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Breakthrough Mobile Water Treatment Converts 75% of Fracturing Flowback Fluid to Fresh Water and Lowers CO₂ Emissions

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Abstract

Treating and recycling flowback from a hydraulically fractured gas shale reservoir is vital to the development of several shale plays. The use and disposal of water in emerging shale plays is expensive and a significant public and political concern. A breakthrough in water treatment combines an advanced oxidation process (AOP) using ozone and ultrasonic transducers to oxidize heavy metals, soluble and insoluble organics. When combined with reverse osmosis (RO) in a mobile unit, this process allows for significant volumes of flowback to be returned to the environment as fresh, clean water, thereby significantly reducing truck traffic. The hydraulic fracturing process in the Woodford Shale requires 50,000 to 110,000 barrels of water per well. By treating flowback on location with the AOP/RO process, 75% of the volume treated will become clean water with total dissolved solid levels less than 500 ppm. 25% will be clean, concentrated brine water which can be used in subsequent hydraulic fracturing operations. Newfield Exploration executed a pilot 4Q08 during which flowback was processed on location with an AOP/RO unit. Sample analysis from this pilot will be provided to state and federal agencies as a validation of the technology. The mobile unit processed 100 barrels per hour using 220 kW power generation to provide a fresh water stream and brine stream from flowback. The proper application of the AOP/RO process could reduce the fluid disposal carbon footprint by 50 tons of CO₂ per well and transform a large portion of industry water use from consumptive to non-consumptive—as much as 25,000 bbl per well. The AOP/RO process could untangle complex operating environments, reduce operating expense and help the environment.

Introduction

Consumptive water use during hydraulic fracturing operations in natural gas producing shale plays has become an issue in the development of the Marcellus Shale, the Barnett Shale, and the Fayetteville Shale. In the Marcellus, disposal of fluid via injection well is perceived by some as a threat to the aquifer that supplies much of metropolitan New York. In the Barnett Shale, finding enough water for hydraulic fracturing is an issue and operators are forced to recycle. For the first time, injection wells in the Barnett are falling under intense scrutiny. In the Fayetteville Shale, operators have had the leniency to land farm flowback and produced fluid, but the state recently placed a moratorium on these operations. Operators are now paying significant trucking costs to truck flowback and produced fluid from Arkansas to Oklahoma. In Oklahoma, state agencies are reevaluating the Oklahoma Comprehensive Water Plan, to include allocation of water to the oil and gas industry for the next 50 years.

Several different water recycling methods are being tested, some that are successful at high costs to the operator and some that simply don't work. A new method of water treatment has surfaced involving an advanced oxidation process combined with traditional reverse osmosis to create high quality fresh water from a flowback stream. A pilot in November 2008 proved this technology in the Woodford Shale.

Woodford Completion Operations

Completion Fluid, Flowback, and Produced Fluid

Woodford Shale completions require approximately 94,000 bbl of completion fluid for a 4600 ft lateral. The majority of this completion fluid is surface water from ponds, lakes or creeks pumped from sources close to the wellhead. Operators in the Woodford will use more fresh water because it is cheaper to pump fluid to location than to truck it. 89,000 bbl of surface water may cost \$72,000 to buy, move and store with pipe and pump. To truck that volume would cost \$300,000.

Operators have found success fracing the Woodford Shale with fluid that has 5,000 to 15,000 ppm chloride. The chloride level is important as an indicator of the presence of sodium or potassium. Operators use flowback or produced fluid trucked in from other wells to blend with surface water, friction reducer, and biocide on location. Flowback is readily available from previous completions but has a lower chloride level, so more of it is required to mix with surface water to reach the target chloride range for completion fluid. Produced fluid is readily available from the more mature wells in the field and has higher chloride concentration, so less volume—and hence, less trucking—is needed to reach required chloride levels.

Woodford Shale wells produce an average of 34% of the frac load in the first two weeks. **Table 1** shows the flowback behavior of thirteen Woodford Shale wells during the initial two weeks of flowback. During that time, flowback normally returns to surface with a similar chemical composition as the initial completion fluid. The level of chloride and other compounds increase steadily over time as the completion fluid leaches minerals from the formation. In the first two weeks, chloride levels range from 5,000 ppm to 25,000 ppm.

Flowback changes to produced fluid by definition when a well returns 100% of the completion fluid volume. From a chemical perspective, flowback assumes produced fluid characteristics at different stages in the life of a well depending on geological variances and downhole conditions. Produced fluid has a more concentrated chloride level because of its residence downhole and contains greater quantities of divalent cations like iron, barium and calcium, which cause scale and impair friction reducer efficiency when allowed to remain as a component of completion fluid.

