSat Potential values were less than zero, ranging from -1.2 to -1.3, which comprise unfavorable conditions for *Dreissena* (***FIGURE 4***). From March to July, the CalSat Potential was greater than zero, but only at the surface of the reservoir. CalSat Potential remained less than zero at the lower depths for the entire year (***FIGURE 4***). The outlet structure from the reservoir is located in the lower depth of the reservoir.

Considering that pH values greater than 7.6 may be favorable for *Dreissena* survival, the water-quality conditions are variable in Jackson Gulch. During summer, pH values at the surface are favorable for their survival, and in the lower reservoir, pH values are favorable from May to July. During winter, the pH value at the surface was 7.05, and in the lower depth the pH was 6.93. *Dreissena* and their veligers would not survive in these low pH's.



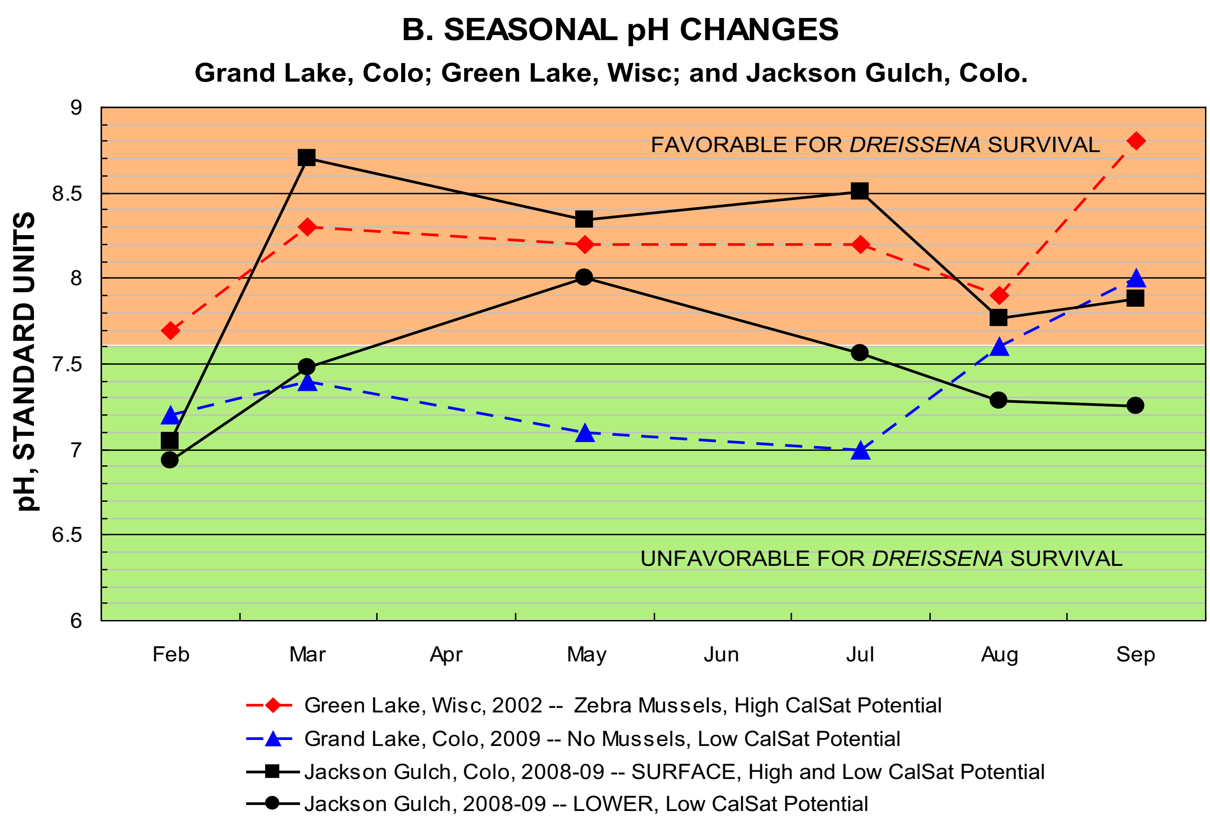


Figure 4. Seasonal changes of CalSat Potential and pH in water from selected lakes.

