Ina Road Wastewater Reclamation Facility Capacity and Effluent Quality Upgrade

Results of Disinfection Byproduct Formation with Free and Sequential Chlorination

PREPARED FOR:	Pima County Regional Wastewater Reclamation Department
PREPARED BY:	Todd Greeley/CH2M HILL
REVIEWED BY:	Barb Engleson/CH2M HILL, Larry Schimmoller/CH2M HILL, Jennifer Phillips/CH2M HILL
DATE:	February 26, 2010
PROJECT NUMBER:	374210

Purpose

This study utilized bench tests to evaluate three disinfection methods for formation of the disinfection byproducts (DBPs) Total Trihalomethanes (TTHM) and N-Nitrosodimethylamine (NDMA). The three methods included free chlorine addition, multiple step addition of free chlorine, and sequential addition of free chlorine and preformed monochloramine. A secondary goal of the bench tests was to compare the efficiency of *E. coli* disinfection among methods.

This memo also includes the results of field observations of the Ina Road WRF East Plant Disinfection process.

Design Criteria

The following section describes the design criteria and assumptions used for testing disinfection methods.

CT Requirement

The Enhanced Chlorination Report recommended a minimum free chlorine CT of 100 mg*min/L at peak day flows to provide sufficient pathogen inactivation.

Contact Times

The volumes of the chlorine contact basins and the theoretical hydraulic retention times are summarized in Table 1.

TABLE 1
Chlorine Contact Basin Volumes
Results of DBP Production with Free and Sequential Chlorination

	Volume (gallons)	Minimum Hour Flow		Average Flow		Peak Day Flow	
		Flow Rate (mgd)	Retention Time (min)	Flow Rate (mgd)	Retention Time (min)	Flow Rate (mgd)	Retention Time (min)
East CCB	350,000	6	85	25	20	35	14
West CCB	500,000	6	121	25	29	35	21
New CCB	1,700,000	12	206	50	49	70	35
Total	2,550,000	12	306	50	73	70	52

Regulatory Requirements

The effluent requirements are summarized in Table 2.

TABLE 2
Effluent Quality Requirements
Results of DBP Production with Free and Sequential Chlorination

	Units	Regulatory Limit
Fecal Coliform		
4 out of 7 samples	cfu / 100 mL	Nondetect
Single sample maximum	cfu / 100 mL	<23
E. Coli		
4 out of 7 samples	cfu / 100 mL	Nondetect
Single sample maximum	cfu / 100 mL	<15
Trihalomethanes		
Total, single sample maximum	ug/L	100 (80 future)[1]
N-Nitrosodimethylamine[2]		
Single sample maximum	ng/L	30

[1] The reporting level is 80% of the regulatory limit.
[2] NDMA is not currently regulated at Ina Road WRF but will be after Upgrade.

Free Chlorine Method

Treatment with free chlorine is expected to have a high rate of disinfection and TTHM production. To achieve a free chlorine residual in the presence of ammonia, 7.6 mg of chlorine are needed to oxidize each 1.0 mg of ammonia-nitrogen.

Step Free Chlorine Method

Free chlorine can be applied in steps to reduce the peak chlorine dose applied. This should maintain a high disinfection rate while potentially slowing TTHM production. The initial free chlorine dose targeted was based on that required to exhaust the initial free chlorine residual after 20-30 minutes. The total CT from both doses should be 100 mg*min/L.

Sequential Chlorination Method

Sequential chlorination includes initially adding chlorine to maintain a free chlorine residual for a short period followed by monochloramine addition to stop TTHM formation and continue disinfection. Sequential chlorination typically results in moderately high disinfection rates while limiting DBP production. Free chlorine residual should be nearly exhausted in the existing basins (20-30 minutes) and provide a CT of 30 mg*min/L. Then a maximum of 5 mg/L preformed monochloramines are added with a ratio of 3.5 Cl_2 : 1 NH_3-N to provide additional disinfection and residual in reuse water.

Bench Testing Results

An unchlorinated secondary effluent sample from the Ina Road WRF East Plant was collected on November 30, 2009 and mailed to the CH2M HILL Applied Sciences Laboratory. Bench scale tests were performed December 1 -2, 2009.

Secondary Effluent Characteristics

The characteristics of the secondary effluent sample are summarized in Table 3. The low ammonia, total suspended solids, and dissolved organic carbon are indicative of good process performance at the time of collection.

