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List of Abbreviations

ADM .... Archer Daniels Midland Company

CCS .... carbon capture and storage

CDM..coal bed methane

CSS.. carbon storage and sequestration

DO...dissolved oxygen

IBDP... Illinois Basin – Decatur Project

ISGS .... Illinois State Geological Survey

MGSC.. Midwest Geological Sequestration Consortium

SEM.. standard error of the mean

TAN..total ammonia nitrogen

Abstract

A considerable quantity of saline water is available in Illinois to support the needs of a marine aquaculture industry. The sources vary from isolated, deep rock aquifers to industrial effluents. In the present study, synthetic saline water prepared using known concentrations of salts, without trace minerals, in the Ironton-Galesville aquifer formation was used to rear striped bass, a euryhaline species. Growth indices were measured over a 24-week period and compared to striped bass reared in saline water prepared using a commercial marine salt mixture. The results indicate no differences in any growth parameter and no effect on body composition. The only observed differences were in fish behavior and water quality. Fish appeared more excitable in the aquifer treatment; however, stress hormone levels were not affected. Ammonia concentrations in the aquifer treatment system were higher throughout the study. From these results, one can conclude that water displaced from the Ironton-Galesville formation as a result of CO_2 sequestration may be suitable for growth of saline aquaculture species assuming trace mineral and contaminant levels are found to be acceptable. It is recommended that a complete analysis (trace minerals and contaminants) of the Ironton-Galesville formation water be completed prior to using this water for food-fish production, because those were not included in the synthetic saline water prepared to mimic the Ironton-Galesville ground water. Undesirable concentrations of trace minerals or contaminates would require some degree of pretreatment prior to use for aquaculture.

Chapter 1: Introductory Material

The United States is the third largest consumer of seafood in the world. In 2010, per capita consumption of seafood by Americans was approximately 15.8 pounds per year (National Marine Fisheries Service Office of Science and Technology, 2010). U.S. demand for seafood is slated to rise as a result of increases in population and consumer awareness of seafood's health benefits. Recent dietary guidelines (U.S. Department of Agriculture and U.S. Department of Health and Human Services, 2010) recommend that Americans increase seafood consumption, from 3 ½ ounces per week to 8 ounces per week and pregnant women consume 8-12 ounces of seafood per week from a variety of seafood products. Wild stocks are not projected to meet increased demand even with rebuilding efforts. Currently, the United States imports 84 percent of its seafood, and about half of those imports (both fresh water and marine production) are from aquaculture. The current trade deficit in seafood is approximately $9 billion (most of it is attributable to shrimp; 34% of total imported product). Thus, the increased demand is likely to be met by a combination of imports and increased domestic production (U.S. Department of Commerce, 2011).

It is, therefore, not surprising that interest in commercial aquaculture production in the marine environment has increased. U.S. marine aquaculture is estimated to be only 20% of total U.S. aquaculture production, with most (66%) of U.S. marine aquaculture production being mollusks, salmon and shrimp (National Marine Fisheries Service, 2013). Growth of domestic aquaculture would support fishing and agricultural communities and new aquaculture-based industries in the United States.

There are a number of barriers facing the expansion of the saline aquaculture industry. Among these are the high cost and limited availability of coastal land, water resources, environmental impact concerns, high production costs, and lack of sufficient quality fish seedstock (Florida Oceans & Coastal Resources Council, 2007).

A number of these concerns can be overcome if saline aquaculture can be practiced inland. The suitability of inland sites for culture of euryhaline and marine species is governed by the availability and quality of saline water. It is in this context that we propose that the feasibility of inland saline aquaculture be examined in the state of Illinois.

Why Illinois?

Agricultural Powerhouse

Illinois ranks first in the nation in soybean production, second in corn, and fourth in hogs and also ranks within the top ten states for winter wheat, oats, and grain sorghum. Illinois also boasts an extensive infrastructure and expertise ranging from transportation networks, processing facilities, storage, and technical expertise to support agriculture-related economic activity. Illinois, in short, is a national agricultural powerhouse. Leveraging this inbuilt economic advantage can potentially aid Illinois aquaculture producers to achieve a competitive edge. An example of this is unfolding in the active interest being taken in the development of aquaculture by the National Soybean Growers Association, the Illinois Soybean Association, and the Illinois Corn Growers Association.

Developing Aquaculture Industry

Aquaculture development in Illinois has grown substantially since the initiation of the Illinois Fish Farmers Cooperative in 2000, making available technical services, processing, and marketing. Illinois growers produce an array of species marketed throughout the U.S. and Canada, including hybrid striped bass, largemouth bass, channel catfish, tilapia, and carp. In 2011, total production of all species sold exceeded 360,000 pounds, worth over $1.5 million (Fisheries and Illinois Aquaculture Center, unpublished).

Access to markets

The Chicago seafood market is the fifth largest in the U.S. and imports 99% of the product consumed in the Midwest (Illinois-Indiana Sea Grant Program, 2001). The majority of aquaculture species currently produced in the Illinois are sold in Chicago, as well as St. Louis and Toronto seafood markets.

Enormous Room for Growth

Currently, less than one percent of the farm-raised seafood consumed in the U.S. is produced in the Midwest (Illinois-Indiana Sea Grant Program, 2009). Indications are that Midwestern aquaculture will continue to grow because: (1) per capita consumption of farm-raised products is increasing; (2) the Midwest provides a ready supply of raw materials for low-cost fish feed (corn and soybeans); (3) the Midwest supports a large consumer base and Chicago, for example, is one of the five largest U.S. seafood markets; and (4) the Midwest has a large number of potential producers who are receptive to incorporating aquaculture into their existing farming operations (Illinois-Indiana Sea Grant Program, 2009).

Proximity to the Sea

The sea is closer to most residents of Illinois than is realized. In fact, Illinois sits on top of an underground sea. Figure 1 depicts the salinity of pore water in rock aquifers in Illinois (Illinois State Geological Survey, 2013). The salinity of water in the northern portions of the state are slightly brackish, in the central portions moderately brackish, and in the bottom portions varying from brackish to marine to hypersaline. This vast resource is currently not utilized or underutilized.

Illinois has an abundant supply of saline water. This includes saline aquifers; saline springs; produced water from oil extraction; effluents from coal beneficiation; waters produced from coal bed methane production; and other industrial effluents resulting from water treatment; waste volume concentration, and food processing.

