Appendix F - ORICA Pilot Report

REPORT ON THE MIEX®[1] PILOT TRIAL

FOR THE CITY OF RUTLAND

RUTLAND, VT

THE MENDON BROOK

REPORT NO: TR-2011-004

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[1] MIEX® is a registered trademark with the U.S. Patent office and owned by Orica Watercare Incorporated

EXECUTIVE SUMMARY

A pilot of the MIEX® Process was operated at the Rutland Water Plant in Rutland, Vermont from the 8th of September 2011 to the 5th of October 2011 to demonstrate disinfection by product (DBP) compliance. Compliance was demonstrated using simulated distribution system (SDS) criteria as detailed in Table 1.

Table 1: SDS Conditions

Contaminant	Unit	Treated Water Average
TTHM	µg/L	< 80
HAA5	µg/L	< 60
pH	units	Ambient
Temperature	C	Ambient
Free Chlorine	mg/L	1.2
Duration	days	3

Results demonstrated the following:

- DOC removal through the MIEX® process averaged 61%. No additional DOC removal was achieved through the slow sand filter (SSF).
- The MIEX® bench test method closely resembled the pilot plant effluent and can be used for qualitative determinations.
- MIEX® Treated samples disinfected under the SDS conditions listed in Table 1, resulted in an average 3-day TTHM concentration of 22.0 µg/L and HAA5 concentration of 15.5 µg/L,with 65% less chlorine demand.
- At a treatment rate of 0.7 – 1.00 gallons of resin regenerated per 1000 gallons of raw water treated, which is equivalent to a bed volume (BV) treatment rate of 1400 - 1000 BV, the pilot effectively treated the raw water to achieve the goals outlined in the trial.
- During the trial, the raw water true color averaged 11 CU, which was consistently reduced to an average of 3 CU in the MIEX® Effluent (Pilot Plant Effluent), and reduced to an average of 1 CU in MIEX® SSF water (Slow sand filtration of MIEX® Effluent).

- The overall average UVA reduction achieved in the MIEX® Effluent was 82%, where the average raw UVA was 0.072 cm^{-1} and MIEX® Effluent UVA was 0.013 cm^{-1}. After slow sand filtration the UVA was reduced to an average of 0.014 cm^{-1} or an 83% average reduction.

In summary, the pilot trial results demonstrated that MIEX® Treatment can:

- significantly enhance the reduction of DOC, color and UVA,
- decrease the plant chemical demand, and
- decrease the DBP formation potential.

LIST OF ACRONYMS & DEFINITIONS

DBP	Disinfection By Product
DOC	Dissolved Organic Carbon
EPA	Environmental Protection Agency
GAC	Granular Activated Carbon
gpm	Gallons Per Minute
HAA	Summation of 5 Regulated Haloacetic Acids
MCL	Maximum Contaminant Level
MGD	Million Gallons Per Day
mg/L	Milligrams Per Liter
ppb	Parts Per Billion
MLT	Multiple load test
ppm	Parts Per Million
NOM	Natural Organic Matter
SDS	Simulated Distribution System
SDWA	Safe Drinking Water Act
SSF	Slow Sand Filtration
TOC	Total Organic Carbon
TTHM	Total Trihalomethanes (4 Species)
UVA	UV_{254} Absorbance
µg/L	Micrograms Per Liter
WTP	Water Treatment Plant

DEFINITIONS:

Test Resin –MIEX® Resin that has been used before and been regenerated

Regenerate – A process of contacting loaded resin with a brine solution to exchange organics and replace them with chloride ions

Virgin Resin – New resin that has not previously been exposed to raw or treated water

Bed Volume – Volumetric ratio of treated water to resin (see example below).

Bed Volume Example Calculation:

Volume of Water to be Treated	$V_1 = 1{,}000$ mL	
Volume of Resin Used for Treatment	$V_2 = 5$ mL	
Bed Volume Calculation	$BV = V_1/V_2$	$BV = 200$

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1 BACKGROUND

The City of Rutland, in an effort to enhance natural organic matter removal to reduce disinfection by products formation (DBP), is evaluating the MIEX® ion exchange technology as well as granular activated carbon (GAC). The MIEX® Process uses a magnetic anion exchange resin specifically designed for use as a fluidized bed process. The process delivers large reductions in dissolved organic carbon (DOC) and chlorine demand with predicable operating cost even when raw water quality conditions change. A small volume of resin is added daily or weekly as part of the normal operation thus eliminating large replacement expenses with ongoing treatment that can be seen with GAC operation.

DOC found naturally in water is a known precursor to DBP formation. DOC is the dissolved portion of total organic carbon (TOC) that passes through a 0.45-µm filter. Disinfection by products (DBPs) are formed when free chlorine acts as a substituting agent and is incorporated in the DOC molecular structure - thereby forming halogenated organic compounds. Currently, the EPA Safe Drinking Water Act (SDWA) regulates the maximum allowable concentration of two general compounds of DBPs: total trihalomethanes (TTHM) and five haloacetic acids (HAAs). A pre-trial feasibility test of the MIEX® Process treating Mendon Brook water indicated a potential to remove a large fraction of the source water dissolved organic carbon prior to slow sand filtration.

A trial of the MIEX® Process was conducted from Thursday the 8th of September 2011 to Wednesday the 5th of October 2011. The MIEX® Process was operated at 10 gpm in a continuous manner prior to a pilot sized slow sand column. The influent water to the MIEX® Process gravity flowed from the raw water header. MIEX® Effluent gravity flowed to a pilot sized SSF column.

Raw water conditions changed significantly against historical water quality averages. Flooding caused by a recent hurricane demanded an emergency source water to supply raw water to the reservoir. Reservoir source water was supplied by a mixture of sources throughout the trial as the Mendon Brook raw water line was repaired. An emergency supply from a neighboring creek provided fresh source water for the reservoir until halfway through the trial. As the Mendon Brook supply lines became repaired, the normal source water mixed into the reservoir. Road construction, traffic in the brook, and rains caused increased turbidity in the raw water.

2 TRIAL OBJECTIVES

The specific pilot plant objectives as described in Orica trial protocol (TP-2011-09) are outlined below.

Pilot Plant Objectives:

1. Validate the design criteria for a full-scale plant, including resin regeneration requirements.
2. To demonstrate that MIEX® Resin treatment will significantly reduce the concentration of DOC and UV_{254} absorbance of the raw water.
3. To quantify the subsequent decrease in DBP formation potential.
4. To determine the optimum level of MIEX® treatment.
5. To determine design parameters for MIEX® equipment and process.
6. Demonstrate that the MIEX® multiple loading bench test method closely resembles water quality as seen in the pilot plant effluent and is an effective tool for further bench top evaluations.

3 METHODOLOGY

3.1 Pilot Plant Operating Parameters

The MIEX® trial was conducted using a 10 gpm high rate pilot plant shown below.

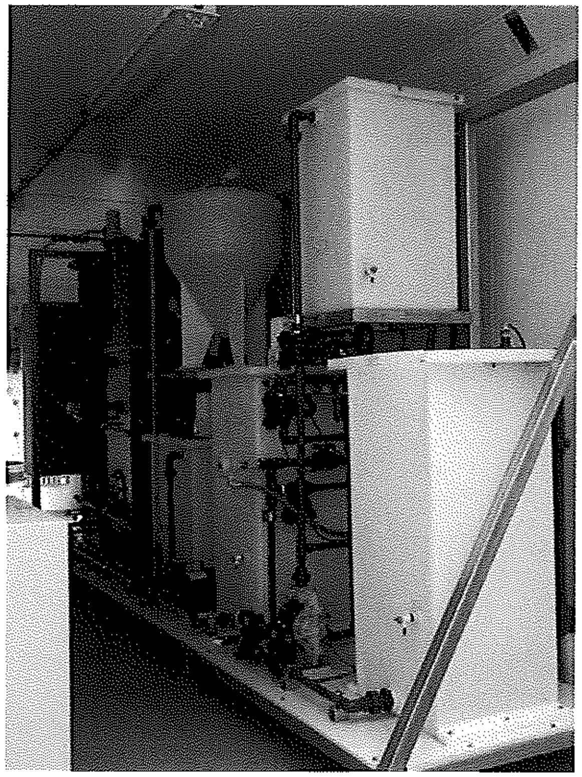

Figure 1: 10 gpm MIEX® Pilot Plant

Prior to the trial, a series of tests were conducted on the Mendon Brook water at Orica Watercare's laboratory to determine the impact of resin dose (treatment rate) on final water quality. This data was then used to select trial start-up conditions and expected operating parameter ranges. Operating parameter ranges used throughout the trial are summarized in Table 2.