TABLE 3
Secondary Effluent Characteristics
Results of DBP Production with Free and Sequential Chlorination

Parameter	Units	Value
Ammonia (average of 3)	mg/L as N	<0.1
pH	units	7.22
Total Suspended Solids (TSS)	mg/L	5.65
Chemical Oxidant Demand (COD)	mg/L	25.0
Total Organic Carbon (TOC)	mg/L	6.29
Dissolved Organic Carbon (DOC)	mg/L	5.76
UV-254 Absorbance	abs*cm-1	0.1503
UV-254 Transmittance (calculated)	%	70.75
Total Coliform (average of 3)	col/100 mL	67,343
E. coli (average of 3)	col/100 mL	4,177

CT Results

The first criterion for each disinfection method is that it must meet the recommended CT of 100 mg*min/L to provide the required biological inactivation, as stated in the Regional Optimization Master Plan Report. Figure 1 shows the total CT over the duration of each free chlorine and step chlorine bench test. A dose of approximately 10 mg/L chlorine was necessary to provide 100 mg*min/L between average and peak day flows using either of these methods.

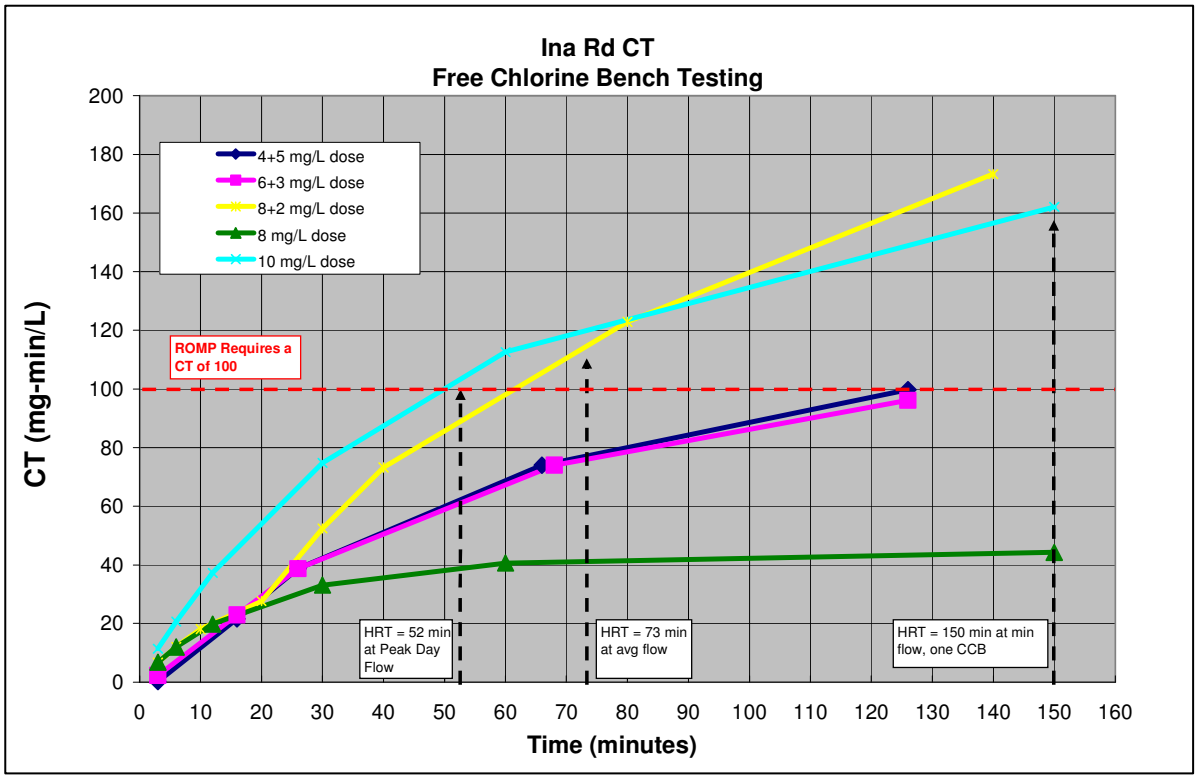

Figure 1: CT for free chlorine and step chlorine bench tests.

For the sequential chlorination tests monochloramine was added when the free chlorine dropped below 1 mg/L. Figure 2 shows the total CT over the duration of each sequential chlorine test. The target free chlorination phase CT of approximately 30 mg*min/L was met with an initial dose of 8 mg/L chlorine. The CT for the sequential chlorination test is high because the monochloramine residual is not as reactive as the free chlorine residual and thus remains in solution for longer periods of time.