Saline Aquifers

Figure 2 provides data on the distribution of salinity and the depths of various formations within the state of Illinois (Bergstrom, 1968). At depths greater than 500 feet the TDS content in the underlying formations increases going south. In general, waters of less than 10,000 mg/L TDS are considered potential sources of drinking water. Waters of TDS greater than 10,000

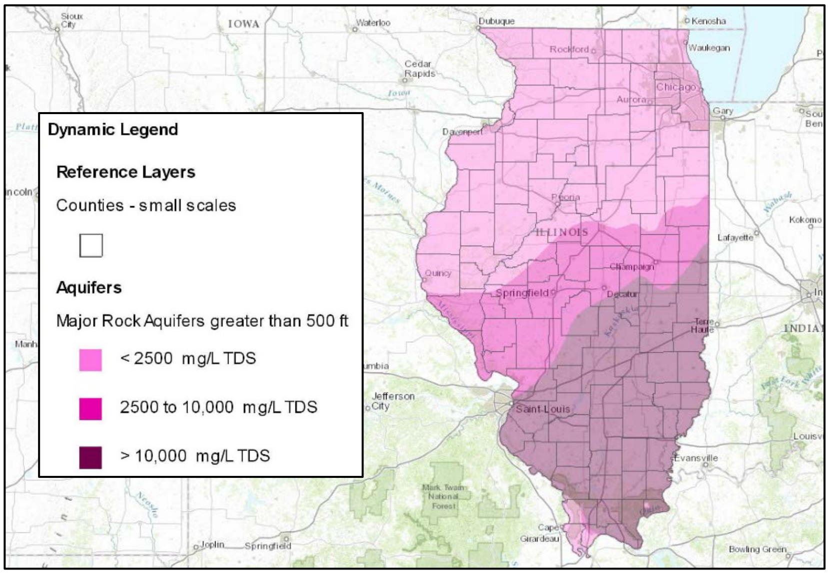

Figure 1. Major rock aquifers of Illinois at depths greater than 500 feet classified by the total dissolved solids (TDS) content (Illinois State Geological Survey, 2013).

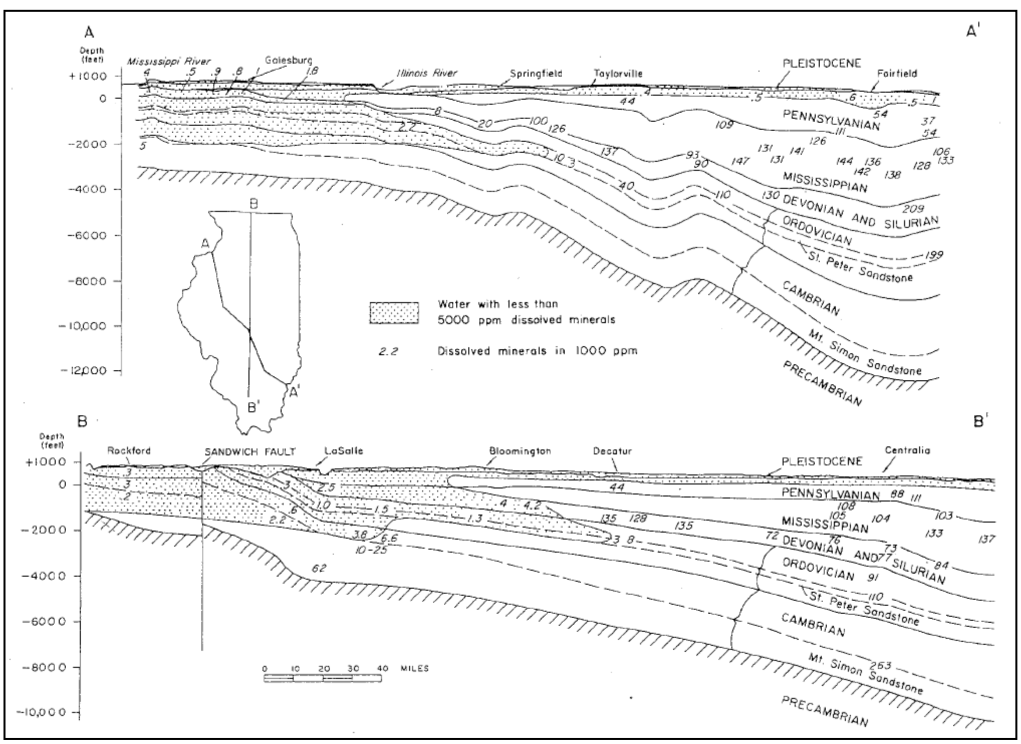

Figure 2. Distribution of salinity and the depths of various formations within the state. Shaded areas in the map represent water of TDS <5,000 mg/L (Bergstrom, 1968).

mg/L have not been historically viewed as drinking water sources and could be accessible for marine aquaculture. The Mt. Simon and the St. Peter formations represent the deeper saline aquifers of the state. The salinity in these aquifers can greatly exceed that of seawater in many locations and with depth.

Geologic Carbon Sequestration and Saline Water Production

Currently, the overwhelming scientific consensus advocates the minimization of emissions of carbon dioxide, a global greenhouse gas. Carbon dioxide emissions in Illinois increased from 94.6 million tons in 2000 to 107 million tons in 2010 (The Environmental Integrity Project, 2011). Coal-based electricity generation in Illinois is one of the major carbon dioxide emitters. Other large emission sources include cement manufacturers, auto manufacturers, glass manufacturers, refineries, ammonia producers, iron and steel producers, and corn-to-ethanol facilities (Lu et al., 2007). One approach to mitigation of this emission is based on geological sequestration. Carbon Storage and Sequestration (CSS) technologies are designed to store CO_2 captured from power plants in deep saline aquifers such as the Mt. Simon and St. Peter formations. The first million ton CO_2 injection project into the Mt. Simon formation began operations at Archer Daniels Midland (ADM) Decatur in Fall 2011. This project is part of the Illinois Basin – Decatur Project (IBDP) and includes Mt. Simon and Ironton-Galesville formations.

The IBDP reached its halfway point in 2013, injecting 500,000 metric tons of carbon dioxide into the saline aquifer at the Archer Daniels Midland facility in Decatur, Illinois (Illinois State Geological Survey, 2014). Injection of supercritical carbon dioxide began in November 2011 at a rate of 1,000 metric tons per day, with the project goal being to inject 1 million metric tons by the end of 2014 (Illinois State Geological Survey, 2014). The IBDP is a project demonstrating the commercial viability of carbon capture and storage (CCS) in the Illinois Basin and is funded by the U.S. Department of Energy. The IBDP, conducted by the Midwest Geological Sequestration Consortium (MGSC), is part of the development phase of the DOE's Regional Carbon Sequestration Partnerships initiative, whereby CCS technologies are being developed and validated as part of a national strategy to reduce greenhouse gas emissions and mitigate climate change (Illinois State Geological Survey, 2014).