Table 1: MIEX® Pilot Plant Operating Parameters

Parameter	Operating Range
Contactor Resin Concentration	200-250 mL/L
Raw Water Contact Time	4-6 minutes
Treatment Rate	0.71 – 1.00 gal. per 1000 gal water treated (1400 - 1000 BV)
Pilot Plant Flow-rate	10 gpm

3.2 Sampling Regime

Samples were taken daily and analyzed for specified water quality parameters. The sample locations are described as follows:

- Raw – Rutland Reservoir water taken from MIEX® Pilot Plant raw water sample tap.
- MIEX® Effluent – MIEX® pilot plant effluent.
- MIEX® SSF (SF#1) – Slow sand filtration after MIEX® pretreatment using a pilot sized column.
- Plant Control – Raw water treated with slow sand filtration, Rutland WTP's clearwell sample tap.
- Sand Filter #2 (SF#2) – Raw water treated with slow sand filtration and GAC using a pilot sized column.
- Sand Filter #3 (SF#3) – Raw water treated with slow sand filtration and GAC using a pilot sized column.

Samples were analyzed on-site for heterotrophic plate count, UVA, pH, turbidity, and color to evaluate optimum operating parameters. DOC samples were analyzed by Eastern Analytical Inc. Simulated distribution system (SDS) samples were prepared on-site and sent to Eastern Analytical Inc. where the samples were then analyzed for TTHM and HAA5 formation. All DOC, SDS, and true color samples were filtered through SSF prior to analysis. UVA samples were filtered using a 0.45 micron filter before analysis per standard laboratory procedure.

3.3 MIEX® Multiple load Bench Method

The multiple loading test (MLT) procedure has been shown to closely approximate full-scale, continuous plant operation. To determine if pilot operating conditions were optimized, water quality testing during the pilot was compared to samples from June 14th 2007 used for bench scale testing. Fresh resin was loaded to a bed volume concentration of 1000 BV in the laboratory using the method outlined below. The treated water was evaluated for UVA and DOC and compared to the pilot plant effluent.

Using a jar stirrer apparatus,

1. Add 5 mL/L fresh resin to an empty jar
2. Add 1 L of raw water sample to jar (200 BV treatment rate per cycle)
3. Mix for 15 minutes
4. Turn mixer off and allow resin to settle

5. Decant treated water into collection vessel while leaving resin in jar
6. Measure UVA, color, and DOC of sample in collection vessel
7. Add another liter of raw water to resin and repeat Steps 3-6 until 1000 BV have been treated

3.4 Slow Sand Filtration Evaluation

A control test was analyzed to determine actual organic carbon removal achieved currently at the water plant. The SSF schmutzdecke is a bio-active layer on top of fine sand media. This layer along with filtration removes organics from the raw water. The water treatment plant's clearwell sample tap provided daily control samples.

Three pilot sized slow sand filters were run in parallel for comparison. MIEX® effluent fed the first filter, SF#1. Sand filter two (SF#2) and sand filter three (SF#3) were fed with raw water. SF#2 recently changed out the GAC media in the filter while SF#3 was tested with GAC from a previous trial.

Samples were collected and analyzed for heterotrophic plate count, turbidity, pH, DOC, DBPs, and true color. Additionally a sample was filtered through a 0.45-micron filter and analyzed for UVA at a wavelength of 253.7 nm.

3.5 Combined Treatment Evaluation

For the MIEX®/slow sand filtration combined tests, MIEX® effluent water from the pilot plant was plumbed to feed at 6 gph to a pilot sized SSF which had been preconditioned prior to receiving MIEX® effluent water. Preconditioning, performed by water plant staff, consisted of running raw water through the filter for a length of time to establish a schmutzdecke. The process treatment train simulated full scale MIEX® pretreatment to the existing slow sand filtration plant. Samples were collected and analyzed for heterotrophic plate count, turbidity, pH, DOC, DBPs, and true color. Additionally a sample was filtered through a 0.45-micron filter and analyzed for UVA at a wavelength of 253.7 nm.

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4 RESULTS

4.1 MIEX® Pilot Plant Optimization

Based on the results from bench scale testing of the June 14th 2007 raw water sample (Table 7), the pilot plant was operated at a resin regeneration rate of 0.71 – 1.0 gallons of resin per 1000 gallons of treated water (1400 - 1000 BV MIEX® Treatment). On-site analysis of DOC and UVA removal collected on this bench sample matched the pilot scale testing indicating optimum pilot performance. Daily pilot plant operation data can be referenced in Appendix A.

4.2 UVA Results

UV absorbance is a quantitative indicator of covalent bonds within an organic molecule and thus is an indicator of organic concentration. The average UVA removal achieved in the MIEX® Effluent was 82% with minimal removal being achieved with downstream slow sand filtration, for an overall average removal rate of 83%. Figure 2 represents the pilot's steady and consistent results.

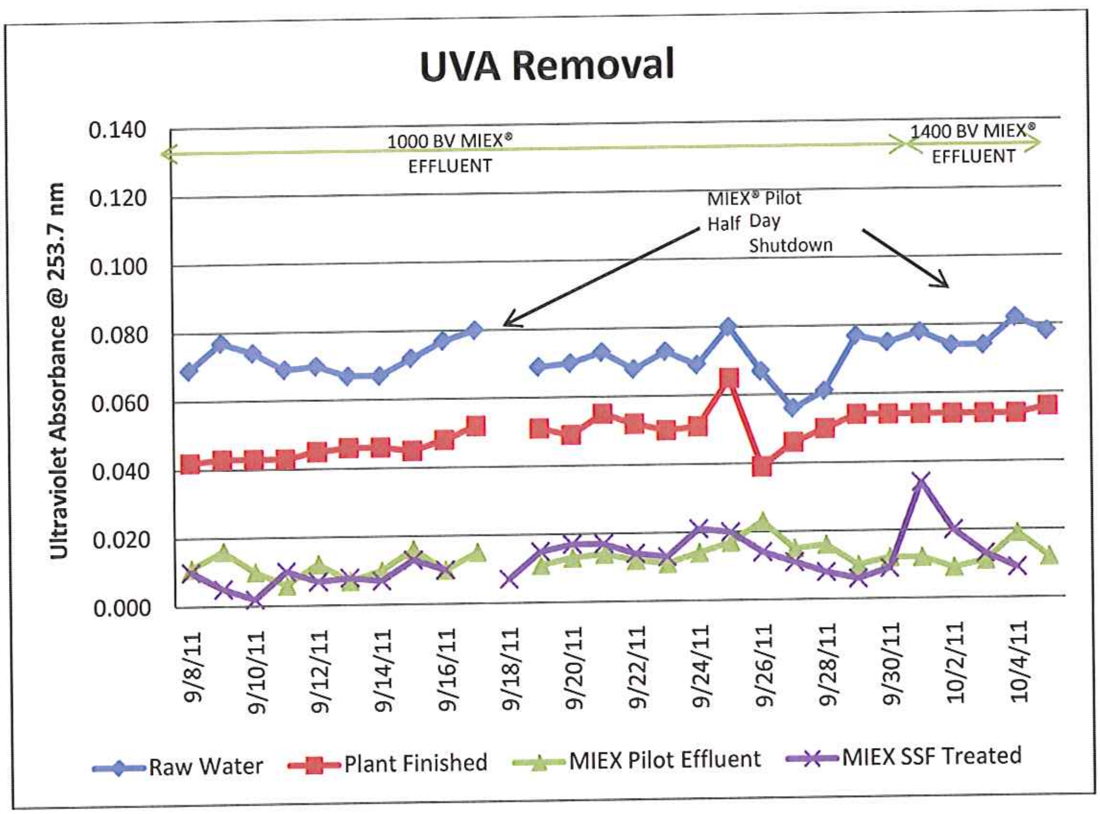


Figure 2: UVA Absorbance during Pilot

4.3 True Color removal

Water can also be an indicator of organic concentration especially true color which is filtered prior to analysis. Figure 3 illustrates the true color removal through the MIEX® pilot as observed from analysis conducted on-site. Average raw water true color was 11 Cobalt units (CU) and MIEX® Effluent was consistently reduced to an average of 3 CU. MIEX® Effluent water followed by slow sand filtration consistently reduced the true color further to 1 CU.