Disposal Methods

Injection wells are the primary means of disposal for flowback and produced fluid in the Woodford Shale operating area. Few local geologic zones will take more than 5,000 barrels per day for long stretches. To get to regions with prolific water disposal zones, trucking companies have to travel more than an hour which increases cost for the operator.

Another form of disposal is soil farming, which is regulated by the Oklahoma Corporation Commission. Permits are usually issued in areas where soil farming companies have access to relatively flat land conducive to minimal runoff. Permits require companies to perform soil tests regularly to ensure salt content does not exceed 6,000 pounds per acre. These disposal facilities concurrently optimize evaporation by cycling the fluid through misting nozzles.

The other option is to reuse flowback and produced fluid in ongoing completions. This is the cheapest method for disposing of fluid while also providing a necessary component (chloride) for completion fluid. During the initial development of the Woodford Shale, Oklahoma was experiencing a drought. To get water for fracs, operators were forced to reuse flowback. As the rig count increased in Oklahoma, the demand for flowback as completion fluid stayed ahead of the flowback production.

There are two significant downsides to using flowback as a component of completion fluid. If this fluid is recycled without treatment, it becomes heavily laden with divalent cations. These divalent cations cause scale, predominantly iron sulfide and calcium carbonate. Divalent cations also cause polyacrylamide friction reducers to mix poorly, increasing chemical cost to the operator. Operators are now researching treatment options.

Completion Fluid Treatment

Simple filters and screens are inexpensive but will not remove divalent cations in solution. Service companies offer chemical treatments which alter the pH level of the fluid, creating downhole conditions that minimize scale precipitation. These treatments range in cost from \$0.30 per bbl to \$3.75 per bbl, depending on the chemical composition of the fluid being treated. Inherently, the use of chemicals creates handling and environmental concerns, especially when dealing with caustic or acidic substances to alter the pH level of a fluid.

Mixing potassium chloride powder with surface water creates an optimal chemical composition for completion fluid, but potassium chloride is costly in the framework of Woodford Shale operational economics. The use of potassium chloride can increase the cost of a completion by \$150,000 to \$250,000.

Trucking

As in the Barnett Shale, fluid transports cause problems for operators in the Woodford. These trucks normally have 110 barrel working capacities and burn five gallons of diesel per hour. The standard trucking rate ranges from \$102 to \$105 per hour. An average trip time is 3.5 to 4.5 hours, which equates to an average of \$3.71 per bbl. Trucks are the only available means to transport oilfield waste. The trucks cause road damage, add risk to an already busy location and area road networks, and add to the environmental impact of the oil and gas industry. Without these trucks, however, water intensive completions required for the Woodford Shale would not be possible. For the foreseeable future, these trucks will remain necessary to haul oilfield waste. A pipe infrastructure is costly due to inflated right-of-way cost. Even if the economics of a pipe infrastructure made sense, most operators will not risk establishing a pipe infrastructure to move brine for fear of the associated liabilities.

A mobile water treatment process that treats flowback on location and creates a fresh water stream could reduce trucking significantly. In the Woodford, 34% of the load flows back in the first two weeks. A mobile water treatment unit could process 33,000 bbl in that time, creating a stream of 25,000 bbl of fresh water. Pumping 25,000 bbl per well back to the environment recycles a valuable, finite natural resource while reducing truck traffic significantly. 25,000 bbl would

eliminate the need for 227 truck trips per well.

Applying a New Water Treatment Technology

Breakthrough Water Treatment Process

When flowback is the influent being treated, it will first be discharged into a frac tank to allow solids to settle. The second step is particulate filtration which decreases suspended solids in the influent. The third step is the advanced oxidation process (AOP) and electro precipitation. Super-saturated ozonated water is flash mixed with the influent using hydro-dynamic cavitation through a liquid sparger. Dual-frequency ultrasonic transducers initiate the dissolved gas flotation of oils and suspended solids and the conversion of ozone to hydroxyl radicals. In the presence of an ultrasonic cavitation field, ozone decomposes into two hydroxyl radicals and oxygen gas. The hydroxyl radical will oxidize all known organic compounds in nano-seconds. Nano-cavitation bubbles imploding provide the liquid-gas interface that is instantaneously heated to approximately 900°F, which in turn oxidizes all known organic compounds in 35-100 picoseconds (one millionth of one millionth of a second). This phenomenon is known as sonoluminescence. Sonoluminescence effects the oxidation of soluble and insoluble organics, bio-slimes, oil sheens and heavy metals. The process also decomposes dissolved ammonia. A continuous ultrasonic field will agglomerate small bubbles into larger bubbles with a diameter of 1/8th the ultrasonic wavelength. This process increases the bubble rise velocity and decreases the flotation time for oils and solid particles. Ultrasonic cavitation cleaves larger particles into smaller particles for faster removal by flotation. The vessel in which sonoluminescence takes place also has two electrodes which precipitate hard salts from the influent.*