At scale deployment, geologic sequestration is expected to lead to increased pressure in the trapped water. The increases in pressure can decrease carbon dioxide holding capacity, risk breaching the capping layer, lead to potential for water seepage, and increase seismic risk. It is likely that pressure relief of the water within the aquifer will lead to the discharge of a highly saline effluent. The geologic sequestration of carbon dioxide emissions from one 1 GW coal-powered plant is estimated to displace 7.5 million m^3 of brine annually (~6 MGD) (Wolery et al., 2009). This highly saline effluent could be potentially useful as a resource for marine aquaculture.

Appendixes A and B provide the available water quality information for the Mt. Simon and St. Peter formations, respectively (Meents et al., 1952; Nandakishore Rajagopalan, Illinois Sustainable Technology Center, personal communication, 2012).

Oil Field Associated Brines

The Illinois basin reservoir is reported to have held 14 billion barrels of oil (Frailey, 2013). Four billion barrels of oil from the basin is estimated to have been extracted. Along with the oil, associated brines – termed produced water – are also extracted. In new wells, the ratio of water to oil produced is on the order of 5:1 to 8:1. In older wells, the ratio may be greater than 50:19 oil (Frailey, 2013). A large fraction of this water is recycled back to the oil well. The remainder is disposed into injection wells. A recent estimate calculates that about 10,752 million gallons/year (29 MGD) of produced water currently disposed into injection wells in Illinois may be potentially available for other uses (U.S. Department of Energy, 2012). Marine aquaculture could benefit from this effluent. Appendix C provides water quality information for the Aux Vases and Cypress formation waters as reported by Demir and Seyler (1999). A more comprehensive compilation is that of Meents et al. (1952).

Coal Bed Methane (CBM) Produced Water

Coal bed methane (CBM) is a form of natural gas that is found in coal seams. CBM extraction requires the removal of groundwater to facilitate flow to the surface. The associated water can be saline and can potentially be used for marine aquaculture. U.S. EPA reports (U.S. Environmental Protection Agency, 2010) water discharges associated with coal bed methane production in Illinois were 0.3 MGD (113.4 million gallons) total in 2008. The quality of water associated with this water is given in Appendix D (U.S. Department of Energy, 2012).

Water from Coal Mining

Two types of water are discharged from coal mining and coal cleaning operations. One is the pumping of water in mines that are below the water table. The second results from coal cleaning operations. Typically, coal cleaning waters are concentrated due to recycling and are moderately saline. Approximately 0.5 MGD may be available from a coal mine (American Company) at Galatia and another 0.5 MGD from White County Coal Company, IL. Water quality information from a couple of locations is given in Appendix E (Nandakishore Rajagopalan, Illinois Sustainable Technology Center, personal communication, 2012).

Industrial Effluents

Many industrial plants including power plants treat water to make it fit for industrial use. Ion exchange and reverse osmosis are commonly used process trains. The regeneration of ion exchange beds and the desalination of water by reverse osmosis frequently generate effluents with TDS in excess of 10,000 mg/L (Nandakishore Rajagopalan, Illinois Sustainable Technology Center, personal communication, 2012). One ethanol plant in Illinois produces 20 tons of salt per day from water treatment operations that is currently being landfilled (Nandakishore Rajagopalan, Illinois Sustainable Technology Center, personal communication, 2012). Typically, these streams are comingled to allow wastewater discharge rendering generation estimates quite difficult. Segregation of these streams can generate additional source of saline water.

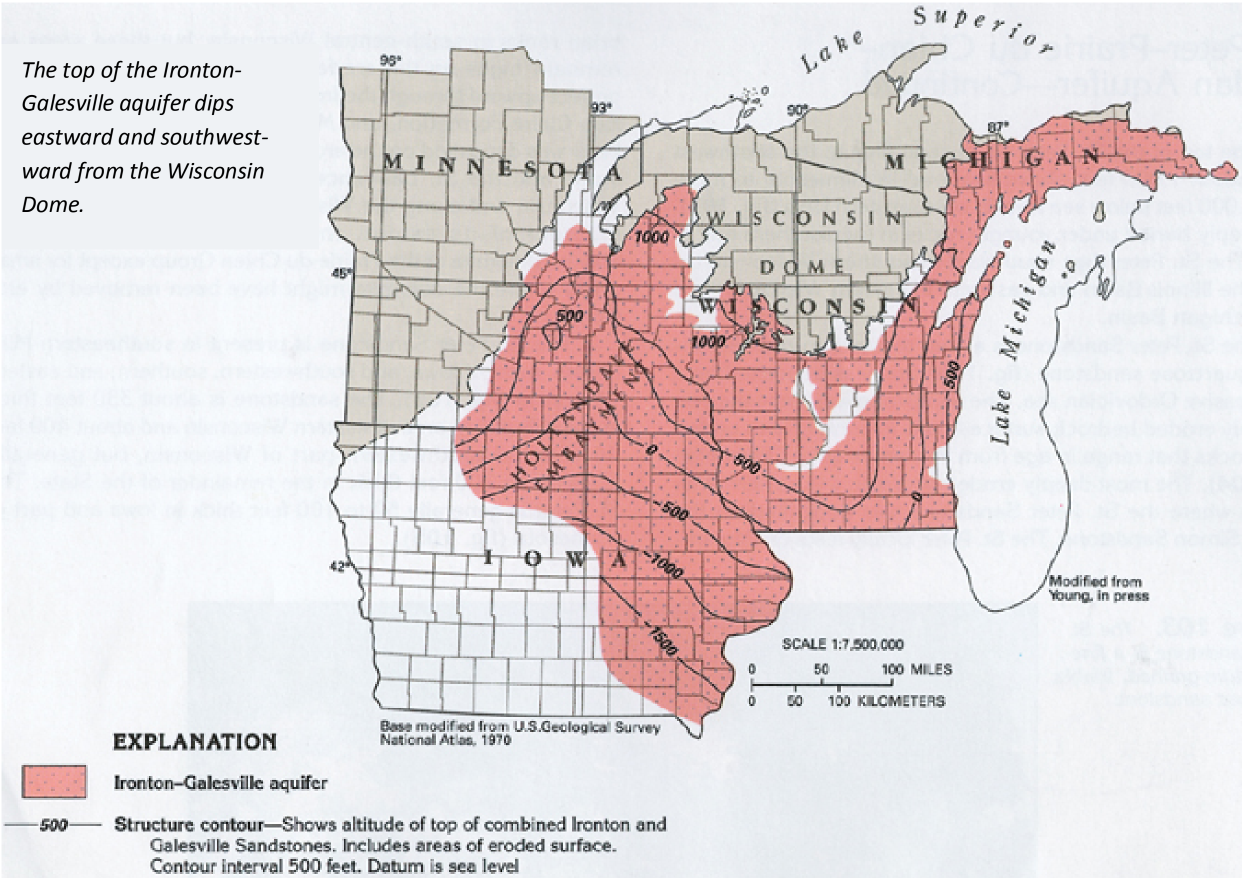

Figure 3. Map of the Ironton-Galesville aquifer formation (Olcott, 1992).