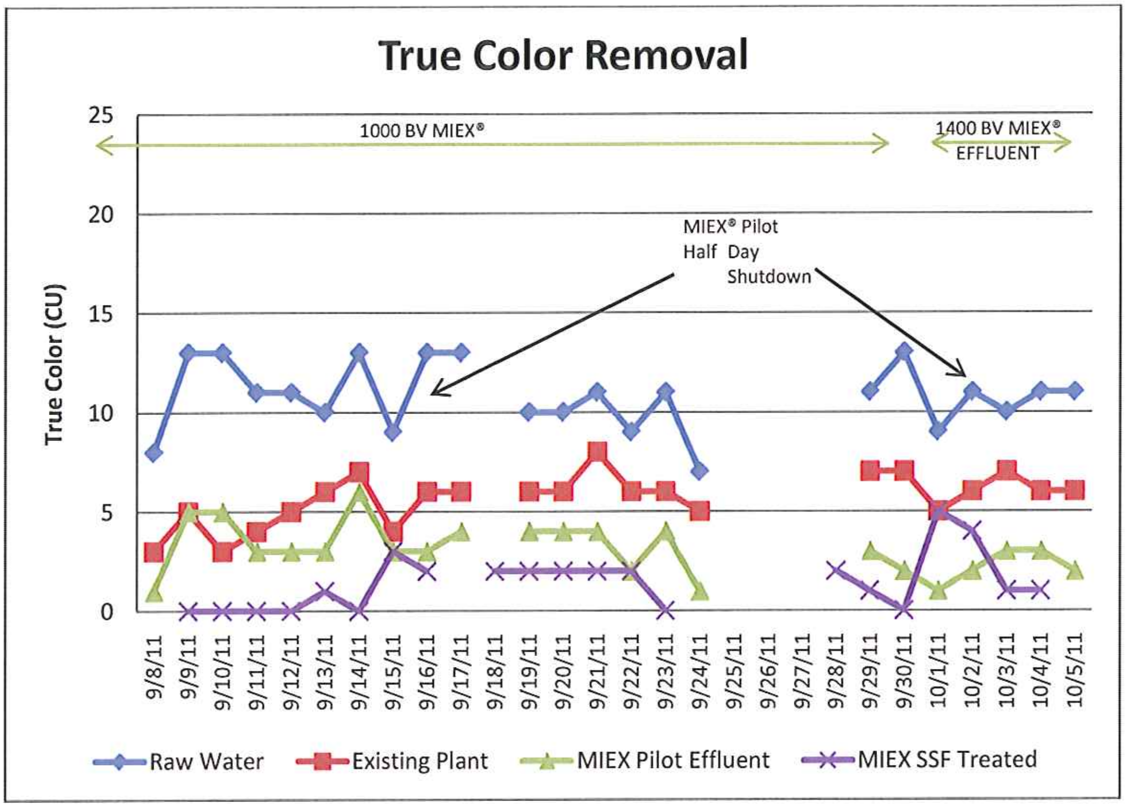


Figure 3: True Color Concentrations during Pilot

4.4 Organic Carbon Removal

DOC samples were filtered at Aquacheck Laboratory's and measured at Eastern Analytical, Inc. The average DOC removal through the pilot was 64% compared to only 22% in the water plant. After subsequent slow sand filtration the average overall DOC reduction of 61% was achieved, indicating a comparable concentration of organics after MIEX® Effluent since a same day evaluation was not weighed against MIEX® SSF. Figure 4 demonstrates consistent organic reduction during the pilot.

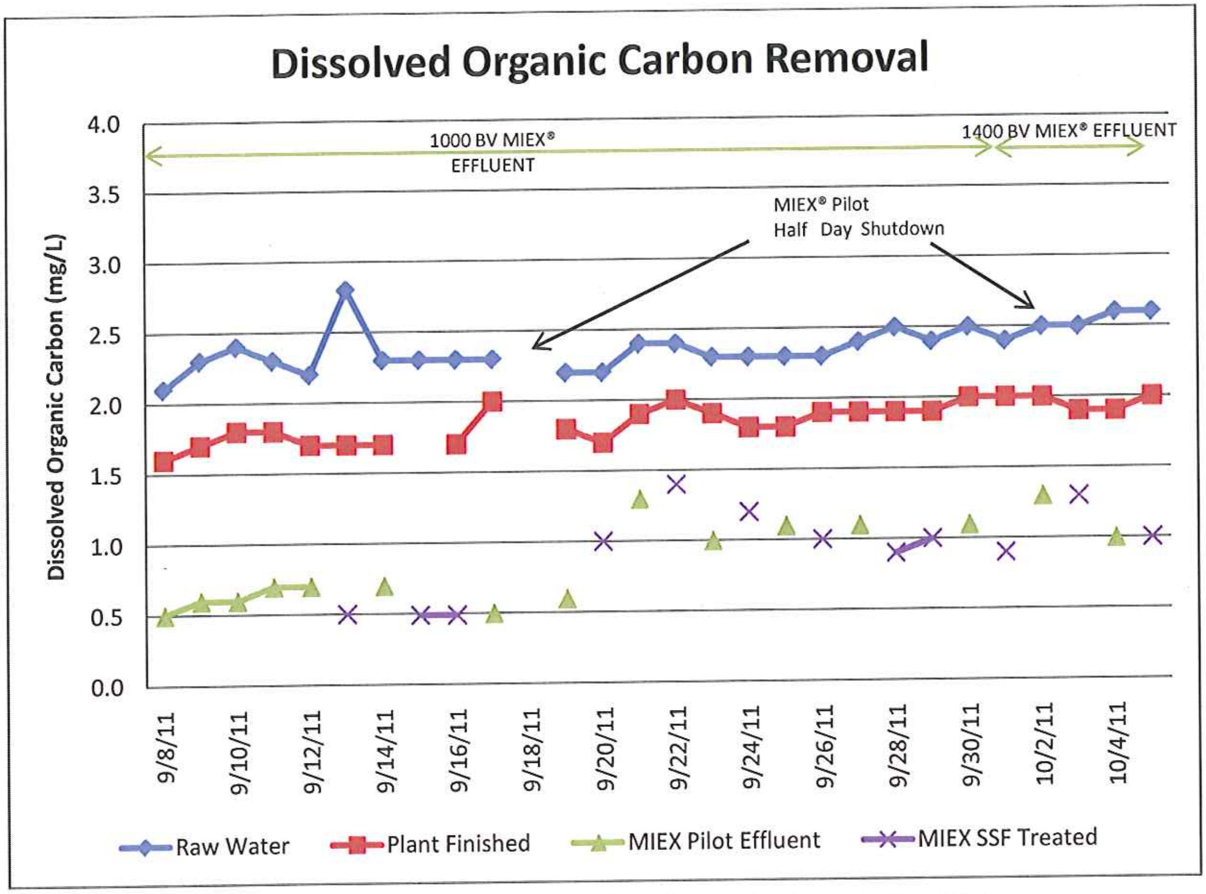


Figure 4: Dissolved Organic Carbon Concentrations during Pilot

4.5 Slow Sand Filtration Results

The results from the SSF Evaluation (Section 3.4) and the Combined Treatment Evaluation (Section 3.5) are presented in Tables 3 and 4, Appendices B, C, and D. Results demonstrate that the plant control reduced the raw water DOC by 22% on average. MIEX® SSF samples achieved an average DOC removal rate of 61%.

Table 2: Pilot Average Values						
Treatment	**UVA (cm^{-1})**	**DOC (mg/L)**	**True Color (CU)**	**pH**	**Turbidity (NTU)**	**Apparent Color (CU)**
Raw Water	0.072	2.37	11	7.63	3.00	38
Plant Clearwell	0.050	1.85	6	7.42	0.089	-
MIEX® Effluent	0.013	0.85	3	7.48	2.98	30
MIEX® SSF	0.012	0.93	1	7.39	0.112	-

Table 3: SDS Sample Average Values					
Treatment	**UV_{254} (cm^{-1})**	**DOC (mg/L)**	**True Color (CU)**	**pH**	**Turbidity (NTU)**
Raw Water	0.074	2.50	11	7.63	2.89
Plant Clearwell	0.051	1.80	7	7.41	0.077
MIEX® SSF	0.012	0.93	2	7.37	0.119
Sand Filter #2	0.018	-	2	7.10	0.136
Sand Filter #3	0.042	-	4	7.09	0.149

4.6 Disinfection By-Product reduction

4.6.1 Simulated Distribution System Protocol and Results

Orica Watercare and The City of Rutland used simulated distribution system (SDS) conditions to prepare samples for DBP formation analysis. Table 1 summarizes incubation conditions for these samples. Four categories of samples were compared: Plant Control, MIEX® SSF, Sand Filter #2, and Sand Filter #3.

In addition to DBP samples, chlorine residual measurements were taken and subsequent chlorine demand values were calculated. SDS results are presented in Table 5 and Appendix C.

Table 4: SDS 3 Day Chlorine Demand Evaluation

Plant Control Samples							
Date	**pH**	**Temperature (°C)**	**Cl_2 Dose (mg/L)**	**Free Cl_2 Residual (mg/L)**	**Cl_2 Demand (mg/L)**	**DOC (mg/L)**	**UVA 254 (cm^{-1})**
9/13/11	7.33	19	4.41	1.54	2.87	1.7	0.046
9/16/11	7.33	19	3.83	1.34	2.49	1.7	0.048
9/29/11	7.56	19	3.53	1.19	2.34	1.9	0.054
10/3/11	7.40	19	3.53	1.11	2.42	1.9	0.054
MIEX® SSF Treated Samples							
Date	**pH**	**Temperature (°C)**	**Cl_2 Dose (mg/L)**	**Free Cl_2 Residual (mg/L)**	**Cl_2 Demand (mg/L)**	**DOC (mg/L)**	**UVA 254 (cm^{-1})**
9/13/11	7.35	19	2.35	1.36	0.99	0.5	0.007
9/16/11	7.26	19	1.77	1.14	0.63	<0.5	0.013
9/29/11	7.52	19	2.06	1.19	0.87	1.0	0.008
10/3/11	7.35	19	2.35	1.26	1.09	1.3	0.020
Sand Filter #2 (GAC)							
Date	**pH**	**Temperature (°C)**	**Cl_2 Dose (mg/L)**	**Free Cl_2 Residual (mg/L)**	**Cl_2 Demand (mg/L)**	**DOC (mg/L)**	**UVA 254 (cm^{-1})**
9/16/11	7.05	19	2.35	1.00	1.35		0.018
10/3/11	7.15	19	2.35	1.43	0.92		0.017
Sand Filter #3 (GAC)							
Date	**pH**	**Temperature (°C)**	**Cl_2 Dose (mg/L)**	**Free Cl_2 Residual (mg/L)**	**Cl_2 Demand (mg/L)**	**DOC (mg/L)**	**UVA 254 (cm^{-1})**
9/16/11	7.08	19	3.53	1.70	1.83		0.040
10/3/11	7.09	19	3.24	1.26	1.98		0.044

Comparing MIEX® SSF water and plant control samples the average chlorine demand was reduced by 65% based on the applied doses of free chlorine at The Rutland WTP.