AOP and electro precipitation is the key. The rest of the treatment process involves well established science and technology. Aluminum sulfate is injected into the influent stream after AOP at a rate of one gallon per thousand. Aluminum sulfate coagulates the oxidized substances from AOP in preparation for the next step, which is the centrifuge. A 100 gpm centrifuge removes the oxidized material. The by-product from this process is extracted from the centrifuge. After the centrifuge, activated carbon filters further clarify the fluid.

If the desired effect is to separate brine from fresh water, the next step is the reverse osmosis process (RO). RO is a well established and proven technology in many industries. RO separates solute from solvent by forcing the solution through a membrane under pressure up to 1,000 psig. The osmotic membranes are sensitive to organic compounds. Hydrocarbon compounds are especially harmful to RO membranes. AOP establishes water quality ideal for RO. Any substances that could foul the filters have been oxidized and/or removed thus increasing RO efficiency.

Pilot

Newfield Exploration Mid-Continent Inc. tested this process during a pilot project in November 2008 near Coalgate, OK. A mobile unit roughly the size of a frac tank processed flowback from two horizontal Woodford Shale wells at 100 bbl per hour, 12 to 14 hours per day for two weeks. An independent third party consultant group managed the sampling and analysis program, enforcing a rigorous quality assurance and quality control (QA/QC) program. Execution of the sampling and analysis program—to include sample custody, analytical procedures, laboratory QA/QC and data validation—adhered to Environmental Protection Agency (EPA) guidelines. **Table 2** lists the specific laboratory analytical methods for the sample analysis.

Eleven sample sets were taken over a two week period, to include three influent (flowback) sample sets, seven effluent (fresh water stream from RO) sample sets and one surface water sample set. **Table 3** shows flowback (influent) compared AOP/RO fresh water (effluent). **Table 4** shows the AOP/RO fresh water compared to the surface water source.

Cost

A 220 kW generator powered the water treatment unit used during the pilot. Aluminum sulfate and scale inhibitor are the only chemicals used during the process. Currently three people operate the unit, but the team could be reduced to two with automation. Energy, chemicals, and people are the primary costs to run the unit. Despite the 900°F liquid-gas interface caused by sonoluminescence during AOP, the vessel in which AOP takes place never exceeds the temperature of the flowback. On the micro level the process oxidizes matter via heat, but on the macro level the temperature of the fluid doesn't change significantly. The cost to run the unit on a per barrel basis is significantly less than the average cost to truck and dispose of a barrel of fluid in the Woodford.

Environmental Impact

The fresh water stream from the mobile water treatment unit could be used by farmers to irrigate land for crops or livestock. It could be returned to a frac pond to be reused by the landowner or operating company or possibly returned to a river as part of the hydrological cycle. This would transform a portion of consumptive water use by the oil and gas industry into a nonconsumptive use.

* Personal communication with D. McGuire. 2009. Ecosphere Energy Solutions, Inc.

Concurrently, eliminating 227 truck trips per well equates to an emission reduction of 50 tons CO₂ per well.* According to the Baker Hughes Rig Count in January 2009, there are 33 drilling rigs in the four Oklahoma counties that comprise the heart of the Woodford Shale play. Assuming each rig drills 9 wells per year, 297 wells will be completed in 2009. On an annualized basis, the water recycling benefit and CO₂ reductions are significant if this technology were allowed to be used as described herein. 25,000 bbl per well for 297 wells equates to enough water to support the needs of 8,500 people for a year.†

Operational Impact

The concentrated brine stream from the mobile water treatment unit can be reused for subsequent fracs. The electro precipitation process reduces the divalent cations by 40-50%. Future developments to the unit involve an increased current to the dual electrodes which should account for more hard salt precipitation. The waste stream from the unit is approximately 1% of the initial bulk volume processed. It is trucked to and disposed in injection wells.