6.0 JACKSON GULCH COMPARED WITH OTHER LAKES IN THE U.S.

Water-quality data were compiled from lakes and rivers in the U.S. where zebra and quagga mussels were reported.[1] Compared with these other sites, Jackson Gulch has values for CO_2, pH, and CalSat Potential that indicate unfavorable conditions for *Dreissena*.

For CO_2 and hardness, Jackson Gulch does not fall into the approximate region of lake vulnerability for *Dreissena* colonization. For pH and CalSat Potential, Jackson Gulch is in the region where sites are not vulnerable to colonization.

The vulnerability of a lake to *Dreissena* colonization may be approximated using CO_2 and hardness concentrations. Lakes are vulnerable to *Dreissena* colonization for CO_2 concentrations less than about 2.0 mg/L and hardness concentrations greater than about 100 mg/L as $CaCO_3$. For Jackson Gulch Reservoir, the annual average for CO_2 and hardness was 5.0 and 88 mg/L, respectively. Jackson Gulch falls outside the approximate region of lake vulnerability for *Dreissena* colonization.

For lakes across the U.S., positive CalSat Potential[1] values exist for every lake where *Dreissena* has been reported. Lakes are vulnerable to *Dreissena* colonization for CalSat Potential greater than zero and pH greater than about 7.6. For Jackson Gulch Reservoir, the annual average for CalSat Potential and pH was -0.59 and 7.68, respectively. Jackson Gulch falls in the region of low vulnerability for *Dreissena* colonization.

[1]Wright, W.G., 2010, CalSat Potential -- Indicator of Lake and River Vulnerability to Zebra and Quagga Mussel Infestation in Colorado and the U.S.: Southwest Hydro-Logic, Hydrologic Investigations Report 2010-04.