4.6.2 Free Chlorine DBP Results

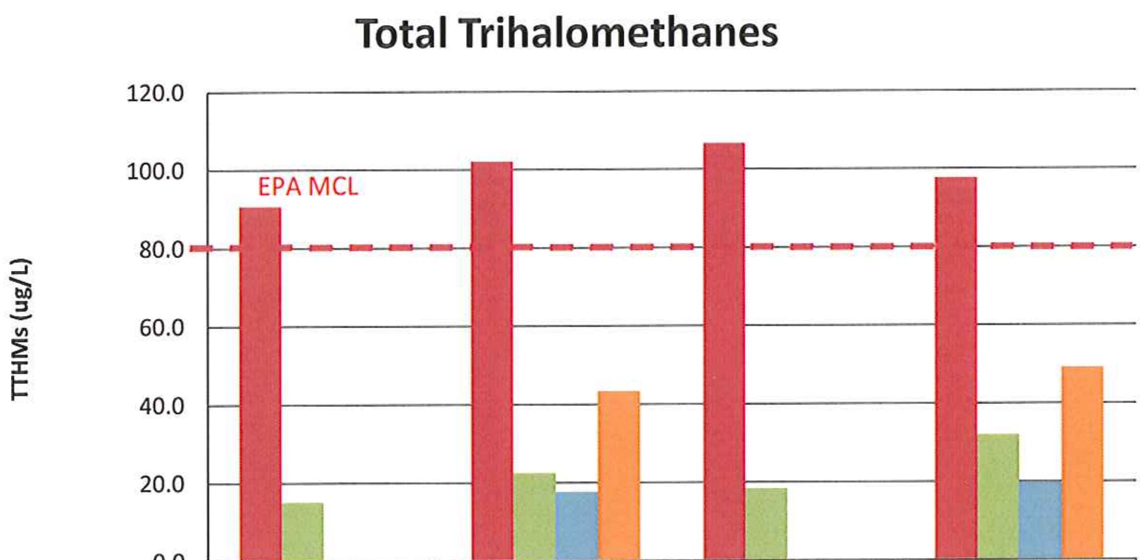
MIEX® SSF samples disinfected under the SDS conditions resulted in DBPs that were safely below the EPA's DBP MCL for both TTHMs and HAA5s of 80 µg/L and 60 µg/L, respectively. Plant Control samples disinfected under the same SDS conditions resulted in DBP concentrations close to or exceeding respective limits. All results are presented in Table 6, Figures 5 and 6, and Appendices C and D.

Table 5: SDS DBP Values and Yields						
Date	Free Cl_2 Residual (mg/L)	DOC (mg/L)	TTHM 3 Day	HAA5 3 Day	TTHM Yield	HAA5 Yield
			µg/L	µg/L	µg TTHM / mg DOC	µg HAA5 / mg DOC
Plant Control Samples						
9/13/11	1.54	1.7	90.7	59	53.4	34.7
9/16/11	1.34	1.7	102.1	59	60.1	34.7
9/29/11	1.19	1.9	106.6	58	56.1	30.5
10/3/11	1.11	1.9	97.7	57	51.4	30.0
AVG	**1.30**	**1.8**	**99.3**	**58**	**55.2**	**32.5**
MIEX® SSF Treated Samples						
9/13/11	1.36	0.5	15.1	12	30.2	24.0
9/16/11	1.14	<0.5	22.5	17	-	-
9/29/11	1.19	1.0	18.4	9	18.4	9.0
10/3/11	1.26	1.3	32.0	24	24.6	18.5
AVG	**1.24**	**0.83**	**22.0**	**16**	**24.4**	**17.2**

DBP yield is calculated as the concentration of DBP formed from the concentration of available DOC. This value should be fairly consistent per water plant no matter if the finished water DOC is 1 or 3 mg/L (for instance). The DBP yield value is derived using the DOC concentration measured from Eastern Analytical. Typically a DBP yield value is calculated with many more values than what was analyzed for this study and these values are presented only as comparative values. The yield of µg DBP per mg of DOC differed by treatment processes as can be expected. MIEX® Treated water selectively removed a significant fraction of the organic precursors that form DBPs. Therefore, the remaining DOC concentration does not have as much potential to form DBPs. An example of how this is useful is if both the Plant Control and the MIEX® SSF each had a resultant DOC of 1.0 mg/L, the plant sample would produce approximately 55.2 µg/L of TTHMs (32.5 µg/L HAAs) while the MIEX® SSF sample would only produce 24.4 µg/L TTHMs (17.2 µg/L HAAs).

The speciation of TTHMs and HAA5s showed no fractions of brominated DBPs. If bromine is present in the water at the time of disinfection, bromine acts as a substituing agent and is incorporated into the DOC molecular structure preferentially to chlorine. No measured brominated DBP species had a concentration above the minimal result limit defined by Eastern Analytical Inc.

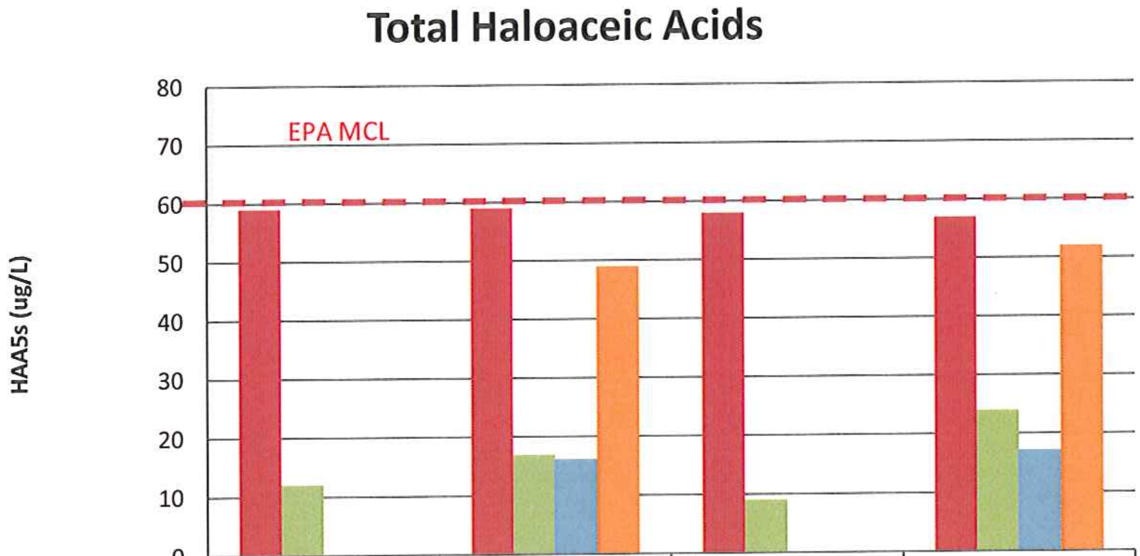
Comparing DBPs from the Plant Control to the MIEX® Treated process shows an average reduction of 78% of the TTHMs and 73% of the HAA5s.



	9/13/11	9/16/11	9/29/11	10/3/11
Plant Finished	90.7	102.1	106.6	97.7
MIEX SSF Treated	15.1	22.5	18.4	32.0
SF# 2		17.3		19.4
SF# 3		43.4		49.1

■ Plant Finished ■ MIEX SSF Treated ■ SF# 2 ■ SF# 3

Figure 5: TTHM Formation w/ Free Chlorine – 3 Days



	9/13/11	9/16/11	9/29/11	10/3/11
Plant Finished	59	59	58	57
MIEX SSF Treated	12	17	9	24
SF# 2		16		17
SF# 3		49		52

Figure 6: HAA5 Formation w/ Free Chlorine – 3 Days

4.7 MIEX® MULTIPLE LOAD BENCH TESTING RESULTS

An evaluation was conducted to determine if the MIEX® Bench Test at 1000 BV was comparable to the average MIEX® Pilot Plant Effluent at the same treatment rate. The results from the 2007 MIEX® MLT (Section 3.3) are presented in Table 6. The average 1000 BV pilot effluent from September 8th thru September 30th was used for comparison purposes.