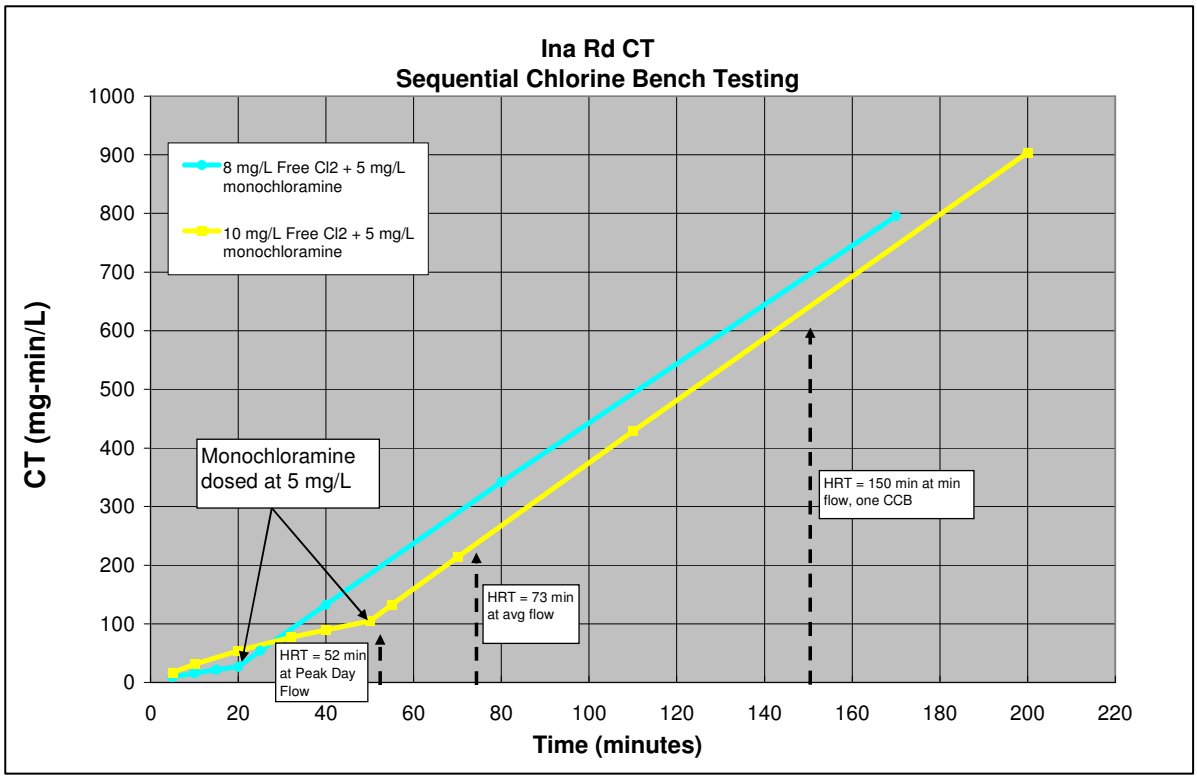

Figure 2: CT for sequential chlorination tests.

Total Trihalomethanes Production

TTHM production from the free chlorine and step chlorine bench tests are summarized in Figure 3. The TTHM concentration never violated current regulatory levels, but the future reporting limit was exceeded near average flows with a dose of 10 mg/L chlorine through free or step addition. Consistently meeting the reporting and regulatory limits at average and minimum flows may be difficult. Process upsets that reduce the secondary effluent quality will make it particularly hard to meet TTHM limits with free chlorine disinfection.

Sequential chlorination resulted in less TTHM formation than using free chlorine alone. The rate of TTHM formation decreased substantially when the monochloramines were added, as illustrated in Figure 4. Using sequential chlorination to limit the free chlorine dose and its contact time was effective in limiting TTHM production and consistent with similar studies conducted at other treatment plants.