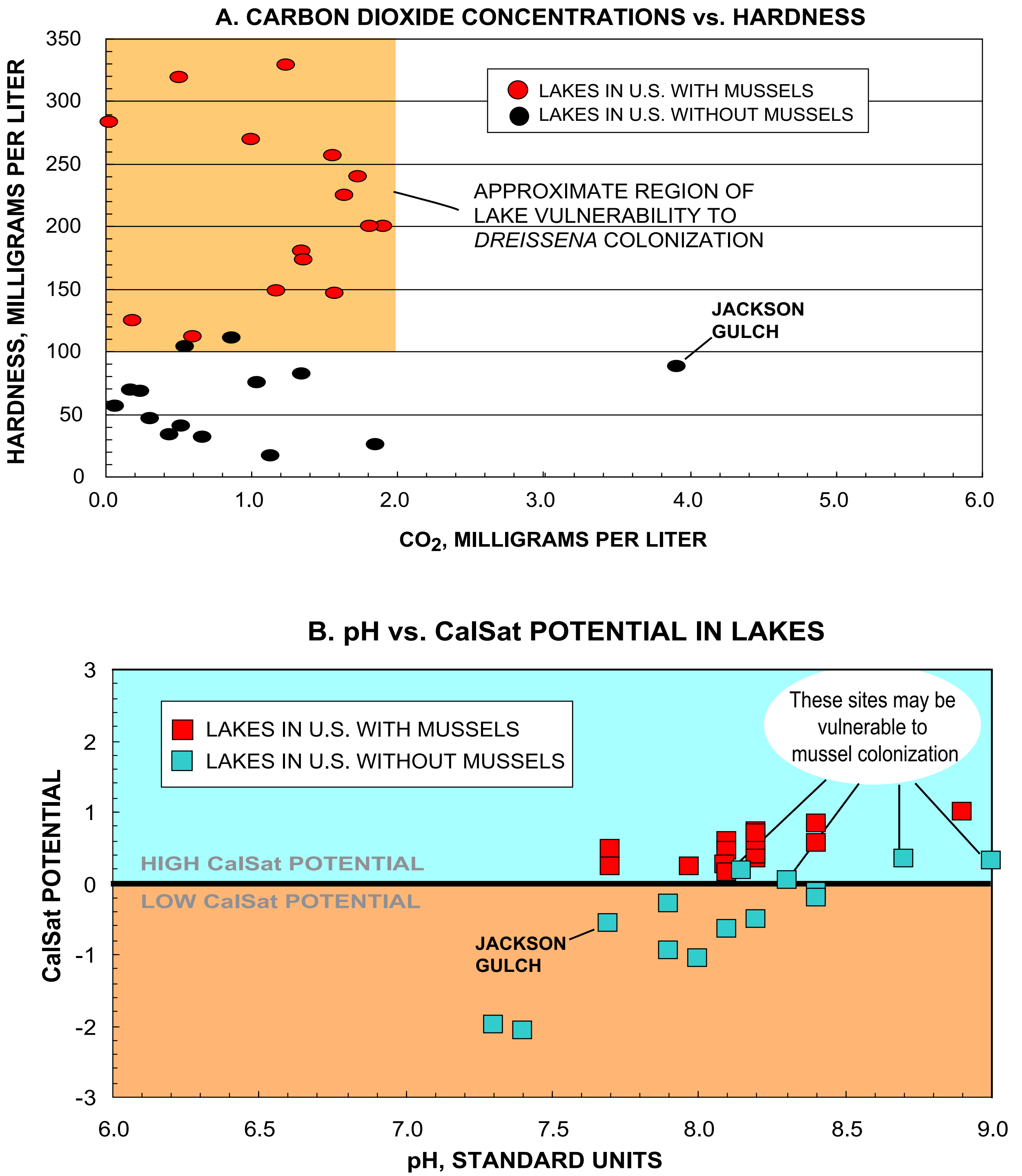


Figure 5. (A) CO_2 related to hardness in water from lakes; (B) pH related to CalSat Potential.

7.0 JACKSON GULCH: *DREISSENA* COLONIZATION POTENTIAL

Water quality of Jackson Gulch is statistically different than the water quality of lakes in the U.S. where *Dreissena* have been reported.

Compared to sites across the U.S., there is a 4.4 percent probability that Jackson Gulch could have a positive *Dreissena* report. Given the water-quality conditions under the ice during winter, it is doubtful that *Dreissena* could survive.

Box plots of CalSat Potential data show the range of values for CalSat in lakes across the U.S. For lakes with *Dreissena*, CalSat Potential values ranged from +0.163 to +1.88, with a median of +0.561. For lakes without mussels, CalSat Potential ranged from -2.066 to +0.336, with a median of -0.346. For Jackson Gulch Reservoir, CalSat Potential values ranged from -1.300 to +0.334, with a median of -0.492. Analysis of variance (ANOVA) shows that CalSat Potential values in water from lakes with *Dreissena* are significantly different (α=0.001) than are CalSat Potential values in water from lakes without *Dreissena*. Significant differences also were shown for CalSat Potential values for lakes with *Dreissena* and Jackson Gulch Reservoir (α=0.001). Considering that the CalSat Potential data might not be normally distributed, Rank ANOVA on the data also shows significant CalSat Potential differences (α=0.05) between lakes with and without *Dreissena*.

Rank sum statistics were done comparing CalSat Potential at Jackson Gulch to sites across the U.S. where *Dreissena* adults or veligers were reported. There is a 4.4 percent probability of a positive *Dreissena* report at Jackson Gulch. However, it is doubtful that *Dreissena* could survive in Jackson Gulch at lower depths where the outlet structure is located given annual averages of 5.0 mg/L CO_2 and -0.59 CalSat Potential. The chances of *Dreissena* becoming established in Jackson Gulch are low.