Summary

A considerable quantity of saline water is available to support the needs of a marine aquaculture industry in Illinois. The sources vary from isolated, deep rock aquifers to industrial effluents. The cost of obtaining these waters will depend on their accessibility. Deeper waters are likely to be more difficult and expensive to extract unless produced through secondary operations such as CO_2 sequestration. Waters from existing coal beneficiation and other industrial plants can be easily accessed provided transportation costs are low. Produced waters that are currently transported for disposal are also likely to be accessible at low cost.

While the sources vary, these waters also vary significantly in composition. The waters from deep aquifers are often contaminated with trace elements; those of produced water with hydrocarbons, nitrogen, and trace elements; and industrial effluents with organic matter. It is also clear that the scope of analytical information available is limited and often incomplete. It is, therefore, safe to assume that some degree of pretreatment would be required prior to use for aquaculture. Thus, the feasibility of utilizing these saline waters for aquaculture is likely to be highly location dependent and hinges on both accessibility and water treatment cost.

The objective of this study was to determine the feasibility of rearing a euryhaline fish species (striped bass *Morone saxatilis*) in one source of saline water from Illinois. The water was of similar consistency to water from the Ironton-Galesville aquifer formation (Figure 3) within the Illinois Basin – Decatur Project (IBDP). This water source was originally chosen due to anticipated availability associated with the IBDP. At the start of the project, discussions with ISGS personnel suggested several hundred gallons of water could be available from the Ironton-Galesville formation.

Chapter 2: Methodology

Water quality information from the Ironton-Galesville formation (Randall Locke, IL State Geological Survey, personal communication, 2012) was used to develop a synthetic mixture to replicate the known salt content on this water source. A stock synthetic mixture (Appendix F) was made and diluted to yield a 2 ppt salinity solution using municipal water treated with sodium thiosulfate ($Na_2S_2O_3$, 0.035g per 10 L) and sodium bicarbonate ($NaHCO_3$) for dechlorination and alkalinity maintenance, respectively. This solution was added to a recirculating culture system containing four replicate tanks, a sump, and a bead filter for solids and bio-filtration, with a total system volume of 745 L. A second system, identical to the first, was filled with 2 ppt salinity water using a commercial synthetic salt solution (Instant Ocean, Spectrum Brands, Madison, WI) as a control treatment.

Channel catfish were then stocked into both systems at a density of approximately 5.5 g/L (5 fish/tank) for system cycling. A concentrated bacterial additive (Nutrafin Cycle, Hagen, West Yorkshire, UK) was then added to boost the nitrogen cycle, following manufacturer's recommended dosing of 25 mL/38 L on Day 1 and 10 mL/38L on Days 2 and 3. Water temperature was maintained at approximately 22^{o}C and dissolved oxygen (DO) was maintained above 6 mg/L. Both were monitored using a YSI Model 550A Oxygen Meter (Yellow Springs, OH). Total alkalinity, total hardness, total ammonia nitrogen (TAN), nitrite, and pH were monitored weekly using a LaMotte Smart3© Colorimeter (La Motte Co., Chestertown, MD) and a S20 SevenEasy pH meter (Mettler Toledo, Columbus, OH). All fish were maintained on a 12-h light:dark cycle. Completion of the nitrogen cycle took two months. After which, the catfish were removed and 20 striped bass fingerlings were weighed (8.5 ± 0.2 g; mean ± SEM) and stocked into each tank in both systems for grow-out. Salinity was increased incrementally to approximately 10 ppt over a three-week period. Water quality analysis was done on a weekly basis for both systems.

The total grow-out period for the striped bass was 24 weeks. At the conclusion of the growth phase, all fish were weighed and five fish per tank were euthanized for determination of proximate carcass composition (moisture, protein, lipid, and ash). The remaining fish were allowed to recover from sampling for three weeks, at which time two fish per tank were rapidly netted and sedated. Blood was collected from the caudal vasculature, plasma separated by centrifugation, and stored until plasma cortisol concentration could be determined. Cortisol is the primary stress hormone in fish. Thus, the purpose was to determine if fish in the aquifer system were experiencing greater stress than the fish in the control system. The remaining fish were then subjected to an acute low-water stressor by draining the tanks until the water level was at the height of the fishes' back. After 15 minutes of stress, two fish per tank were netted, sedated, and bled as described for cortisol analysis. Cortisol was measured by ELISA (DRG International, Inc, NJ). The purpose of the acute stressor was to determine if there were differences in stress response relative to treatment.

Chapter 3: Results

Percent weight gain was not statistically different (P>0.05) between systems at any time throughout the 24-week growth study (Figure 4). Percent weight gain over 24 weeks averaged 1094.1 and 1094.2% (pooled SEM = 44.7%) for the aquifer and control treatments, respectively. There were also no statistical differences (P>0.05) for feed efficiency (Figure 4) or feed consumption (Figure 6) between systems. Final proximate composition of the carcass produced from fish in both treatments was not significantly different (P>0.05). Treatment means are presented in Figure 7.

Mean 24-week water quality results are presented in Table 1. Total ammonia nitrogen (TAN) concentrations increased over the duration of the study (Figure 8). TAN concentrations averaged lower (P<0.0001) in the control (1.18 ppm) than in the aquifer treatment (4.56 ppm) throughout the study. Total hardness was also higher (P<0.0001) in the aquifer treatment relative to the control treatment, but did not change with time.

Although qualitative, there were observed differences in behavior between the two treatments. Fish in the control treatment appeared relatively calm during feeding and handling during sampling. On the other hand, fish in the aquifer treatment were excitable during feeding and appeared agitated during sampling. To determine whether fish in the aquifer treatment were experiencing a chronic stress, plasma cortisol levels were measured in fish from both treatments before and after an acute low-water stress event. No differences (P>0.05) in plasma cortisol were observed between fish in the two treatments either pre- or post-stress (Figure 9).