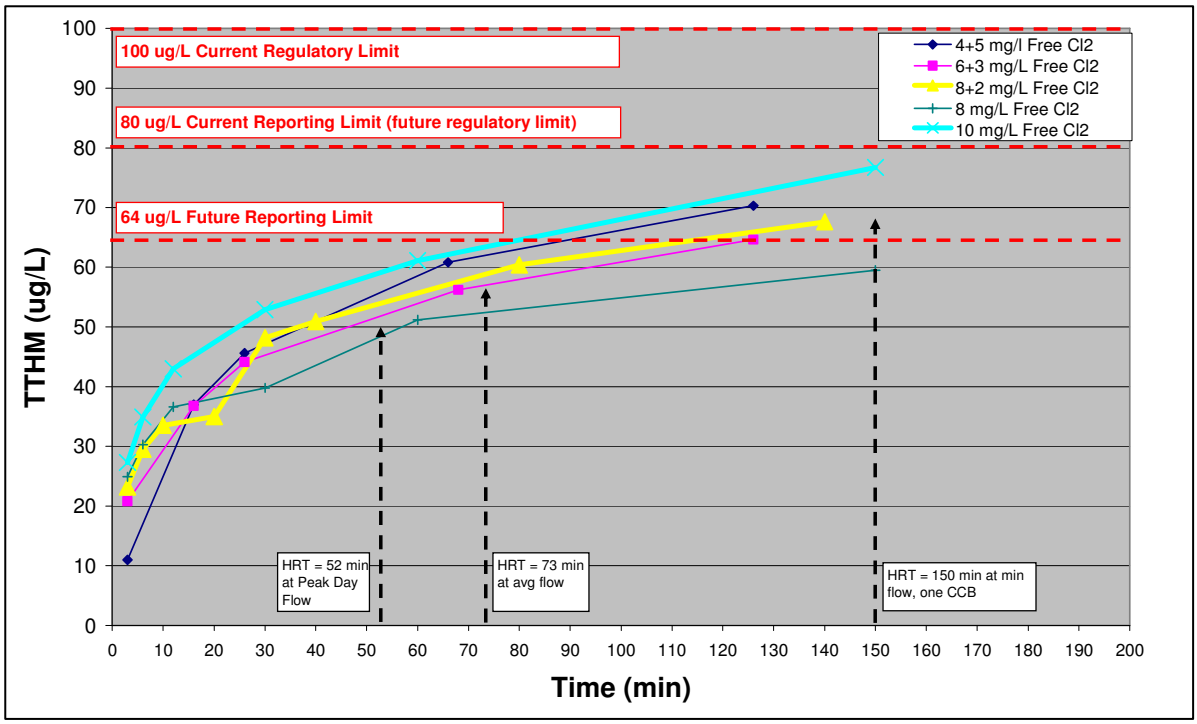

Figure 3: TTHM formation from free chlorine and step chlorine bench tests.

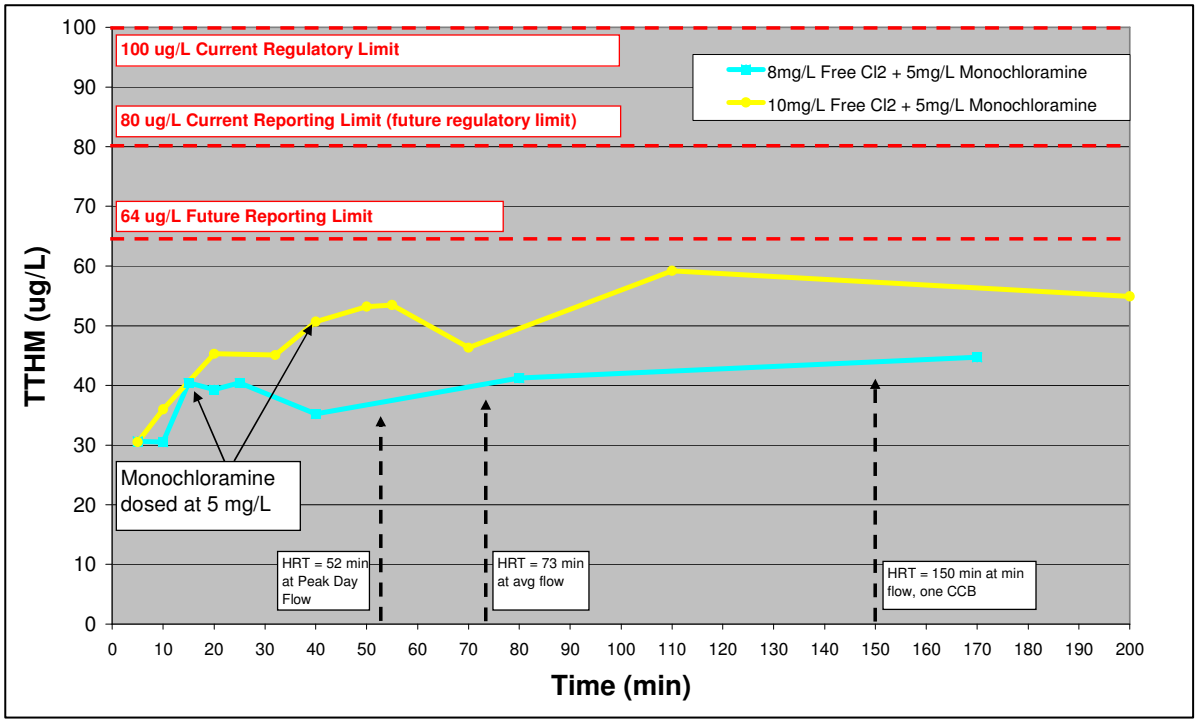

Figure 4: TTHM formation from sequential chlorination bench tests.