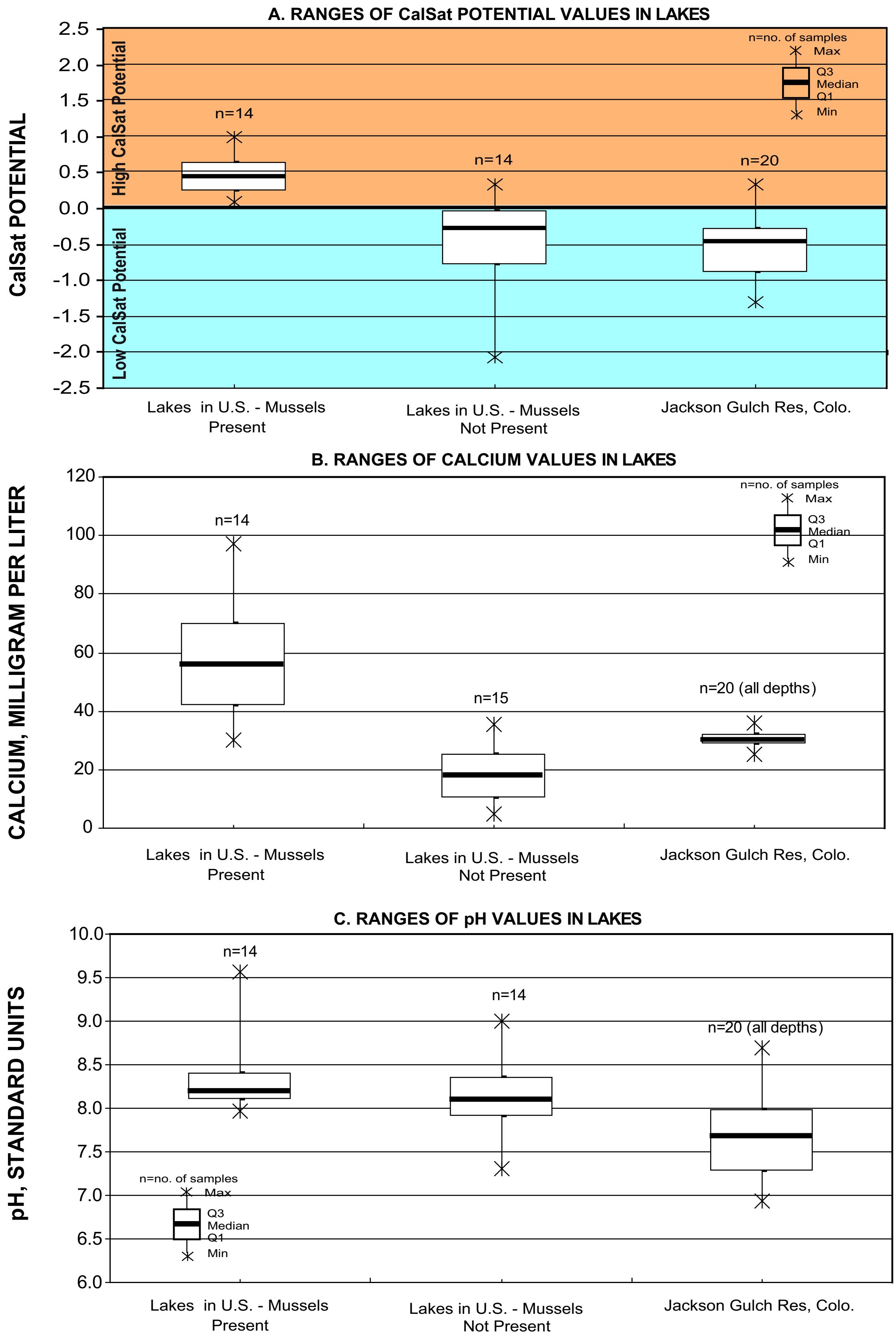


Figure 6. Ranges of CalSat Potential, calcium, and pH for U.S lakes and Jackson Gulch.

8.0 SUMMARY AND CONCLUSIONS

Chances of *Dreissena* colonization in Jackson Gulch Reservoir are very low. Coal outcrops contribute CO_2 to the lake, and CO_2 concentrations are fatal for *Dreissena*.

Given the adaptive nature of the quagga mussels, the growth and expansion of *Dreissena* needs to be monitored for many years before any lake or water body can be declared invulnerable to colonization. Environmental conditions that they can tolerate should be studied further.

The potential is low for establishment of *Dreissena* at Jackson Gulch Reservoir. The geology of the reservoir basin includes coal seams in the Dakota Formation. Coal contributes dissolved CO_2 to the water, and high CO_2 concentrations are fatal for *Dreissena* and interfere with development of their shells.