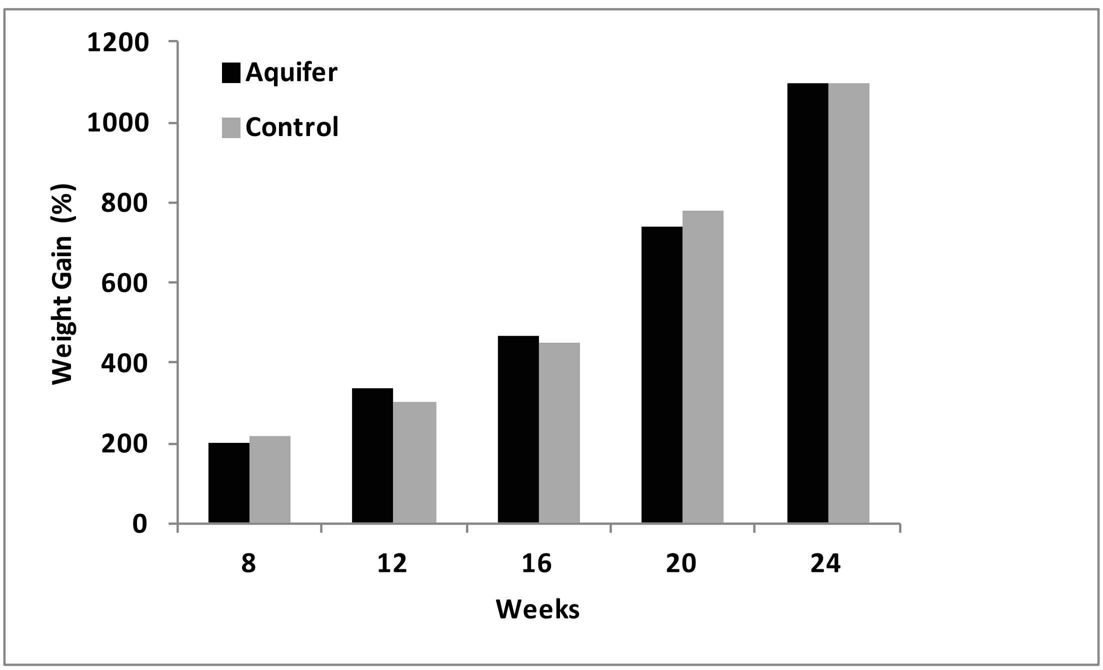

Figure 4. Cumulative weight gain of striped bass reared in synthetic aquifer water compared to fish reared in control water prepared from Instant Ocean sea salt; no statistical differences were observed (P>0.05).

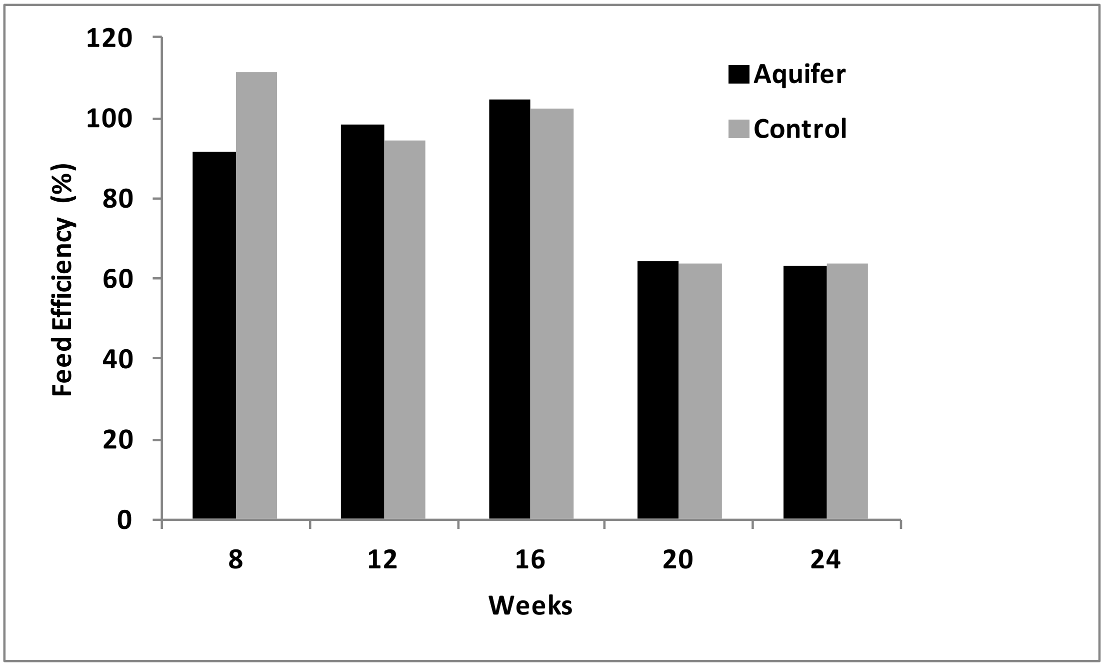

Figure 5. Cumulative feed efficiency (FE = weight gain (g)/feed consumed (g) x 100) of striped bass reared in synthetic aquifer water compared to fish reared in control water prepared from Instant Ocean sea salt; no statistical differences were observed (P>0.05).

