Evaluation of Disinfection Technologies for the Calumet and North Side Water Reclamation Plants

Technical Memorandum 2

Date: December 21, 2011

To: Disinfection Task Force Advisory Committee

From: Disinfection Task Force

Subject: Historic Plant Flows, Water Quality Data, and Other Test Results

1.0. Purpose

This technical memorandum summarizes historic plant flows, water quality data, and test results for the Calumet and North Side Water Reclamation Plants (WRPs) that are of interest in selecting a disinfection technology for each plant. The data will be used in evaluating disinfection technologies for applications at the two WRPs, such as determining size of facilities and determining the amount of chemicals required.

2.0. Calumet Water Reclamation Plant Data

2.1. Historic Flows

The historical daily average plant flows at the Calumet WRP ranged from 102 to 514 million gallons per day (MGD) from 2005 through 2010. The frequency of the daily average flows during the six years is shown in Figure 1. The frequency of hourly flows from 2006 through 2010 is shown in Figure 2. The highest hourly flow during this time was 550 MGD. Due to limitations of new infrastructure currently being installed at the Calumet WRP, the maximum hourly flow that can be pumped in the future will be 480 MGD. As a result, a maximum flow of 480 MGD and an average flow of 270 MGD will be used when estimating costs of disinfection alternatives at the Calumet WRP.

2.2. Water Quality Data

A summary of water quality parameters of interest from 2005 through 2010 is given in Table 1. The summary includes the ranges, averages, and standard deviations of all the data from the six year period. The ranges, averages, and standard deviations of the data only from the proposed disinfection season, March 1 through November 30, for the six years were also determined, but are not presented here due to their being very similar to the summary of all the