Compared with lakes across the U.S. with zebra and quagga mussels, Jackson Gulch has much different water quality with lower CalSat Potential, low pH values, and high CO_2 concentrations. The conditions are Jackson Gulch, therefore, are unsuitable for zebra and quagga mussel colonization.

However, given the ability of these mussels to adapt to their environment, the growth and expansion of *Dreissena* needs to be monitored, and water-quality conditions where they survive must be documented. More research needs to be done on the potential for *Dreissena* to be transported downstream from lakes to rivers and canals.

Augering a hole in the ice, February 2009.

Hole in the ice and Teflon lake sampler, February 2009.

Iron-rich snowmelt runoff from coal seam flows into lake, March 2009. CalSat Potential of the water was -2.59 (unsuitable for *Dreissena* survival).

Coal seam where inlet canal flows into the lake, March 2009. Coal contributes CO_2 to the lake, and CO_2 becomes trapped under the ice during winter.

Coal in stream where the inlet canal flows into the lake, March 2009. CO_2 concentration of the stream was 64 mg/L (unsuitable for *Dreissena* survival).

Figure 7. Photographs of field work at Jackson Gulch Reservoir, and features that contribute to the unfavorable conditions for *Dreissena* establishment.

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Appendix

Appendix A1. Water-quality data for Jackson Gulch Reservoir, southwestern Colorado, 2008-09

[dd, decimal degrees; ft, feet; µS/cm, microsiemens per centimeter; °C, degrees Celsius; mg/L, milligrams per liter; $CaCO_3$, calcium carbonate; atm, atmospheres]