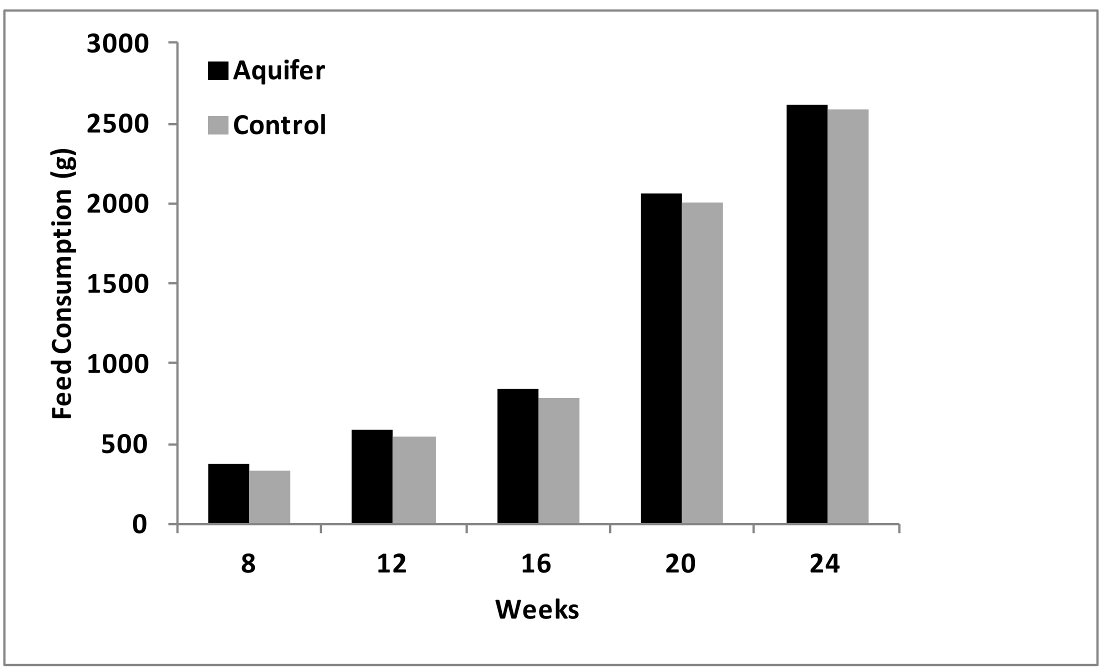

Figure 6. Cumulative feed consumption of striped bass reared in synthetic aquifer water compared to fish reared in control water prepared from Instant Ocean sea salt; no statistical differences were observed (P>0.05).

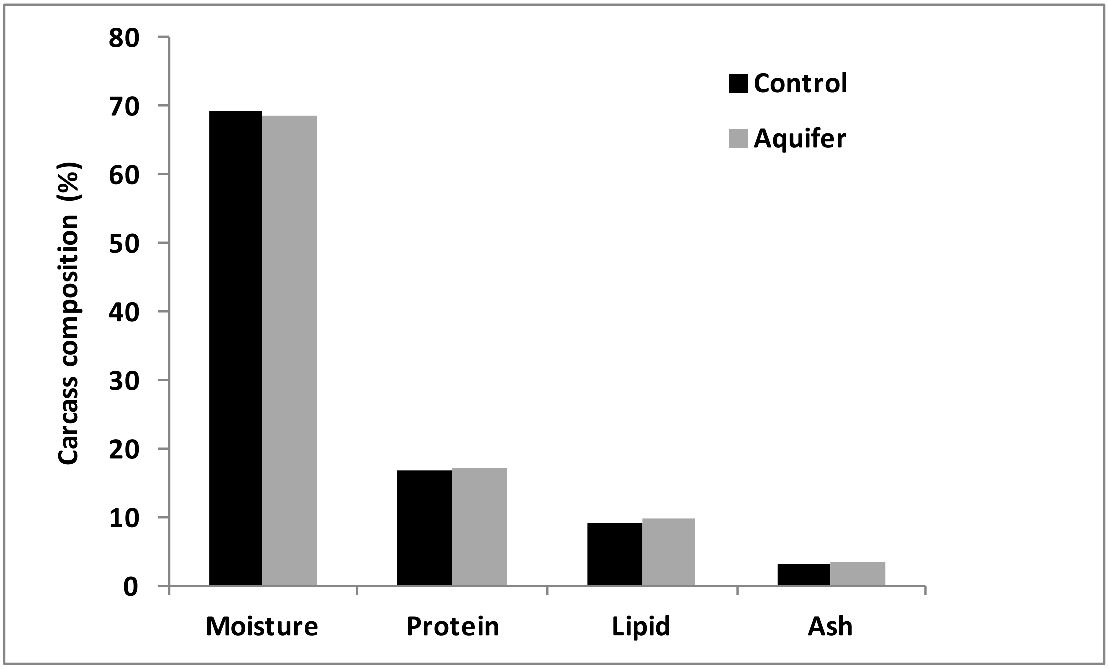

Figure 7. Proximate carcass composition of striped bass reared in synthetic aquifer water compared to fish reared in control water prepared from Instant Ocean sea salt; no statistical differences were observed (P>0.05).

Table 1. Mean water quality over 24 weeks

Treatment	Salinity (ppt)	Temp (^{o}C)	pH	TAN (ppm)	Nitrite (ppm)	Alkalinity (ppm)	Hardness (ppm)
Aquifer	9.5	21.9	8.1	4.56	0.16	90.6	480.5
Control	9.1	21.5	8.1	1.18	0.15	89.9	297.0
pSEM	0.5	0.2	0.1	0.42	0.02	7.9	18.4
P-value	0.57	0.22	0.92	<0.0001	0.80	0.94	<0.0001

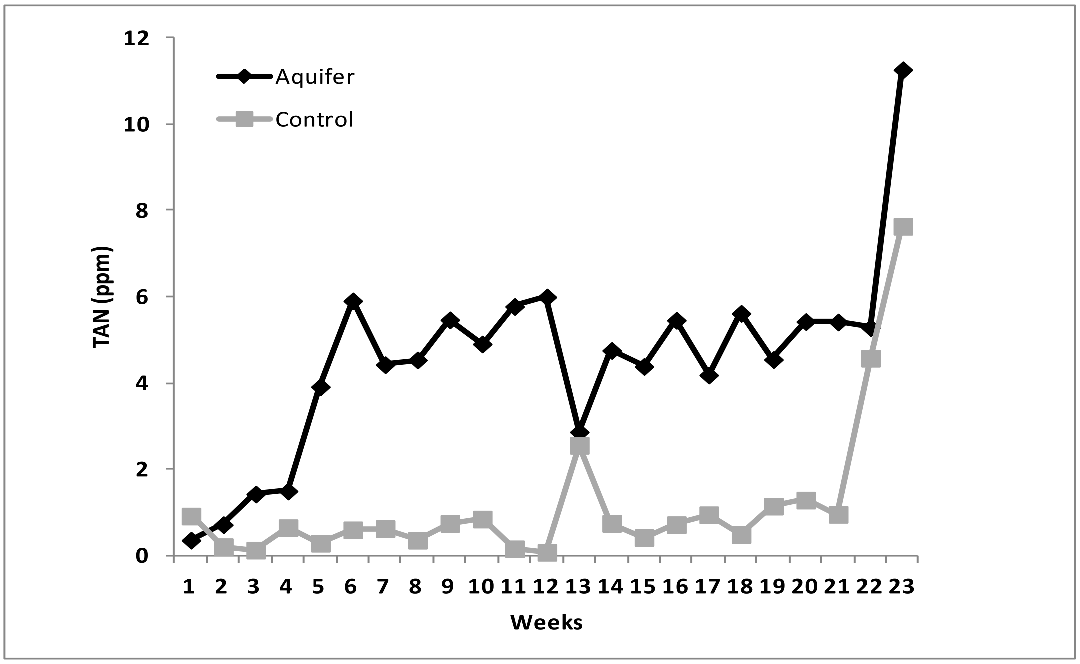

Figure 8. Weekly total ammonia nitrogen (TAN) over 23 weeks (Note: Water quality was not measured in week 24).