NDMA

NDMA was sampled at the middle and end of each bench test. All NDMA concentrations were below the detection limit (1 ng/L). This is consistent with expectations because NDMA is primarily the product of reactions with dichloramine. The free and step chlorine tests had no ammonia to form dichloramine. The sequential chlorination test used preformed monochloramine to avoid dichloramine reactions. If chloramines were formed in the bulk water, some dichloramine and NDMA production would be expected.

E. coli and Total Coliform

In the bench tests sequential chlorination provided the best disinfection, as illustrated in Figure 5. However, this data represents a test on only one grab sample and disinfection efficacy will likely vary with changing water quality in the secondary effluent.

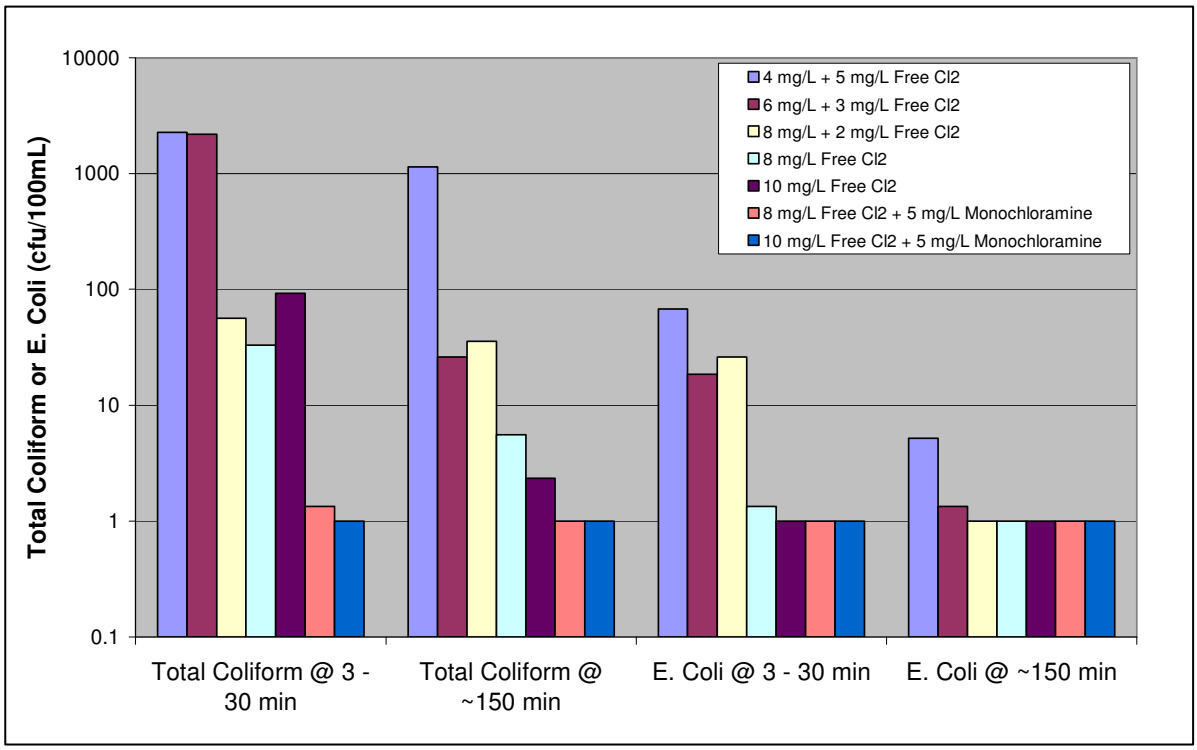

Figure 5: Disinfection results for all bench tests. Times are approximate. A value of 1 is used for nondetects.

Bench Test Conclusions

Free Chlorine and Step Free Chlorine

- It may be difficult to meet the current reporting limit and the future reporting and regulatory limits for TTHM.
- No NDMA formation was observed.
- A free chlorine dose of 10 mg/L was required to achieve a CT of 100 mg*min/L.

Sequential Chlorination

- Sequential chlorination with free chlorine and preformed monochloramine resulted in lower TTHM formation than disinfection with free chlorine alone.
- No NDMA formation was observed.
- For this one bench test, sequential chlorination outperformed free chlorine in inactivating total coliform and *E. coli*.
- A free chlorine dose of 8 mg/L followed by 5 mg/L of preformed monochloramine was adequate to lower TTHM formation. Lower doses may be possible with adequate testing.