Site Name	Latitude, dd	Longitude, dd	Data Source(s)	Date	Sample Depth, ft	Altitude, ft	Specific Conductance, µS/cm	pH, standard units	Water Temp-erature, °C	Dissolved Oxygen, mg/L	Hardness as $CaCO_3$ (Ca, Mg), mg/L	Alkalinity, mg/L as CaCO3	Bicarbonate (HCO_3^-), mg/L
JACKSON GULCH RESERVOIR, SOUTHWESTERN COLORADO													
Jackson Gulch Reservoir, CO (upper) - Sept 08	37.4011386	-108.2731135	SWHL	9/18/2008	3	7,799.0	182	7.88	16.8	7.7	89	64.1	78.1
Jackson Gulch Reservoir, CO (middle) - Sept 08	37.4011386	-108.2731135	SWHL	9/18/2008	50	7,757.0	182	7.68	15.59	6.45	88	64.1	78.1
Jackson Gulch Reservoir, CO (lower) - Sept 08	37.4011386	-108.2731135	SWHL	9/18/2008	85	7,717.0	180	7.25	14.03	4.89	87	64.1	78.1
Jackson Gulch Reservoir, CO (upper) - Feb 09	37.4011386	-108.2731135	SWHL	2/20/2009	5	7,783.0	156	7.05	2.94	13.9	101.1	72	88
Jackson Gulch Reservoir, CO (middle) - Feb 09	37.4011386	-108.2731135	SWHL	2/20/2009	35	7,753.0	225	6.97	3.49	8.95	89.7	68	83
Jackson Gulch Reservoir, CO (lower) - Feb 09	37.4011386	-108.2731135	SWHL	2/20/2009	70	7,718.0	224	6.94	3.5	6.68	102.2	70	85.4
Jackson Gulch Reservoir, CO (bottom) - Feb 09	37.4011386	-108.2731135	SWHL	2/20/2009	75	7,713.0	225	6.93	3.45	6.5	103.3	70	85.4
Jackson Gulch Reservoir, CO (upper) - Mar 09	37.4011386	-108.2731135	SWHL	3/19/2009	5	7,789.0	182	8.7	5.1	12.19	79.5	58	70.7
Jackson Gulch Reservoir, CO (middle) - Mar 09	37.4011386	-108.2731135	SWHL	3/19/2009	35	7,755.0	194.9	7.84	3.6	9.47	98	68	83.1
Jackson Gulch Reservoir, CO (lower) - Mar 09	37.4011386	-108.2731135	SWHL	3/19/2009	75	7,715.0	213.9	7.48	3.9	7.2	93	70	85.4
Jackson Gulch Reservoir, CO (upper) - May 09	37.4011386	-108.2731135	SWHL	5/18/2009	5	7,819.5	156.1	8.33	14.9	10.4	73.7	56	68.4
Jackson Gulch Reservoir, CO (middle) - May 09	37.4011386	-108.2731135	SWHL	5/18/2009	50	7,774.5	161.5	7.97	6.1	9.17	74.9	58	70.3
Jackson Gulch Reservoir, CO (lower) - May 09	37.4011386	-108.2731135	SWHL	5/18/2009	100	7,724.5	165.3	8	5.9	8.28	87.9	60.8	74.2
Jackson Gulch Reservoir, CO (upper) - July 09	37.4011386	-108.2731135	SWHL	7/27/2009	5	7,810.5	169.5	8.51	20.6	7.19	80.2	58.8	71.7
Jackson Gulch Reservoir, CO (middle) - July 09	37.4011386	-108.2731135	SWHL	7/27/2009	50	7,765.5	160.8	7.68	9.9	6.85	79.7	55.2	67.3
Jackson Gulch Reservoir, CO (lower) - July 09	37.4011386	-108.2731135	SWHL	7/27/2009	100	7,715.5	159.4	7.56	8.3	5.49	81.5	56	68.3
Jackson Gulch Reservoir, CO (surface) - Aug 09	37.4011386	-108.2731135	SWHL	8/27/2009	0	7,795.0	160.4	7.77	18.5	7.5	84.3	58.5	71.3
Jackson Gulch Reservoir, CO (upper) - Aug 09	37.4011386	-108.2731135	SWHL	8/27/2009	10	7,786.0	161.6	8.04	17.9	7.32	91	56.8	69.3
Jackson Gulch Reservoir, CO (middle) - Aug 09	37.4011386	-108.2731135	SWHL	8/27/2009	50	7,746.0	159.6	7.66	16	4.9	88.5	59.3	72.3
Jackson Gulch Reservoir, CO (lower) - Aug 09	37.4011386	-108.2731135	SWHL	8/27/2009	90	7,706.0	158.1	7.28	12.7	1.2	85.5	53.6	65.4
Jackson Gulch Res, Average upper depths							168	8	13	10	85	61	75
Jackson Gulch Res, Average all depths							179	7.68	10.16	7.61	88	62	76
Jackson Gulch Inlet Canal	37.4097612	-108.2606147	SWHL	3/3/2009	--	7,820	220	6.22	2.9	9.0	107	76	92.7
Snowmelt near Inlet Canal	37.4077619	-108.2619945	SWHL	3/3/2009	--	7,790	868	6.5	1.8	9.0	195	12	14

Appendix A1. Water-quality data for Jackson Gulch Reservoir, southwestern Colorado, 2008-09 -- continued

[dd, decimal degrees; ft, feet; µS/cm, microsiemens per centimeter; °C, degrees Celsius; mg/L, milligrams per liter; $CaCO_3$, calcium carbonate; atm, atmospheres]