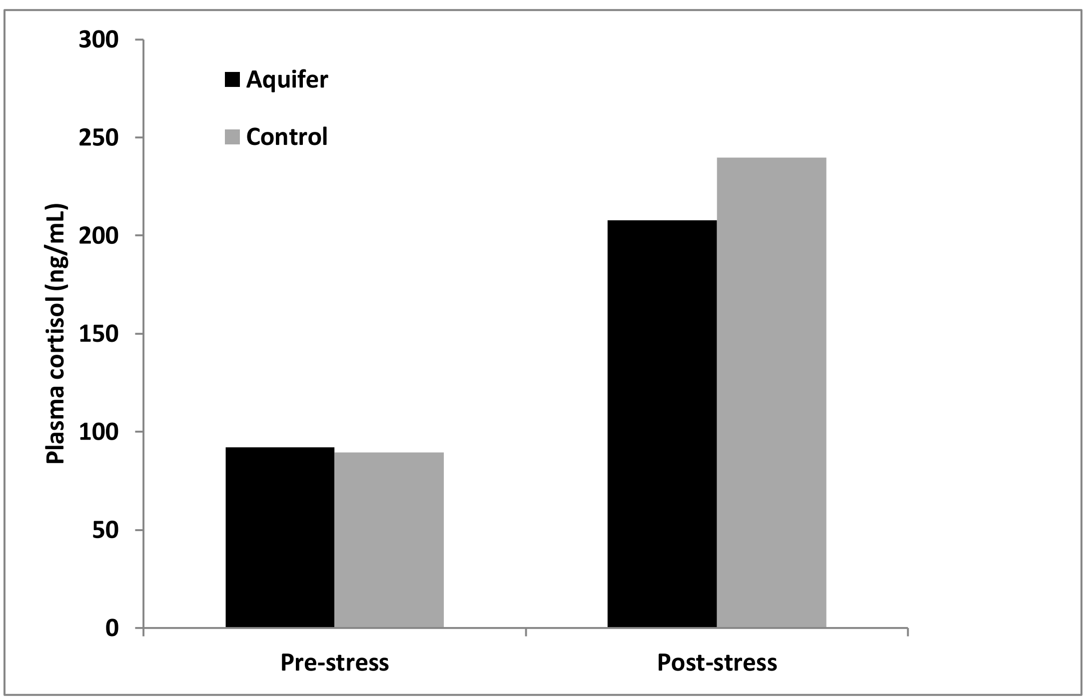

Figure 9. Plasma cortisol concentration of striped bass reared in synthetic aquifer water compared to fish reared in control water prepared from Instant Ocean sea salt. Fish were exposed to a 15-min low-water stressor; no statistical differences were observed ($P>0.05$).

Chapter 4: Discussion

Overall, there were no negative effects on fish growth performance, with weight gain, feed efficiency, and proximate carcass composition being similar between treatments. These results indicate that the major constituents of regional saline water aquifers are acceptable for the production of striped bass during the early growth phase and suggest suitability for the culture of other euryhaline or saline fishes. The preliminary results were shared with individual regional aquaculture producers, extension agents, and researchers at the North Central Regional Aquaculture Center board meeting in February 2013 to gauge potential interest in use of regional saline water resources. It was suggested by some that regional production of shrimp might be a viable use for this water resource. Since that time Dr. Rajagopalan and his colleague, Srirupa Ganguly, of the Illinois Sustainable Technology Center have been in contact with regional shrimp producers to discuss production options.

For this study, the concentrations of trace elements in the Ironton-Galesville formation were unavailable. Although the results to date demonstrate similar fish growth performance between treatments, increasing TAN concentrations in the aquifer system are indicative of inefficient biological filtration. One possible explanation may be a lack of essential trace elements for the bacteria colonizing the biofilter. This may also explain the apparent excitability and agitation of fish held in the aquifer system. Another possibility for the apparent excitability and agitation observed is the higher total hardness in the aquifer treatment water; however, this is unlikely to have affected the fish given seawater has a total hardness of approximately 6630 ppm. Therefore, modification of the aquifer salt composition to add trace minerals may be necessary to improve biological filtration to try to moderate TAN concentrations and reduce excitability of the fish.

Chapter 5: Conclusions

A considerable quantity of saline water is available in Illinois to support the needs of a marine aquaculture industry. The sources vary from isolated, deep rock aquifers to industrial effluents. In the present study, synthetic saline water prepared using known concentrations of salts in the Ironton-Galesville aquifer formation was used to rear striped bass, a euryhaline species. Growth indices were measured over a 24-week period and compared to striped bass reared in saline water prepared using a commercial marine salt mixture. The results indicate no differences in any growth parameter and no effect on body composition. Thus, one can conclude that water displaced from the Ironton-Galesville formation as a result of CO_2 sequestration is suitable for growth of euryhaline aquaculture species, dependent on more knowledge of trace minerals and contaminants in that water. The assumption, then, is that this would also be true for marine species requiring higher salinity water.

Although growth was not affected by the water source, fish reared in the synthetic aquifer water were more excitable. However, this did not translate to increased stress, as indicated by similar stress hormone (cortisol) concentrations in the plasma of fish reared in both water sources pre- and post-stress.

Because a complete analysis of the Ironton-Galesville formation was not available, trace minerals were not included in the synthetic mixture. This omission may have accounted for the observed differences in behavior. It may also have played a role in higher ammonia concentrations in the aquifer water culture system. Another factor that would need to be considered is the potential contamination with undesirable hydrocarbons, nitrogen, and industrial effluents with organic matter. As such, trace mineral and contaminant analysis needs to be completed prior to using this water for food-fish production. Undesirable concentrations of trace minerals or contaminates would require some degree of pretreatment prior to use for aquaculture.