There is considerable traffic on location following a Woodford Shale completion. In many cases, operators are drilling four well pads which quadruples the traffic on location—most of which is fluid transports. Eliminating three fourths of that traffic in the first two weeks would make a much safer location for employees.

Regulatory Approval

In order to discharge treated flowback to “surface waters of the United States,” EPA approval is needed. This type of discharge is controlled by the EPA under the Clean Water Act. The specific prohibition is found in Title 40 of the Code of Federal Regulations (CFR), Chapter I, Part 435 (Oil & Gas Extraction Point Source Category). There is currently an exception to the prohibition, which is found at 40 CFR, Chapter I, Part 435, Subpart E, Section 435.50. This exemption allows produced water discharge for the beneficial use of agriculture and/or wildlife propagation west of the 98th meridian, provided the discharge complies with the requirements of Sections 435.51 and 435.52. Discharges into inland waters allowed outside this exception could be accomplished by one or both of the following changes in EPA rules:

1. Short term relief can be achieved by amending the Federal Register at 40 CFR, Chapter I, Part 435, Subpart E, Section 435.50 to read a different meridian to the east, say the 90th Meridian.
2. Long term relief can be achieved through the process required by the Clean Water Act, Section 304 (m) by including an effluent guideline for oil and gas extraction produced water discharges to the biennial Effluent Guideline Program Plan. This process identifies any new or existing industrial categories to be selected for effluent guideline rulemaking and provides a schedule for such rulemaking. Given recent technology advances in treating produced water it would follow that an effluent guideline would be forthcoming and would allow discharge under certain prescribed conditions.

Discharges from coal-bed methane extraction west of the 98th meridian are allowed under the Exemption discussed above. In addition, there is rule-making currently under way through the EPA process for a specific Effluent Guideline to expand that discharge capability beyond the exemption.‡

Limitations

The next step is to lobby for an effluent discharge guideline change or for legislative action that supports discharging treated wastewater to the environment provided the chemical composition of the fluid meets certain permitted guidelines. There are other applications of this technology, but the AOP/RO process is only economical to Woodford operators if they are allowed to discharge the treated fresh water stream back to the environment from the well location, thus eliminating trucking for the volume discharged.

Reverse Osmosis does not work on waters with chloride levels above approximately 40,000 ppm. At that point, the pressure needed to separate solute from solvent becomes operationally impractical. This process, then, would not work on most produced fluids. It would also not work in areas where connate fluid increases the initial flowback of a well beyond the critical point. With AOP, it would still be possible to take produced fluid and clean it sufficiently for reuse; however, the application this manuscript focuses on would not apply.

Operators will assume a certain amount of liability even after the EPA permits the use of this AOP process on a mobile basis. QA/QC programs will ensure that attempts at frivolous lawsuits are met with professional documentation proving the AOP/RO fresh water stream has a benign effect on the environment.

Conclusions

The future development of natural gas producing shale plays hinges on environmentally friendly, cost efficient water management programs customized to each operational area. The AOP/RO process presents a unique opportunity for the oil and gas industry to improve economics while acting as environmental stewards. By properly leveraging this technology,

* According to the EPA, 1 gallon of oxidized diesel equates to 22.2 pounds of CO₂ emissions.

† According to the EPA, one person consumes 100 gallons of water per day.

‡ Personal communication with B. Hathaway. 2009. The Benham Companies.

operators can create a water management plan that decreases operating cost, conserves water, reduces carbon dioxide emissions, and provides a safer working environment. US energy independence lay beneath American soil in the form of trillions of cubic feet of natural gas in the Fayetteville, Woodford, Haynesville, Marcellus and Barnett Shales. The benefits derived from an economic, “green” solution to the water problem associated with the development of these shales could have far-reaching political, environmental and socio-economic impact.