Table 6: Comparative Methods: MLT to Pilot Plant Effluent

	Bed	UV 254		DOC	
	Volume	Treated	Removal	Treated	Removal
	Treatment	1/cm	%	mg/L	%
Bench MLT	**1000 BV**	**0.013**	**78%**	**0.79**	**63%**
Pilot Effluent	**1000 BV**	**0.013**	**82%**	**0.81**	**65%**

Analysis of the resultant data shows minimal difference in treatment performance. This evaluation showed that a 1000 BV bench scale treatment rate was less than one standard deviation from the mean DOC removal rate when the pilot was operating at 1000 BV. These results demonstrate that the bench scale MIEX® MLT results are similar in effluent water quality to pilot plant results; however, a same day comparison was not performed.

4.8 MIEX® SSF Treated Operations

MIEX® Pilot Plant Effluent flowed to a pilot sized SSF at 6 gph to simulate filter loading conditions at The Rutland WTP. One of the trial objectives was to ensure that the MIEX® Process did not interfere with downstream sand filter operations, including the schmutzdecke. Samples were measured for turbidity, organics removal, and heterotrophic plate count. If the schmutzdecke bio-layer became inactive or unsustainable, the filter pore size would be larger, increasing filter effluent turbidity. Secondly, increased organics removal efficiencies compared to raw water quality would not occur.

Results demonstrate that the raw water turbidity flowed through the MIEX® Pilot and remained in the MIEX® Pilot Plant Effluent at effectively the same concentration as the raw water, Section 4.5. The MIEX® Pilot Plant is designed for an upflow rate to allow small solids such as turbidity to flow through the system, while retaining MIEX® DOC Resin. The schmutzdecke was stirred and leveled on 9/15/11. Stirring of the schmutzdecke layer, the top 6 inches of the sand filter, is the usual filter maintenance procedure performed at Rutland WTP when the head pressure through the filter begins presenting a filter overflow situation. The top layer of sand was then leveled to provide an equal distribution of flow through the sand filter. Full scale filter maintenance is completed by sending filter effluent to waste until effluent turbidity is below operational criteria. The sand filter effluent sample on 9/16/11 was the first opportunity to measure turbidity after maintenance; the result of 0.190 NTU met operational criteria.

The routine maintenance allowed uninterrupted flow for the remainder of the trial. MIEX® Pilot Effluent turbidity differences did not distinctly cause filter operation issues. Filter effluent turbidities averaged 0.112 NTU, meeting EPA drinking water quality standards of less than 0.3 NTU.

UVA removal through the sand filter increased after the MIEX® Process averaging 82% and 83% respectively. True color removal efficiencies of 87% were achieved in the SSF effluent compared to 72% in the MIEX® Pilot Plant Effluent. DOC sampling did not compare MIEX® Pilot Plant Effluent to SSF effluent on the same day.

4.8.1 Heterotrophic Plate Count Protocol and Results

Heterotrophic plate count (HPC) is a protocol to estimate the number of live heterotrophic bacteria in water to evaluate changes during water treatment and distribution. Standard Methods procedure 9215 was used for the evaluation; results are reported in colony-forming units (CFUs). While the data set is small, testing of MIEX® Pilot Effluent and MIEX® SSF water showed an increase in HPC. The increase of HPC infers that biologically assimilable organic carbon (AOC) is present in concentrations necessary for bio-propagation for sustainable schmutzdecke operations. The results are presented in Table 8.

Table 7: HPC Data

Date Sampled	Raw (CFU)	MIEX (CFU)	Clearwell (CFU)	SF#1 - MIEX Feed (CFU)	SF#1 - Raw Feed (CFU)	Notes
9/21/11		7680		58		5% dilution used for MIEX
9/27/11	672	5127		39		0.1%, 1%, and 10% dilutions for MIEX, average result reported
10/4/11	12	3670	2	64		0.1%, 1%, and 10% dilutions for MIEX, average result reported
11/15/11	56		28		9	4 additional amorphous blobs in raw result, 2 in clearwell
AVERAGE	**247**	**5492**	**15**	**54**	**9**	

5 CONCLUSIONS

Based on the data collected during the trial the following conclusions can be made for the City of Rutland Water Plant:

- DOC removal through the MIEX® process averaged 61%. No additional DOC removal was achieved through the SSF.
- The MIEX® bench test method closely resembled the pilot plant effluent and can be used for qualitative determinations.
- MIEX® Treated samples disinfected under the SDS conditions listed in Table 1, resulted in an average 3-day TTHM concentration of 22.0 µg/L and HAA5 concentration of 15.5 µg/L,with 65% less chlorine demand.
- At a treatment rate of 0.7 – 1.00 gallons of resin regenerated per 1000 gallons of raw water treated, which is equivalent to a bed volume (BV) treatment rate of 1400 - 1000 BV, the pilot effectively treated the raw water to achieve the goals outlined in the trial.
- During the trial, the raw water true color averaged 11 CU, which was consistently reduced to an average of 3 CU in the MIEX® Effluent (Pilot Plant Effluent), and reduced to an average of 1 CU in MIEX® SSF water (Slow sand filtration of MIEX® Effluent).
- The overall average UVA reduction achieved in the MIEX® Effluent was 82%, where the average raw UVA was 0.072 cm^{-1} and MIEX® Effluent UVA was 0.013 cm^{-1}. After slow sand filtration the UVA was reduced to an average of 0.014 cm^{-1} or an 83% average reduction.

In summary, the trial results showed that MIEX® Resin Treatment can reduce finished water DOC levels and therefore produce water with a significantly lower potential to form DBPs in the distribution system. Secondary treatment benefits such as true color removal and decreased chlorine usage were also demonstrated with MIEX® Treatment.

APPENDIX A: PILOT OPERATIONAL LOG

Date		Contactor			Regeneration			
	Bed Volumes	Flow	Top Concentration	Bottom Concentration	Tank Concentration	Last Vol. Regenerated	Ave. Volume Dosed	Brine Conductivity
	BV	gpm	%	%	%	%	%	mS/cm
9/8/2011	1000	9.9	1	24	49	23.9	2.1	149
9/9/2011	1000	10.0	1	24	49	23.4	2.1	148
9/10/2011	1000	10.1	1	24	50	25.0	2.1	147
9/11/2011	1000	10.1	1	24	49	24.5	2.1	151
9/12/2011	1000	10.0	1	23	51	26.0	2.1	154
9/13/2011	1000	9.9	1	23	52	25.6	2.1	152
9/14/2011	1000	10.0	1	23	52	25.0	2.1	150
9/15/2011	1000	10.0	1	23	49	24.7	2.1	148
9/16/2011	1000	9.9	1	23	51	26.0	2.1	151
9/17/2011	1000	10.1	1	22	53	25.8	2.1	153
9/18/2011	1000	10.0	1	22	49	23.3	2.1	149
9/19/2011	1000	10.1	1	22	49	25.2	2.1	148
9/20/2011	1000	10.0	1	22	51	27.3	2.1	149
9/21/2011	1000	9.9	1	22	52	27.4	2.1	147
9/22/2011	1000	10.0	1	22	49	24.0	2.1	151
9/23/2011	1000	9.9	1	22	50	24.9	2.1	150
9/24/2011	1000	10.0	1	22	51	25.9	2.1	149
9/25/2011	1000	10.0	1	22	52	25.2	2.1	147
9/26/2011	1000	10.1	1	22	49	24.5	2.1	151
9/27/2011	1000	10.0	1	22	50	24.2	2.1	150
9/28/2011	1000	10.0	1	22	50	26.3	2.1	153
9/29/2011	1000	10.1	1	22	52	24.9	2.1	148
9/30/2011	1000	10.0	1	22	50	23.8	2.1	151
10/1/2011	1400	12.1	1	22	48	22.9	2.1	153
10/2/2011	1400	12.0	1	22	52	26.1	2.1	149
10/3/2011	1400	12.0	1	22	51	25.5	2.1	152
10/4/2011	1400	12.2	1	22	50	24.2	2.1	151
10/5/2011	1400	12.0	1	22	52	25.0	2.1	149
Average		**10.4**	**0**	**22.5**	**50**	**25.0**	**2.10**	**150**