FIGURE 1: FREQUENCY DISTRIBUTION OF DAILY AVERAGE FLOWS AT THE CALUMET WATER RECLAMATION PLANT DURING 2005 THROUGH 2010

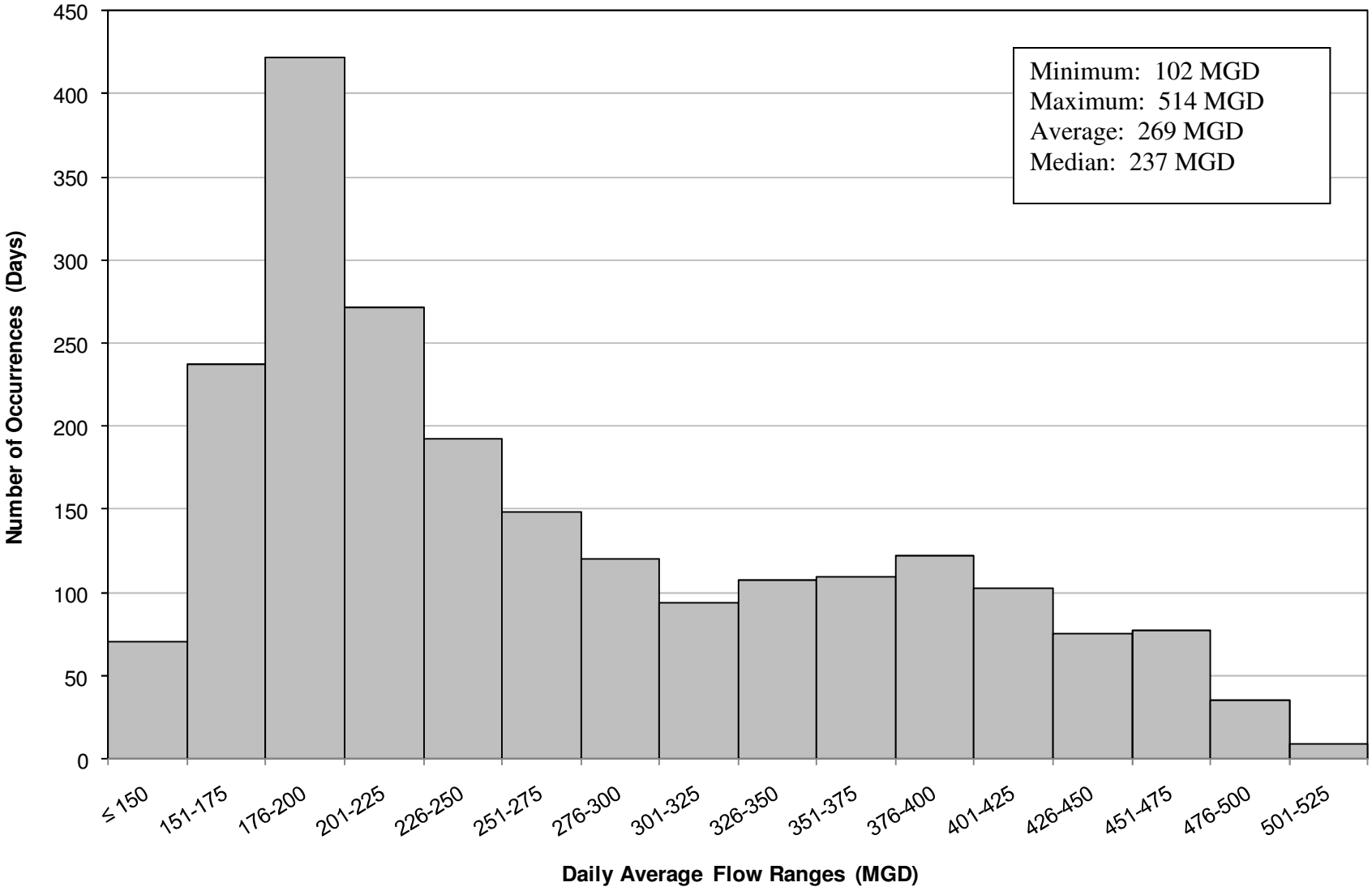


FIGURE 2: FREQUENCY DISTRIBUTION OF HOURLY FLOWS AT THE CALUMET WATER RECLAMATION PLANT DURING 2006 THROUGH 2010

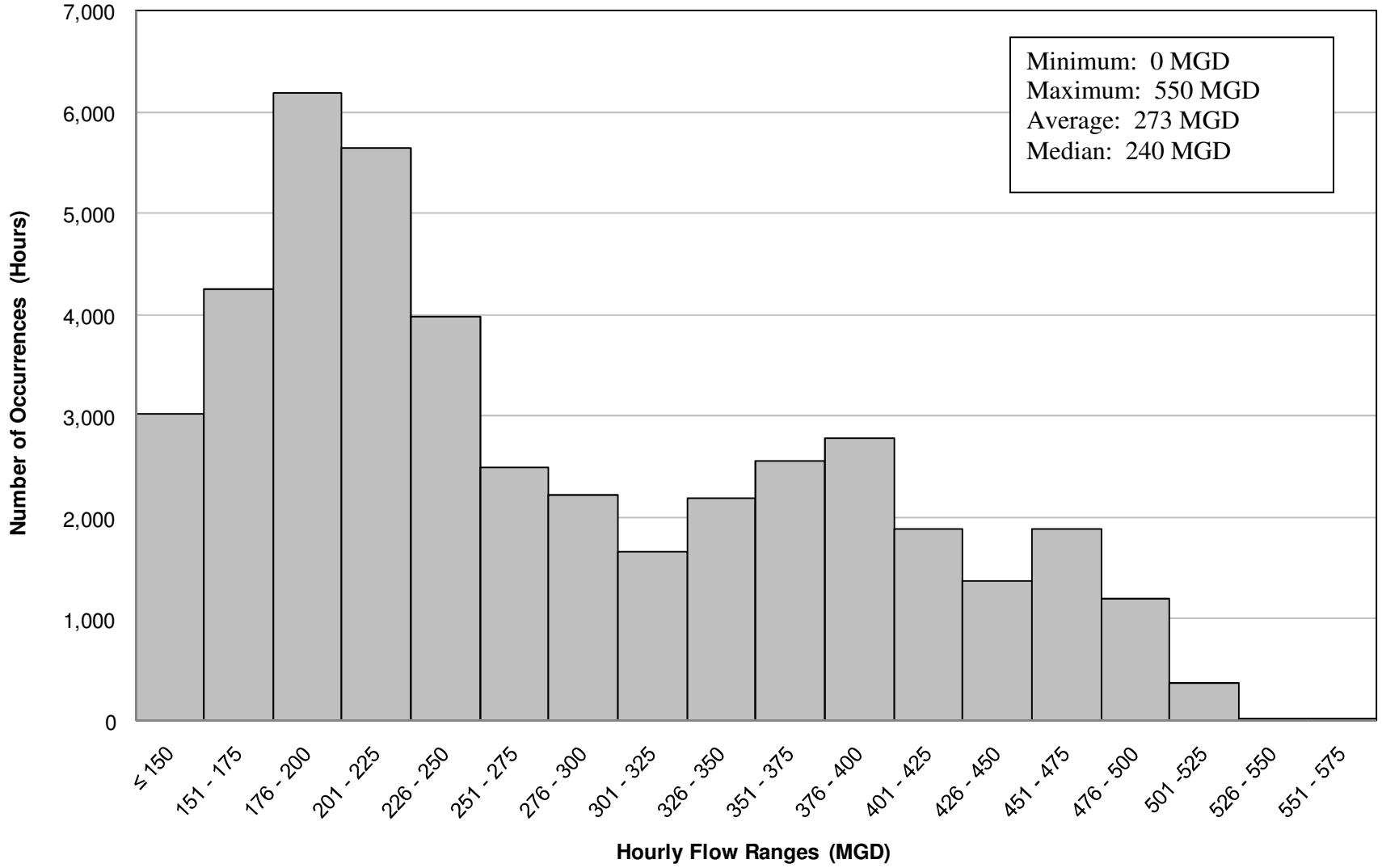


TABLE 1: FINAL EFFLUENT WATER QUALITY AT THE CALUMET WATER RECLAMATION PLANT FROM 2005 THROUGH 2010

Parameter	Minimum	Maximum	Average	Standard Deviation
Ammonia Nitrogen[1] (mg/L)	< 0.02	7.22	0.19	0.35
Suspended Solids[1] (mg/L)	< 2	30	5	2
Total Solids[1] (mg/L)	42	1979	659	288
5-Day Biochemical Oxygen Demand[1] (mg/L)	< 2	16	5	2
Total Organic Carbon[2] (mg/L)	2.6	7.5	5.3	0.9
Nitrate + Nitrite[1] (mg/L)	1.36	18.97	8.50	2.46
pH[1] (pH units)	6.8	7.5	7.1	0.1
Iron, Total[1] (mg/L)	< 0.02	0.97	0.12	0.07
Magnesium, Total[1] (mg/L)	11.3	56.0	25.5	4.5
Calcium[1], Total (mg/L)	33	158	72	12
Hardness[1] (mg/L as $CaCO_3$)	132	624	285	47
Fecal Coliform[3] (CFU/100 mL)	1,600	120,000	9,799	11,139
UV_{254} Transmittance[4] (%)	68.6	76.9	71.9	2.0

[1] Daily composite; measured every day
[2] Daily composite; measured every Tuesday
[3] Grab sample; measured every Monday;
[4] Daily composite; measured every other Thursday in 2006

data. The water quality data are from the routine sampling conducted at the plant. The exception to this is the absorbance data which were from special sampling conducted every two weeks in 2006. The fecal coliform (FC) and ultraviolet (UV) transmittance data are provided in more detail in a later section.

2.3. Fecal Coliform Data

The frequency of FC data from the Calumet WRP during 2005 through 2010 is shown in Figure 3. The FC data were from grab samples collected every Monday during the six year period. During the six years, two out of 313 samples had FC greater than or equal to 100,000 colony forming units (CFU)/100 mL (/100 mL). Figure 4 represents the percent distribution of the log removals that would have been required to meet various disinfection goals using the 2005 through 2010 FC data. The three disinfection goals considered were 200, 100, and 50 CFU/100 mL.