Acknowledgments

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Tables

Table 1--Flowback Data on 13 Woodford Shale Wells	
Day	Avg Load Recovery / Day
1	3,678
2	4,414
3	3,654
4	3,515
5	2,859
6	2,258
7	1,952
8	1,786
9	1,619
10	1,341
11	1,207
12	1,235
13	1,058
14	951
Avg Frac Load	94,357
Avg Frac Rec in 2 wks	33,672
Avg Daily Rec	1,981
% Rec in 2 wks	34%

TABLE 2--Treatment of Constituents of Concern

General Category	Constituent	EPA Method Number	Standard Det Limits (mg/l)
General Chemistry	Alkalinity, Total	SM 2320 B (18th, 19th, 20th ed.)	10
	Ammonia, as N	EPA 350.1, Rev 2.0 (1993)	0.1
	Total Organic Nitrogen	Calculation (TKN - Ammonia; TKN = EPA 351.1(Rev. 1978))	0.1
	BOD - 5 day	SM5210 B (18th, 19th, 20th ed.)	2
	COD	EPA 410.4, Rev. 2.0 (1993)	10
	Chlorides	EPA 300.0, Rev. 2.1 (1993)	1
	Phosphorus	EPA 365.4	0.1
	Sulfates	EPA 300.0, Rev. 2.1 (1993)	1
	Total Dissolved Solids	SM 2540 C (18th, 19th, 20th ed.)	20
	Total Suspended Solids	SM 2540 D (18th, 19th, 20th ed.)	1
	Hardness, Total	SM 2340 B or C (18th, 19th, 20th ed.)	10
	Oil and Grease	EPA 1664 A	5
	Total Organic Carbon	SM 5310 B, C, or D (18th, 19th, 20th ed.)	1
	Phenolics	EPA 420.1 (Rev. 1978)	
	Fluoride	EPA 300.0, Rev. 2.1 (1993)	0.1
	Cyanide	EPA 353.4, (Rev. 1.0 (1993)	
	Nitrates (as N)	EPA 300.0, Rev. 2.1 (1993)	0.1
	Bromide (influent only)	EPA 300.0, Rev. 2.1 (1993) for Bromide	1.0 for Bromide
	Bromates (effluent only)	EPA 300.1	
Metals	Aluminum	EPA 200.7, Rev. 4.4 (1994)	
	Antimony	EPA 200.7, Rev. 4.4 (1994)	0.006
	Arsenic	EPA 200.7, Rev. 4.4 (1994)	0.01
	Barium	EPA 200.7, Rev. 4.4 (1994)	0.01
	Beryllium	EPA 200.7, Rev. 4.4 (1994)	0.004
	Cadmium	EPA 200.7, Rev. 4.4 (1994)	0.001
	Calcium	EPA 200.7, Rev. 4.4 (1994)	1
	Chromium	EPA 200.7, Rev. 4.4 (1994)	0.005
	Copper	EPA 200.7, Rev. 4.4 (1994)	0.01
	Iron	EPA 200.7, Rev. 4.4 (1994)	0.05
	Lead	EPA 200.7, Rev. 4.4 (1994)	0.005
	Magnesium	EPA 200.7, Rev. 4.4 (1994)	1
	Mercury	EPA 245.1, Rev. 3.0 (1994)	0.0002
	Nickel	EPA 200.7, Rev. 4.4 (1994)	0.01
	Selenium	EPA 200.7, Rev. 4.4 (1994)	0.01
	Silver	EPA 200.7, Rev. 4.4 (1994)	0.005
	Thallium	EPA 200.7, Rev. 4.4 (1994)	0.01
	Zinc	EPA 200.7, Rev. 4.4 (1994)	0.05
	Radium 226, 228	903.0, 904.0	1 pCi/L
	Isotopic Uranium	A-01-R	1pCi/L
Volatile Organics	Priority Pollutants	EPA 624	
Semi-Volatile Organics	Priority Pollutants	EPA 625	

Note: In addition to the parameters listed above each sample will analyzed, in the field, for dissolved oxygen, temperature, pH, and specific conductivity.