APPENDIX B: WATER QUALITY ANALYSIS

Date	Time	Water Quality																					
		Aquacheck DOC (mg/L)				UVA (1/cm)						True Color (CU)						Aquacheck Color (CU)				Apparent Color (CU)	
		Raw	MIEX	Plant	SF #1	Raw	MIEX	Plant	SF #1	SF #2	SF #3	Raw	MIEX	Plant	SF #1	SF #2	SF #3	Raw	MIEX	Plant	SF #1	Raw	MIEX
9/8/11	14:30	2.1	0.5	1.6		0.069	0.011	0.042	0.050	0.006	0.036	8	1	3	3			33	30	<1		68	61
9/9/11	16:15	2.3	0.6	1.7		0.077	0.016	0.043	0.010	0.007	0.038	13	5	5				34	33	<1		61	50
9/10/11	12:45	2.4	0.6	1.8		0.074	0.010	0.043	0.005	0.008	0.039	13	5	3	0	0	3	14	<1	<1		51	41
9/11/11	15:30	2.3	0.7	1.8		0.069	0.006	0.043	0.002	0.008	0.038	11	3	4	0	1	4	28	21	5		41	35
9/12/11	14:00	2.2	0.7	1.7		0.070	0.012	0.045	0.010	0.010	0.039	11	3	5	0	0	2	38	36	21		35	28
9/13/11	14:00	2.8		1.7	0.5	0.067	0.007	0.046	0.007	0.013	0.035	10	3	6	0	0	3	33	30		26	31	23
9/14/11	12:00	2.3	0.7	1.7		0.067	0.010	0.046	0.008	0.017	0.042	13	6	7	1	3	5	1	<1	<1		35	28
9/15/11	11:00	2.3			0.5	0.072	0.016	0.045	0.007	0.012	0.040	9	3	4	0	0	3	15			<1	49	45
9/16/11	11:30	2.3		1.7	0.5	0.077	0.010	0.048	0.013	0.018	0.040	13	3	6	3	2	4	46		<1	<1	61	52
9/17/11	11:15	2.3	0.5	2.0		0.080	0.015	0.052	0.010	0.021	0.046	13	4	6	2	3	5	28	26	2		53	42
9/18/11																							
9/19/11	11:00	2.2	0.6	1.8		0.069	0.011	0.051	0.007	0.013	0.031	10	4	6	2	2	4	14	<1	<1		40	31
9/20/11	14:30	2.2		1.7	1.0	0.070	0.013	0.049	0.015	0.011	0.036	10	4	6	2	3	4	10		1	<1	36	28
9/21/11	15:15	2.4	1.3	1.9		0.073	0.014	0.055	0.017	0.015	0.045	11	4	8	2	1	5	18	<1	<1		34	27
9/22/11	14:15	2.4		2.0	1.4	0.068	0.012	0.052	0.017	0.015	0.037	9	2	6	2	2	3	30		5	<1	31	23
9/23/11	12:00	2.3	1.0	1.9		0.073	0.011	0.050	0.014	0.014	0.039	11	4	6	2	2	4	5	<1	<1		28	22
9/24/11	11:30	2.3		1.8	1.2	0.069	0.014	0.051	0.013	0.014	0.037	7	1	5	0	0	2	33		<1	<1	24	17
9/25/11	7:30	2.3	1.1	1.8		0.080	0.017	0.065	0.021	0.019	0.046							12	10	<1			
9/26/11	7:00	2.3		1.9	1.0	0.067	0.023	0.039	0.020	0.017	0.036							1		<1	<1		
9/27/11		2.4	1.1	1.9		0.056	0.015	0.046	0.014	0.017	0.020							28	<1	<1			
9/28/11		2.5		1.9	0.9	0.061	0.016	0.050	0.011	0.010	0.024							20		<1	<1		
9/29/11	14:25	2.4		1.9	1.0	0.077	0.010	0.054	0.008	0.016	0.035	11	3	7	2	2	4	10		<1	<1	28	19
9/30/11	14:15	2.5	1.1	2.0		0.075	0.012	0.054	0.006	0.018	0.040	13	2	7	1	3	5	32	<1	<1		34	23
10/1/11	11:30	2.4		2.0	0.9	0.078	0.012	0.054	0.009	0.022	0.041	9	1	5	0	0	2	<1		<1	<1	26	18
10/2/11	17:00	2.5	1.3	2.0		0.074	0.009	0.054	0.034	0.016	0.037	11	2	6	5	5	3	24	<1	<2		25	18
10/3/11	12:00	2.5		1.9	1.3	0.074	0.011	0.054	0.020	0.017	0.044	10	3	7	4	2	6	20		7	18	24	15
10/4/11	13:00	2.6	1.0	1.9		0.082	0.019	0.054	0.013	0.019	0.045	11	3	6	1	2	4	47	30	29		27	20
10/5/11	6:30	2.6		2.0	1.0	0.078	0.012	0.056	0.009	0.017	0.046	11	2	6	1	1	3	32	40		32	27	20
Average		**2.37**	**0.85**	**1.85**	**0.93**	**0.072**	**0.013**	**0.050**	**0.012**	**0.014**	**0.038**	**11**	**3**	**6**	**1**	**2**	**4**	**23**	**28**	**10**	**25**	**38**	**30**

Date	Time	Water Quality												Notes
		Turbidity (NTU)						pH						
		Raw	MIEX	Plant	SF #1	SF #2	SF #3	Raw	MIEX	Plant	SF #1	SF #2	SF #3	
9/8/11	14:30	6.72	7.50	0.118	0.960	0.213	0.164							1000 BV, SF #1 on Raw Feed
9/9/11	16:15	5.60	5.51	0.217	0.120	0.151	0.144							1000 BV, SF #1 on MIEX Feed
9/10/11	12:45	4.98	4.96	0.075	0.140	0.240	0.125							1000 BV
9/11/11	15:30	3.55	3.86	0.064	0.093	0.181	0.137							1000 BV
9/12/11	14:00	2.92	2.90	0.073	0.078	0.117	0.096							1000 BV
9/13/11	14:00	2.29	2.22	0.076	0.076	0.111	0.095		7.35	7.33				1000 BV
9/14/11	12:00	2.75	2.69	0.062	0.074	0.186	0.107							1000 BV
9/15/11	11:00	4.72	4.64	0.115	0.085	0.112	0.153							1000 BV, SF #1 Stirred after sampling, SF #2 DOC = 0.7
9/16/11	11:30	6.08	5.74	0.074	0.190	0.163	0.125	7.66	7.40	7.33	7.26	7.05	7.08	1000 BV
9/17/11	11:15	4.77	4.67	0.073	0.078	0.228	0.128							1000 BV
9/18/11														1000 BV, Alarm due to low water pressure, MIEX Pilot off for 10 hrs
9/19/11	11:00	3.33	3.10	0.092	0.075	0.158	0.135							1000 BV
9/20/11	14:30	2.85	2.74	0.072	0.088	0.258	0.113							1000 BV
9/21/11	15:15	2.72	2.46	0.070	0.176	0.147	0.162							1000 BV
9/22/11	14:15	2.37	2.33	0.112	0.158	0.355	0.214							1000 BV
9/23/11	12:00	2.02	2.04	0.073	0.110	0.112	0.142							1000 BV
9/24/11	11:30	2.14	1.93	0.101	0.096	0.142	0.094							1000 BV
9/25/11	7:30	1.91	1.74	0.075	0.084	0.121	0.097							1000 BV
9/26/11	7:00	2.11	2.17	0.114	0.110	0.151	0.148							1000 BV
9/27/11		2.46	2.41	0.081	0.221	0.114	0.174							1000 BV
9/28/11		2.37	2.29	0.077	0.171	0.149	0.108							1000 BV
9/29/11	14:25	1.77	1.72	0.087	0.079	0.097	0.113	7.67	7.58	7.56	7.52			1000 BV
9/30/11	14:15	1.98	1.97	0.101	0.074	0.120	0.110							1000 BV
10/1/11	11:30	1.91	2.00	0.128	0.103	0.130	0.112							1400 BV
10/2/11	17:00	1.53	1.70	0.080	0.076	0.323	0.099							1400 BV, High Flow Shutdown Alarm at 10PM 10/1, Reset at 4:30PM 10/2
10/3/11	12:00	1.43	1.31	0.074	0.130	0.108	0.172	7.57	7.50	7.40	7.35	7.15	7.09	1400 BV
10/4/11	13:00	1.86	1.84	0.064	0.109	0.148	0.100	7.62	7.58	7.48	7.43	7.27	7.20	1400 BV
10/5/11	6:30	1.91	2.02	0.068	0.106	0.117	0.136							1400 BV
Average		**3.00**	**2.98**	**0.089**	**0.112**	**0.165**	**0.130**	**7.63**	**7.48**	**7.42**	**7.39**	**7.16**	**7.12**	

Note:

Water samples used for SDS 24 hour demand testing are indicated by the yellow highlighted values. The green highlighted values indicate water used for SDS testing and DBP analysis.