East Plant Field Data

Data was collected for the East Plant secondary effluent and disinfection process from December 7, 2009 to January 29, 2010.

There was significant daily variation in the composite ammonia concentration of the East Plant secondary effluent, as illustrated in Figure 6. There was only a loose correlation between composite ammonia concentration and daily flow through the East Plant. Incomplete nitrification may be due to inadequate control of the aeration system to match diurnal oxygen demand conditions.

The secondary effluent ammonia concentration is causing a cycling between free chlorine residual and chloramine residual during disinfection. This cycling is evident from the oxidation-reduction potential (ORP) measurements shown in Figure 7. For clarity, Figure 7 only graphs data from December 7 – 17 but it is representative of the entire observation period. During the evenings there is usually a chloramine residual, as indicated by an ORP near 450 mV. The ORP near 750 mV often seen during the day is characteristic of a free chlorine residual. Due to the retention time of the process basins, the free chlorine residual observed during the day may be a result of good nitrification during night-time flows.

Cycling between free chlorine and chloramine residuals will affect the type of DBPs produced. TTHM form more readily in the presence of a free chlorine residual. Samples collected when operating with a chloramine residual, as indicated by the ORP, ranged from only 11 – 29 ug/L TTHM. Two samples were collected while the contact basin was operated with a free chlorine residual and had TTHM concentrations of 52 and 61 ug/L. This is very close to the future 64 ug/L reporting limit.

No NDMA formation was observed while operating with either free chlorine or chloramines residuals.

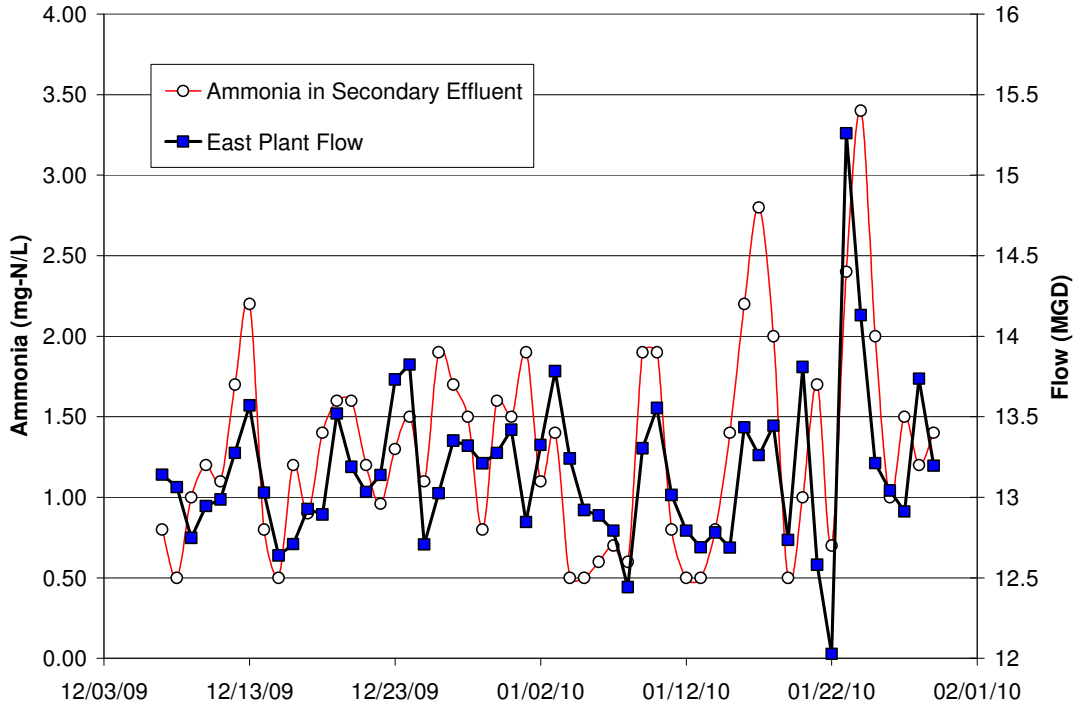

Figure 6: Ammonia concentration in composite secondary effluent samples and daily East Plant flow.