Table 3--Constituent Sample Analysis Results from Pilot

Parameter	Unit	Flowback Influent	AOP/RO Effluent	% Change
Total Dissolved Solids	mg/L	13833	128	99.1%
Chloride	mg/L	8393	27	99.7%
Hardness, calculated	mg/L	1163	0	100.0%
Alkalinity, Total (CaCO ₃)	mg/L	1002	31	96.9%
Calcium	mg/L	352	0	99.9%
Chemical Oxygen Demand	mg/L	248	2	99.3%
BOD - 5 Day	mg/L	196	9	95.4%
Magnesium	mg/L	69.0	0.0	100.0%
Total Organic Carbon	mg/L	65.4	3.0	95.4%
Total Suspended Solids	mg/L	64.5	0.0	100.0%
Total Kjeldahl Nitrogen	mg/L	43.6	3.1	92.8%
Ammonia as N	mg/L	39.9	1.1	97.2%
Barium	mg/L	34.9	0.0	99.9%
Sulfate	mg/L	23.5	0.0	100.0%
Oil & Grease	mg/L	13.8	1.1	92.3%
Iron	mg/L	13.4	0.0	99.9%
Total Organic Nitrogen	mg/L	3.84	2.06	46.3%
Nitrate as N	mg/L	3.37	0.00	100.0%
Fluoride	mg/L	1.76	0.00	100.0%
Phosphorus	mg/L	1.15	0.00	100.0%
Aluminum	mg/L	0.347	0.000	100.0%
Phenolics	mg/L	0.111	0.051	54.4%
Silver	mg/L	0.087	0.001	99.0%
Chromium	mg/L	0.068	0.000	100.0%
Copper	mg/L	0.068	0.020	70.9%
Nickel	mg/L	0.056	0.025	55.3%
Thallium	mg/L	0.038	0.000	100.0%
Arsenic	mg/L	0.037	0.000	100.0%
Cadmium	mg/L	0.014	0.000	98.6%
Cyanide	mg/L	0.005	0.004	4.5%
Lead	mg/L	0.000	0.000	100%
Mercury	mg/L	0.000	0.000	100%
Bromide	mg/L	79.6	NA	NA
Zinc	mg/L	0.000	0.070	NA
Phenol	µg/L	38.6	0.0	100.0%
Bis(2-chloroethyl)ether	µg/L	38.3	0.0	100.0%
Xylenes, total	µg/L	24.3	0.0	100.0%
Toluene	µg/L	5.62	0.97	82.7%
Benzene	µg/L	4.73	0.00	100.0%
Ethylbenzene	µg/L	4.25	0.00	100.0%
Chlorobenzene	µg/L	0.00	2.04	NA
Chloroform	µg/L	0.00	1.40	NA
Gross Alpha	pCi/L	265	0	100.0%
Gross Beta	pCi/L	72.0	0.0	100.0%
Radium 226	pCi/L	81.8	0.0	100.0%
Radium 228	pCi/L	7.34	0.00	100.0%
Uranium 234	pCi/L	1.12	0.00	100.0%
Uranium 238	pCi/L	0.960	0.000	100.0%

Note-The results shown are averages of sample sets taken over a two week period. Samples returning "zero" trace for both influent and effluent are removed.

Table 4--Surface Water vs AOP/RO Clean Water

Parameter	Unit	Surface Water	AOP/RO Effluent	Difference
Total Dissolved Solids	mg/L	222.0	128.3	(93.7)
Total Suspended Solids	mg/L	64.0	0.0	(64.0)
Hardness, calculated	mg/L	35.8	0.0	(35.8)
Chemical Oxygen Demand	mg/L	31.7	1.8	(29.9)
Alkalinity, Total (CaCO ₃)	mg/L	29.7	31.0	1.3
Sulfate	mg/L	10.7	0.0	(10.7)
Iron	mg/L	10.4	0.0	(10.4)
Aluminum	mg/L	9.55	0.00	(9.55)
BOD - 5 Day	mg/L	7.94	9.07	1.13
Total Organic Carbon	mg/L	7.60	3.03	(4.57)
Calcium	mg/L	7.22	0.20	(7.02)
Magnesium	mg/L	4.32	0.00	(4.32)
Chloride	mg/L	4.15	27.29	23.14
Total Kjeldahl Nitrogen	mg/L	1.94	3.13	1.19
Total Organic Nitrogen	mg/L	1.75	2.06	0.31
Fluoride	mg/L	0.323	0.000	(0.323)
Ammonia as N	mg/L	0.192	1.112	0.920
Phosphorus	mg/L	0.114	0.000	(0.114)
Barium	mg/L	0.111	0.022	(0.089)
Chromium	mg/L	0.015	0.000	(0.015)
Nickel	mg/L	0.012	0.025	0.013
Lead	mg/L	0.005	0.011	0.006
Nitrate as N	mg/L	0.000	0.000	0.000
Arsenic	mg/L	0.000	0.000	0.000
Thallium	mg/L	0.000	0.000	0.000
Mercury	mg/L	0.000	0.000	0.000
Cadmium	mg/L	0.000	0.000	0.000
Silver	mg/L	0.000	0.001	0.001
Cyanide	mg/L	0.000	0.004	0.004
Copper	mg/L	0.000	0.020	0.020
Phenolics	mg/L	0.000	0.051	0.051
Zinc	mg/L	0.000	0.070	0.070
Oil & Grease	mg/L	0.000	1.066	1.066
Bromide	mg/L	0.000	NA	NA