Site Name	Acidity, measured, mg/L as CO_2	pCO_2, atm*	CO_2, Calculated, mg/L	Calcite Saturation Index (CalSat Potential)	Calcium, mg/L	Magnesium, mg/L	Sodium, mg/L	Chloride, mg/L	Sulfate, mg/L	Silicate (SiO_2), mg/L	Dissolved solids, mg/L	Nitrate+ Nitrite, mg/L as N	Ammonia, mg/L as N	Iron, mg/L
JACKSON GULCH RESERVOIR, SOUTHWESTERN COLORADO														
Jackson Gulch Reservoir, CO (upper) - Sept 08	--	9.23E-04	1.36	-0.24	29.75	3.72	--	--	--	--	111	--	--	--
Jackson Gulch Reservoir, CO (middle) - Sept 08	--	1.45E-03	2.14	-0.46	29.14	3.84	--	--	--	--	111	--	--	--
Jackson Gulch Reservoir, CO (lower) - Sept 08	--	8.49E-03	12.55	-1.3	29.14	3.84	--	--	--	--	111	--	--	--
Jackson Gulch Reservoir, CO (upper) - Feb 09	6.34	6.08E-03	8.99	-1.2	33.5	4.2	0.35	0.4	27.2	--	153	--	--	--
Jackson Gulch Reservoir, CO (middle) - Feb 09	7.04	6.95E-03	10.27	-1.3	31.5	2.5	0.93	0.4	28.1	--	146	--	--	0.02
Jackson Gulch Reservoir, CO (lower) - Feb 09	11.26	7.64E-03	11.29	-1.3	35	3.8	1.4	0.4	37.9	--	163	--	--	0.06
Jackson Gulch Reservoir, CO (bottom) - Feb 09	14.8	7.81E-03	11.55	-1.3	36	3.2	1.4	0.5	46.9	--	173	--	--	0.06
Jackson Gulch Reservoir, CO (upper) - Mar 09	0	1.04E-04	0.15	0.28	27	3	0.32	0.6	26.3	--	128	--	--	--
Jackson Gulch Reservoir, CO (middle) - Mar 09	4.2	9.32E-04	1.38	-0.42	34.5	3	0.38	0.5	31.7	--	153	--	--	--
Jackson Gulch Reservoir, CO (lower) - Mar 09	5.98	2.21E-03	3.27	-0.78	33.4	2.25	1.7	0.5	39.7	--	163	--	--	--
Jackson Gulch Reservoir, CO (upper) - May 09	1.76	2.75E-04	0.41	0.029	25.3	3.6	0.45	0.5	23	--	122	0.01	0.02	0.05
Jackson Gulch Reservoir, CO (middle) - May 09	3.52	6.00E-04	0.89	-0.442	25.6	3.6	0.38	0.8	23	--	129	0.01	0.01	0.11
Jackson Gulch Reservoir, CO (lower) - May 09	4.57	5.88E-04	0.87	-0.323	30.5	3.4	0.54	0.7	25	--	140	0.01	0.03	0.08
Jackson Gulch Reservoir, CO (upper) - July 09	0	1.89E-04	0.28	0.334	28.4	3.66	0.69	0.62	23	4.6	130	0.01	0.01	--
Jackson Gulch Reservoir, CO (middle) - July 09	2.64	1.17E-03	1.73	-0.642	28.5	3.44	0.49	0.42	22	6	129	0.01	0.02	--
Jackson Gulch Reservoir, CO (lower) - July 09	4.4	1.54E-03	2.28	-0.773	29	3.65	0.55	0.62	22	6.2	131	0.01	0.05	--
Jackson Gulch Reservoir, CO (surface) - Aug 09	2.46	1.11E-03	1.64	-0.383	29.7	2.9	0.46	0.2	25	3.68	134	0.01	0.01	--
Jackson Gulch Reservoir, CO (upper) - Aug 09	2.37	5.68E-04	0.84	-0.134	30.25	4.35	0.27	0.1	25	3.6	134	0.01	0.01	--
Jackson Gulch Reservoir, CO (middle) - Aug 09	5.37	1.41E-03	2.08	-0.523	29.75	4	0.42	0.1	24	3.26	135	0.01	0.02	--
Jackson Gulch Reservoir, CO (lower) - Aug 09	7.92	2.95E-03	4.36	-1.004	28.9	3.9	0.39	0.2	23	4.97	128	0.01	0.04	--
Jackson Gulch Res, Average upper depths	2.11	1.59E-03	2.35	-0.20	28.9	3.5	0.45	0.46	24.9	4.1	130	0.01	0.01	0.05
Jackson Gulch Res, Average all depths	5.0	2.65E-03	3.9	-0.59	30.24	3.49	0.65	0.44	28	4.62	136	0.01	0.02	0.06
Jackson Gulch Inlet Canal	5.28	4.33E-02	64.0	-2.01	35	4.8	1.06	0.6	40.6	--	174.8	--	--	0.06
Snowmelt near Inlet Canal	9.68	3.27E-03	4.83	-2.59	46.9	19.0	21.5	1.2	331	--	433.6	--	--	0.05

*Partial pressure of CO_2 calculated from geochemical model WATEQ4F

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