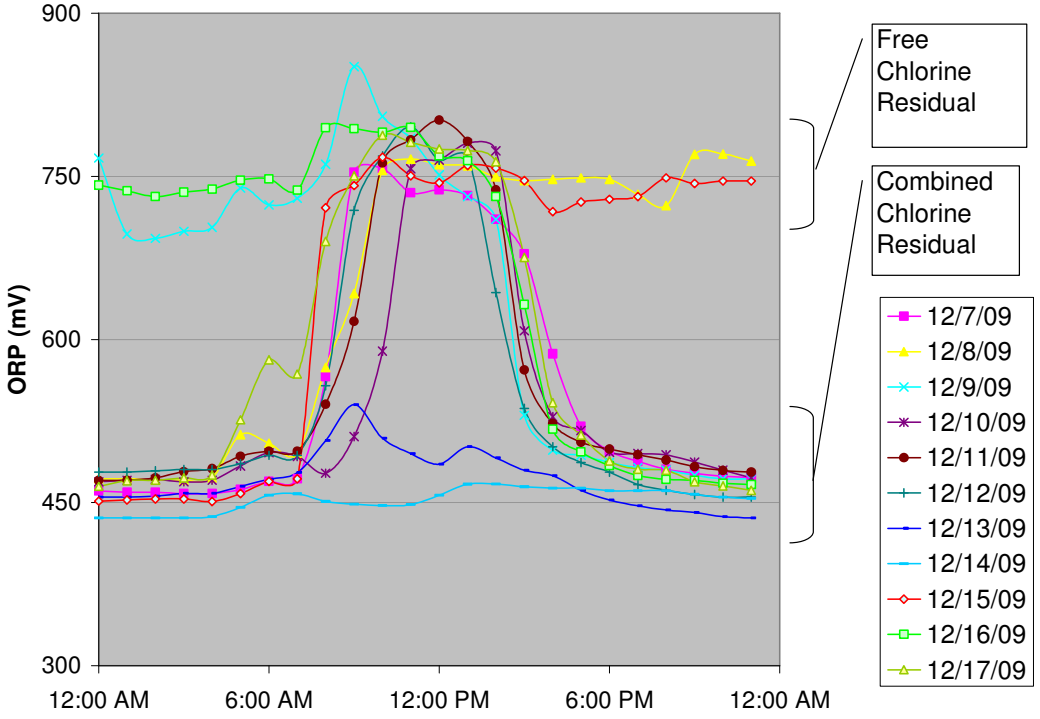

Figure 7: Hourly variation in Oxygen Reduction Potential (ORP).

The current East Plant disinfection process is not consistently meeting the BADCT regulatory requirements for biological inactivation that the Ina Road WRF will be required to achieve after the Upgrade Project is complete. Over the two months of *E. coli* sampling, the single sample maximum was exceeded once and the 4 out of 7 nondetect criterion was met less than 1/3 of the time. The average daily chlorine dose over this period ranged from approximately 4 – 11 mg/L. These observations are summarized in Figure 8.