APPENDIX C: SDS Results and DBP Data

Date Dosed	Date Sampled	ID	BV	Jar #	Temp	pH	UVA (1/cm)	DOC (mg/L)	Turbidity (NTU)	Chlorine Dose (mL)	Chlorine Dose (mg/L)	Free Chlorine Residual (mg/L)	Chlorine Demand (mg/L)	CL2 Demand ppm / DOC ppm	Sampled for DBPs
9/12/11	9/13/11	Clearwell		1	19		0.045	1.70	0.073	4.00	4.7	1.66	3.05	1.8	
9/12/11	9/13/11	Clearwell		2	19		0.045	1.70	0.073	4.50	5.3	>2.20			
9/12/11	9/13/11	Clearwell		3	19		0.045	1.70	0.073	5.00	5.9	n/m			
9/12/11	9/13/11	MIEX	1000	4	19		0.010		0.078	2.00	2.4	1.45	0.90		
9/12/11	9/13/11	MIEX	1000	5	19		0.010		0.078	2.50	2.9	1.87	1.07		
9/12/11	9/13/11	MIEX	1000	6	19		0.010		0.078	3.00	3.5	>2.20			
9/13/11	9/16/11	Clearwell #1		1	19	7.33	0.046	1.70	0.073	3.75	4.4	1.54	2.87	1.7	X
9/13/11	9/16/11	Clearwell #1		2	19	7.33	0.046	1.70	0.073	4.00	4.7	1.75	2.96	1.7	
9/13/11	9/16/11	Clearwell #1		3	19	7.33	0.046	1.70	0.073	4.25	5.0	n/m			
9/13/11	9/16/11	MIEX #1	1000	4	19	7.35	0.007	0.50	0.078	2.00	2.4	1.36	0.99	2.0	X
9/13/11	9/16/11	MIEX #1	1000	5	19	7.35	0.007	0.50	0.078	2.25	2.6	1.67	0.98	2.0	
9/13/11	9/16/11	MIEX #1	1000	6	19	7.35	0.007	0.50	0.078	2.50	2.9	n/m			
9/16/11	9/19/11	Clearwell #2		1	19	7.33	0.048	1.70	0.074	3.25	3.8	1.34	2.49	1.5	X
9/16/11	9/19/11	Clearwell #2		2	19	7.33	0.048	1.70	0.074	3.50	4.1	1.55	2.57	1.5	
9/16/11	9/19/11	Clearwell #2		3	19	7.33	0.048	1.70	0.074	3.75	4.4	n/m			
9/16/11	9/19/11	MIEX #2	1000	4	19	7.26	0.013	<0.5	0.190	1.50	1.8	1.14	0.63		X
9/16/11	9/19/11	MIEX #2	1000	5	19	7.26	0.013	<0.5	0.190	1.75	2.1	1.45	0.61		
9/16/11	9/19/11	MIEX #2	1000	6	19	7.26	0.013	<0.5	0.190	2.00	2.4	n/m			

Date Dosed	Date Sampled	ID	BV	Jar #	Temp	pH	UVA (1/cm)	DOC (mg/L)	Turbidity (NTU)	Chlorine Dose (mL)	Chlorine Dose (mg/L)	Free Chlorine Residual (mg/L)	Chlorine Demand (mg/L)	CL2 Demand ppm / DOC ppm	Sampled for DBPs
9/16/11	9/19/11	SF #2 - 1		7	19	7.05	0.018		0.163	2.00	2.4	1.00	1.35		X
9/16/11	9/19/11	SF #2 - 1		8	19	7.05	0.018		0.163	2.50	2.9	1.47	1.47		
9/16/11	9/19/11	SF #2 - 1		9	19	7.05	0.018		0.163	3.00	3.5	n/m			
9/16/11	9/19/11	SF #3 -1		10	19	7.08	0.040		0.125	3.00	3.5	1.70	1.83		X
9/16/11	9/19/11	SF #3 -1		11	19	7.08	0.040		0.125	3.25	3.8	1.81	2.02		
9/16/11	9/19/11	SF #3 -1		12	19	7.08	0.040		0.125	3.50	4.1	n/m			
9/29/11	10/2/11	Clearwell #3		1	19	7.56	0.054	1.90	0.087	2.75	3.2	0.92	2.32	1.2	
9/29/11	10/2/11	Clearwell #3		2	19	7.56	0.054	1.90	0.087	3.00	3.5	1.19	2.34	1.2	X
9/29/11	10/2/11	Clearwell #3		3	19	7.56	0.054	1.90	0.087	3.25	3.8	n/m			
9/29/11	10/2/11	MIEX #3	1000	4	19	7.52	0.008	1.00	0.079	1.25	1.5	0.78	0.69	0.7	
9/29/11	10/2/11	MIEX #3	1000	5	19	7.52	0.008	1.00	0.079	1.50	1.8	1.02	0.75	0.7	
9/29/11	10/2/11	MIEX #3	1000	6	19	7.52	0.008	1.00	0.079	1.75	2.1	1.19	0.87	0.9	X
10/3/11	10/6/11	Clearwell #4		1	19	7.4	0.054	1.90	0.074	3.00	3.5	1.11	2.42	1.3	X
10/3/11	10/6/11	Clearwell #4		2	19	7.4	0.054	1.90	0.074	3.25	3.8	1.35	2.48	1.3	
10/3/11	10/6/11	MIEX #4	1400	5	19	7.35	0.020	1.30	0.130	2.00	2.4	1.26	1.09	0.8	X
10/3/11	10/6/11	MIEX #4	1400	6	19	7.35	0.020	1.30	0.130	2.25	2.6	1.56	1.09	0.8	
10/3/11	10/6/11	SF #2 - 2		7	19	7.15	0.017		0.108	2.00	2.4	1.43	0.92		X
10/3/11	10/6/11	SF #2 - 2		8	19	7.15	0.017		0.108	2.25	2.6	1.58	1.07		
10/3/11	10/6/11	SF #2 - 2		9	19	7.15	0.017		0.108	2.50	2.9	1.88	1.06		
10/3/11	10/6/11	SF #3 -2		10	19	7.09	0.044		0.172	2.25	2.6	1.02	1.63		
10/3/11	10/6/11	SF #3 -2		11	19	7.09	0.044		0.172	2.50	2.9	1.12	1.82		
10/3/11	10/6/11	SF #3 -2		12	19	7.09	0.044		0.172	2.75	3.2	1.26	1.98		X