2.4. UV Transmittance Data

UV absorbance at a wavelength of 254 nm and with a 1-cm path length was measured using the plant's daily composite sample once every two weeks during 2006. The UV absorbance was converted to UV transmittance (UVT) and is summarized above in Table 1. Since the 2006 data was limited to only 27 data points and the results were for the daily composite, a UVT sensor was installed in the final effluent of the Calumet WRP. A summary of the available data to date is shown in Figure 5. The UVT will continue to be monitored and an updated summary of the data will be documented.

2.5. UV Dose-Response Data

Collimated beam tests were completed in October 2007 for the Calumet WRP in order to establish a UV dose-response curve. Additional tests were completed in November 2011. Figure 6 shows the resulting FC after irradiating samples with various UV doses from the 2007 and 2011 testing. Figure 7 shows the same results in terms of log inactivation of FC. The UVT and other water quality data from the samples used for each collimated beam test are listed in Table 2. A conservative UV dose typically used when designing UV disinfection systems is 40 mJ/cm^2. The Illinois Environmental Protection Agency requires a minimum of three months of pilot testing if a design UV dose less than 40 mJ/cm^2 is to be used. The collimated beam tests show that a lower dose may be sufficient to meet the proposed FC standard. However, due to the uncertainty of whether or not pilot testing will be completed, a calculated UV dose of 40 mJ/cm^2 will be used for comparing disinfection alternatives.