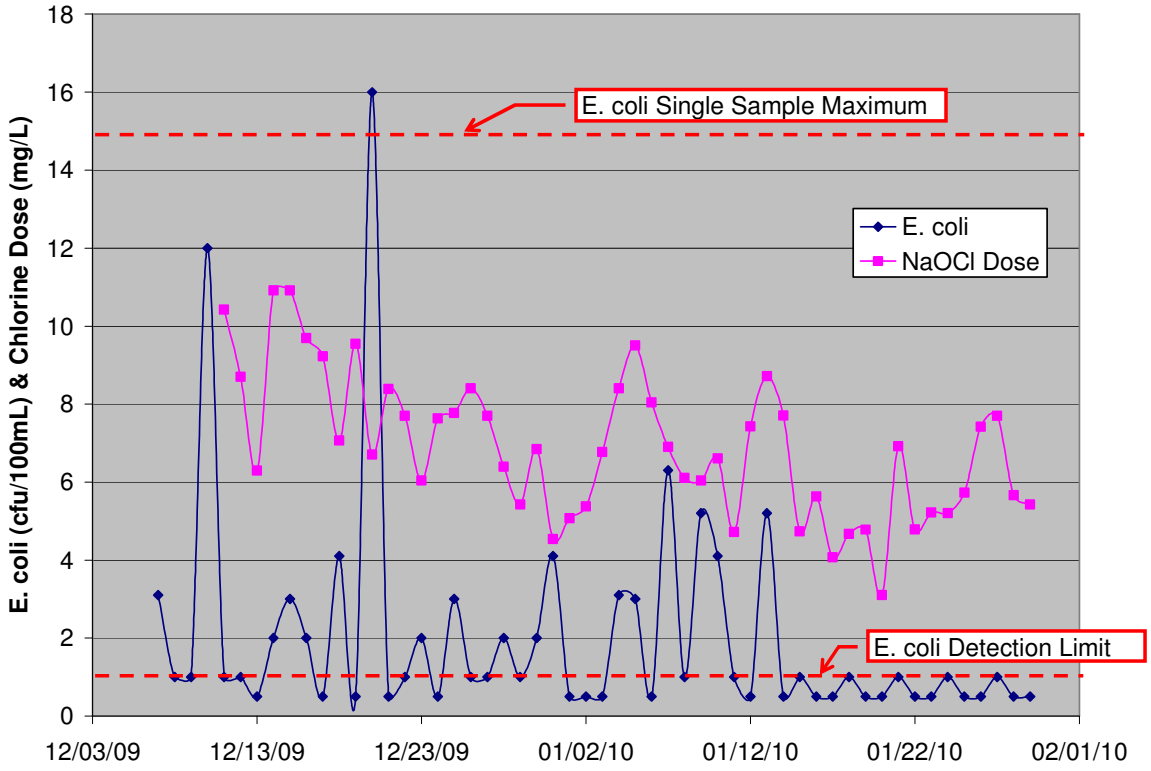

Figure 8: Chlorine dose and final effluent E. coli from East Plant.

Recommendations

Based on the results of this study we recommend proceeding with sequential chlorination for the Ina Road Upgrade design. A schematic of the proposed system is shown in Figure 9.

The system should be sized to provide a free chlorine dose of approximately 4 – 12 mg/L, although the final dose range will be selected during final design. Designing for this dose range would allow sequential chlorination or free chlorine disinfection if desired. The dose will need to be larger if nitrification is incomplete.

Multiple monochloramine application points should be provided to dose approximately 2 – 8 mg/L, although the final dose range will be selected during final design. Availability of multiple dosing locations will allow operators to balance disinfecting power with limiting TTHM production.

Process control of the sequential chlorination process will require control and monitoring of secondary effluent ammonia. Process models of the Upgrade Project treatment process using Biowin indicate secondary effluent ammonia levels varying from 0 – 0.5 mg-N/L.

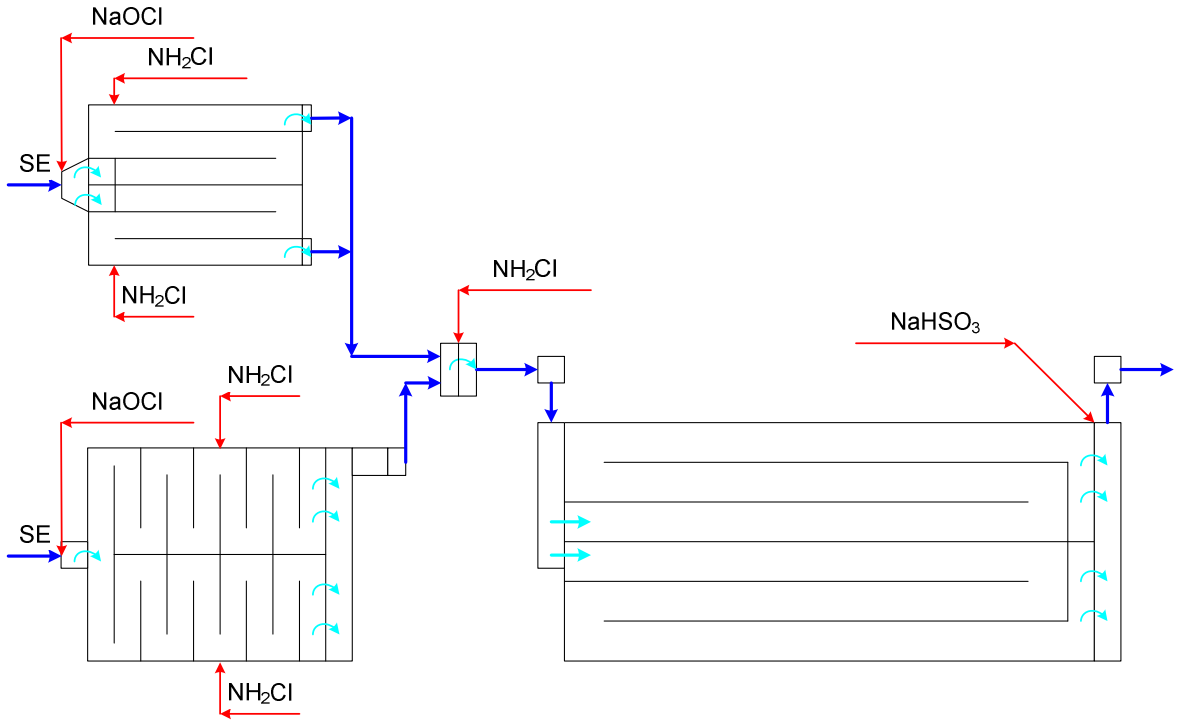

Figure 9: Proposed chemical dosing locations for sequential chlorination.