Chapter 6: Recommendations

Based on the results of this research, it was concluded that euryhaline species of fish can be reared in synthetic saline water that mimicked the major mineral composition of the groundwater in the Ironton-Galesville aquifer formation. However, there was no analysis of the specific trace mineral and contaminants that are present in the aquifer; therefore, those were not included in the synthetic saline water. Further research is required to determine if trace minerals in the Ironton-Galesville formation water would ameliorate fish excitability and elevated ammonia levels observed in the present study. Analysis on contaminants in the Ironton-Galesville formation would also be required prior to use for food fish aquaculture. In addition to these analyses, it is recommended that other marine species be reared in actual saline water obtained from the Ironton-Galesville formation following necessary pretreatment. Given that most of the current $9 billion trade deficit in seafood is attributable to shrimp, it would be prudent to determine the feasibility of utilizing this water for inland shrimp production and conduct an associated cost analysis, including water acquisition, pretreatment and disposal.

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Appendix A. Mt. Simon Brine Composition at Select Locations

Table A-1. Mt. Simon Brine Composition (mg/L) at Select Locations

Formation	Mt. Simon	Mt. Simon
County	Douglas*	Decatur**
Depth (ft)	4046-4090	N/A
pH	7.3	5.9
TDS	128312	190,000
Na	34567	50,000
Ca	10590	19,000
Mg	1916	1,800
SiO_2	13	N/A
Fe Filtered	13	N/A
Fe Unfiltered	20	N/A
Al_2O_3	77	N/A
Mn	9.4	N/A
SO_4	1292	N/A
Cl	76570	120000
NO_3	11	N/A
CO_3	N/A	N/A
HCO_3	174	97.6
NH_4	13	N/A

*Meents et al. (1952)

** Nandakishore Rajagopalan, Illinois Sustainable Technology Center, personal communication (2012)

N/A – not available

Appendix B. St. Peter Brine Composition at Select Locations

Table B-1. St. Peter Brine Composition (mg/L) at Select Locations*

Formation	St. Peter	St. Peter	St. Peter	St. Peter	St. Peter	St. Peter
County	Adams	Adams	Bond	Clark	Clark	Crawford
Depth (ft)	344-971	666-675	2505-3154	3945-3960	2923-3009	4650-4654
pH	7.4	7.2	N/A	N/A	N/A	6.3
TDS	8210	12258	12201	124550	24114	160730
Na	2443	3715	3563	37346	6941	44295
Ca	319	456	583	6778	1551	11260
Mg	157	266	260	2418	494	2306
SiO_2	36	22	6	5	33	32
Fe Filtered	0.4	0.8	ND	40	0.8	ND
Fe Unfiltered	1	0.8	N/A	128	N/A	0.4
Al_2O_3	11	6	332	81	0.9	37
Mn	ND	1.3	ND	3	ND	1.2
SO_4	992	987	1614	121	2618	945
Cl	3876	6398	5973	76000	12563	94257
NO_3	9.6	8.1	32	13	N/A	21
CO_3	10	N/A	N/A	N/A	N/A	N/A
HCO_3	292	328	217	7	678	110
NH_4	3.6	5.2	13	142	N/A	41

*Meents et al. (1952)

N/A – not available

ND – not detected

Appendix C. Composition of Brines Associated with Oil Production

Table C-1. Composition (mg/L) of Brines Associated with Oil Production*

Formation	Aux Vases	Cypress
	Mean (std. deviation)	Mean (std. deviation)
pH	6.61 (0.51)	6.60 (0.57)
TDS	126212 (20763)	101577 (28434)
Na	43792 (7210)	35863 (9714)
Ca	4816 (1148)	3317 (1586)
Mg	1602 (482)	1103 (367)
K	200 (56)	111 (34)
Sr	279 (183)	150 (76)
Ba	3.16 (4.42)	21.32 (51.89)
Li	8.22 (3.04)	4.96 (2.36)
Fe	5.84 (10.34)	8.20 (12.5)
Mn	0.88 (0.59)	1.52 (1.19)
B	3.9 (1.39)	2.58 (0.57)
Si	4.5 (1.60)	5 (2.80)
Al	0.2 (0.1)	0.2 (0.1)
Cl	74654 (12558)	60383 (17018)
Br	156 (47)	120 (48)
I	8.8 (2.8)	6 (4)
SO_4	690 (584)	392 (374)
NO_3	0.27 (0.24)	0.62 (0.87)
CO_3	0.18 (0.27)	0.20 (0.21)
HCO_3	127 (70)	177 (125)
NH_4	29 (8)	24 (8)

*Demir and Seyler (1999)

Appendix D. Composition of Coal Bed Methane Waters

Table D-1. Composition (mg/L) of Coal Bed Methane Waters*

Project	Delta	Shelby	Macoupin	Pioneer
pH	8.1	7	7.69	7.3
TDS	2532	83920	12611	32291
Na	552	27911	4304	10105
Ca	9.07	2271	241	1307
Mg	3.79	970	194	646
Fe	1.66	3.27	2	N/A
K	2	62	N/A	N/A
Ba	0.5	37	3	35
Sr	0.32	182.6	N/A	N/A
Mn	0.08	0.58	N/A	N/A
Cl	500	52300	7300	19506
CO_3	1464	244	560	705
SO_4	1	1	6	N/A

*U.S. Department of Energy (2012)

N/A – not available

Appendix E. Composition of Coal Mine Associated Waters

Table E-1. Composition (mg/L) of Coal Mine Associated Waters*

Company	American Coal Company	White County Coal Company
Sample	Thickener Underflow	Mine Water
TDS	9010	21000
Na	3100	6900
K	31	28
Ca	150	450
Mg	53	150
Cl	3400	9400
SO_4	1780	2700
Br	7.6	16
F	0.86	1.1
NO_2	0.42	1.4
NO_3	0.78	3.5
Alkalinity (meq/L)	2.9	8.2

*Nandakishore Rajagopalan, IL Sustainable Technology Center, personal communication (2012)

Appendix F. Synthetic Salt Composition for Making Aquifer Treatment Water

Table F-1. Synthetic Salt Composition for Making Aquifer Treatment Water*

Salt	g/100 g	g/2000 g
KCl	1.57	31.34
$MgCl_2$	5.90	118.08
$CaCl_2$	22.84	456.79
$NaHCO_3$	0.35	6.96
NaBr	0.36	7.28
Na_2SO_4	3.01	60.15
NaCl	65.97	1319.40

* Formulated to be similar to the composition of the Ironton-Galesville aquifer formation at Decatur, IL (Randall Locke, IL State Geological Survey, personal communication, 2012)