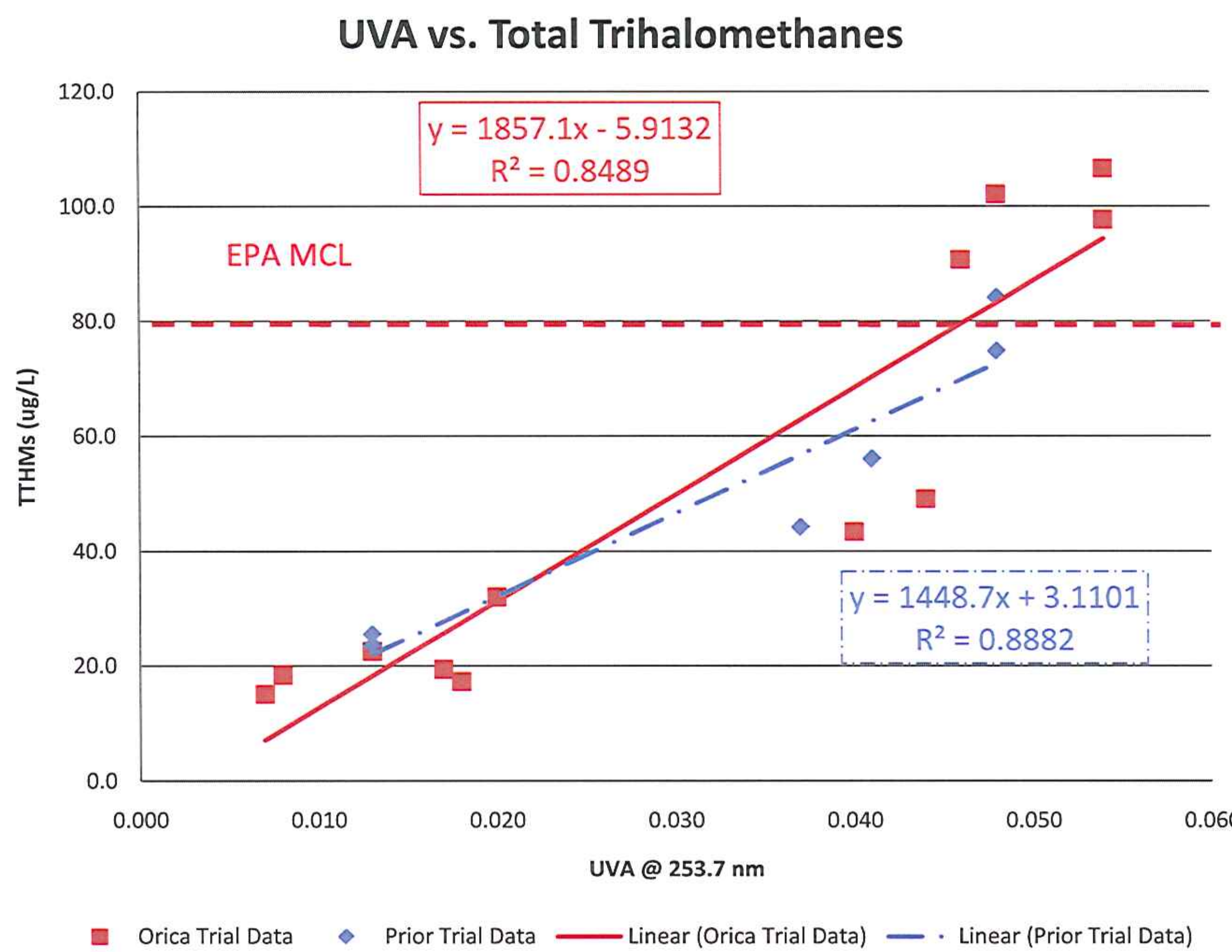
DBP Results

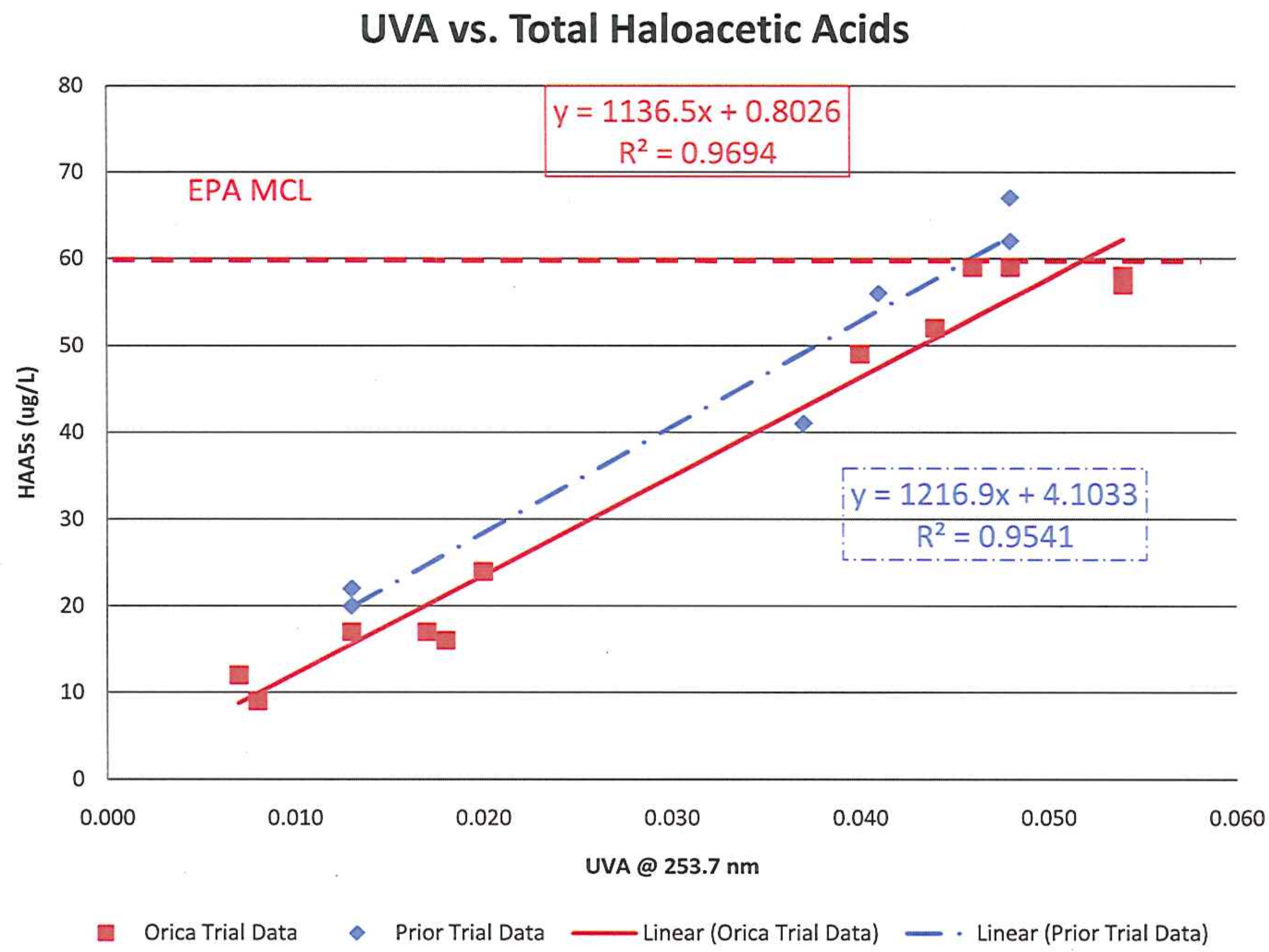
Date Dosed	Date Sampled	ID	BV	Temp	pH	UVA (1/cm)	DOC (mg/L)	Turbidity (NTU)	Chlorine Dose (mg/L)	Free Chlorine Residual (mg/L)	Chlorine Demand (mg/L)	3 Day TTHM	3 Day HAA5	TTHM Yield	HAA5 Yield
9/13/11	9/16/11	Clearwelll #1		19	7.33	0.046	1.70	0.073	4.41	1.54	2.87	90.7	59	53.4	34.7
9/16/11	9/19/11	Clearwell #2		19	7.33	0.048	1.70	0.074	3.83	1.34	2.49	102.1	59	60.1	34.7
9/29/11	10/2/11	Clearwell #3		19	7.56	0.054	1.90	0.087	3.53	1.19	2.34	106.6	58	56.1	30.5
10/3/11	10/6/11	Clearwell #4		19	7.40	0.054	1.90	0.074	3.53	1.11	2.42	97.7	57	51.4	30.0
AVERAGE				**19**	**7.41**	**0.051**	**1.80**	**0.077**	**3.83**	**1.30**	**2.53**	**99.3**	**58**	**55.2**	**32.5**
9/13/11	9/16/11	MIEX #1	1000	19	7.35	0.007	0.50	0.078	2.35	1.36	0.99	15.1	12	30.2	24.0
9/16/11	9/19/11	MIEX #2	1000	19	7.26	0.013	<.5	0.190	1.77	1.14	0.63	22.5	17		
9/29/11	10/2/11	MIEX #3	1000	19	7.52	0.008	1.00	0.079	2.06	1.19	0.87	18.4	9	18.4	9.0
10/3/11	10/6/11	MIEX #4	1400	19	7.35	0.020	1.30	0.130	2.35	1.26	1.09	32.0	24	24.6	18.5
AVERAGE				**19**	**7.37**	**0.012**	**0.93**	**0.11925**	**2.13**	**1.24**	**0.90**	**22.0**	**16**	**24.4**	**17.2**
9/16/11	9/19/11	SF #2 - 1		19	7.05	0.018		0.163	2.35	1.00	1.35	17.3	16		
10/3/11	10/6/11	SF #2 - 2		19	7.15	0.017		0.108	2.35	1.43	0.92	19.4	17		
AVERAGE				**19**	**7.10**	**0.018**		**0.136**	**2.35**	**1.22**	**1.14**	**18.4**	**17**		
9/16/11	9/19/11	SF #3 -1		19	7.08	0.040		0.125	3.53	1.70	1.83	43.4	49		
10/3/11	10/6/11	SF #3 -2		19	7.09	0.044		0.172	3.24	1.26	1.98	49.1	52		
AVERAGE				**19**	**7.09**	**0.042**		**0.149**	**3.38**	**1.48**	**1.90**	**46.3**	**51**		

DBP Results (June and August 2011)

Date Dosed	Date Sampled	ID	BV	Temp	pH	UVA (1/cm)	DOC (mg/L)	Turbidity (NTU)	Chlorine Dose (mg/L)	Free Chlorine Residual (mg/L)	Chlorine Demand (mg/L)	3 Day TTHM	3 Day HAA5	TTHM Yield	HAA5 Yield
6/19/11	6/22/11	SF #1 - 1				0.048						74.8	62		
6/19/11	6/22/11	SF #2 - 1				0.013						23.6	20		
6/19/11	6/22/11	SF #3 - 1				0.041						56.1	56		
8/3/11	8/6/11	SF #1 - 2				0.048						84.2	67		
8/3/11	8/6/11	SF #2 - 2				0.013						25.5	22		
8/3/11	8/6/11	SF #3 - 2				0.037						44.2	41		

Ultraviolet absorbance at 253.7 nm can potentially be used as an indication to predict disinfection by products. Using simulated distribution system conditions from Table 1, results from Orica Trial Data are compared to previous trial data in the two figures below:


UVA vs. Total Trihalomethanes
y = 1857.1x - 5.9132
R² = 0.8489
EPA MCL
y = 1448.7x + 3.1101
R² = 0.8882
TTHMs (ug/L)
120.0
100.0
80.0
60.0
40.0
20.0
0.0
0.000
0.010
0.020
0.030
0.040
0.050
0.060
UVA @ 253.7 nm
Orica Trial Data
Prior Trial Data
Linear (Orica Trial Data)
Linear (Prior Trial Data)


UVA vs. Total Haloacetic Acids
y = 1136.5x + 0.8026
R² = 0.9694
EPA MCL
y = 1216.9x + 4.1033
R² = 0.9541
HAA5s (ug/L)
80
70
60
50
40
30
20
10
0
0.000
0.010
0.020
0.030
0.040
0.050
0.060
UVA @ 253.7 nm
Orica Trial Data
Prior Trial Data
Linear (Orica Trial Data)
Linear (Prior Trial Data)

APPENDIX D: Aquacheck, Eastern Analytical INC. and Rutland Laboratory Data