2.6. PAA Dose-Response Data

Preliminary dose-response testing was conducted by PERAGreen Solutions, the technical support for Proxitane® WW-12, a form of peracetic acid (PAA) manufactured by Solvay Chemicals. The testing was completed on November 16, 2011, in the Monitoring and Research Laboratory at the Stickney WRP. Various concentrations of PAA were added to aliquots of a final effluent sample from the Calumet WRP. The concentrations of PAA added were 2, 3, 5, and 6 mg/L. The PAA was allowed to react for 20 minutes, after which sodium thiosulfate was added to quench the PAA. FC was measured in each aliquot following the 20-minute contact time. Figure 8 shows the preliminary dose-response for PAA using final effluent from the

FIGURE 3: FREQUENCY DISTRIBUTION OF FECAL COLIFORM DATA FROM THE CALUMET WATER RECLAMATION PLANT DURING 2005 THROUGH 2010

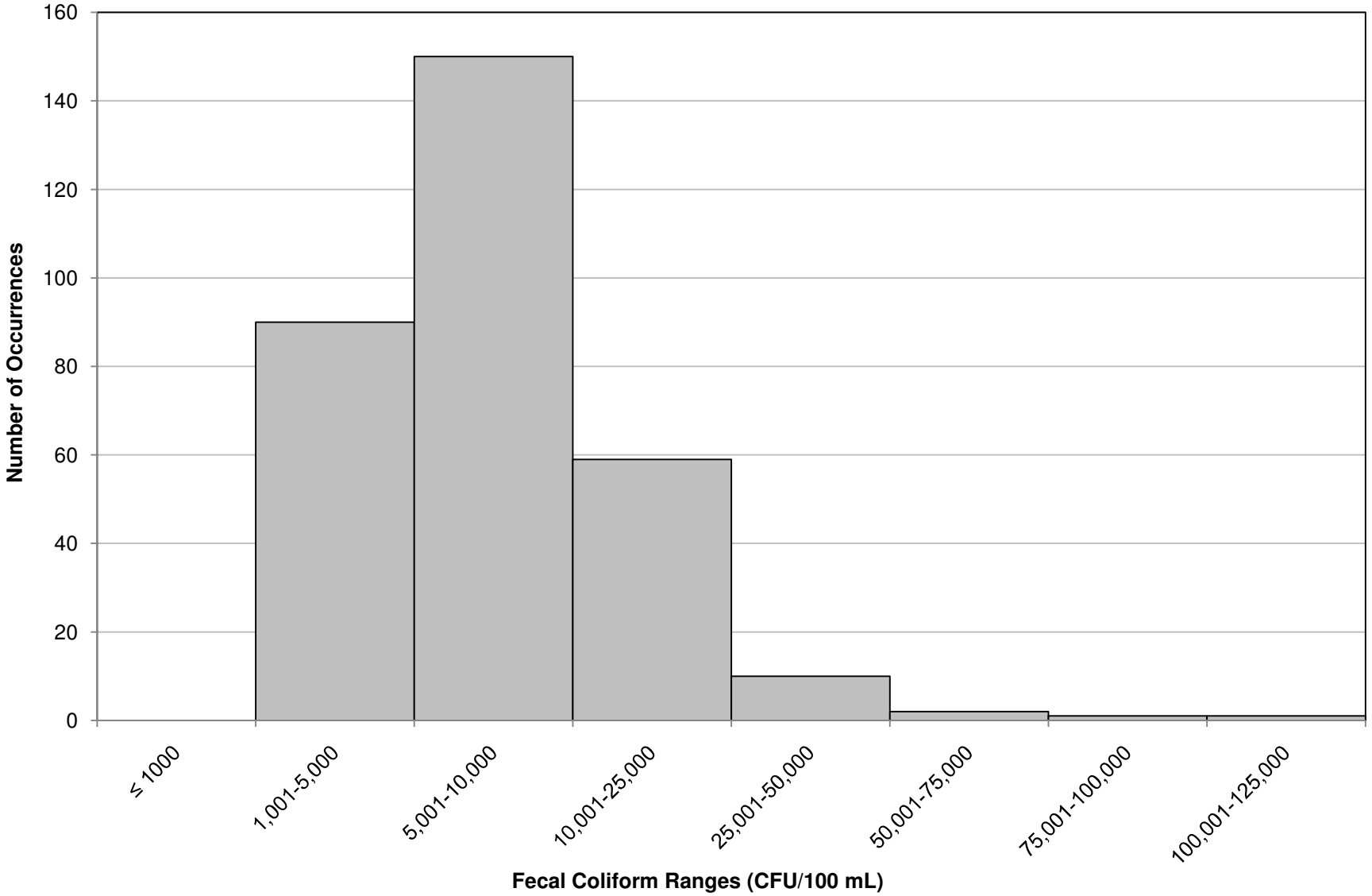


FIGURE 4: PERCENT DISTRIBUTION OF LOG REMOVALS REQUIRED FOR MEETING DISINFECTION GOALS BASED ON FECAL COLIFORM DATA FROM THE CALUMET WATER RECLAMATION PLANT DURING 2005 THROUGH 2010

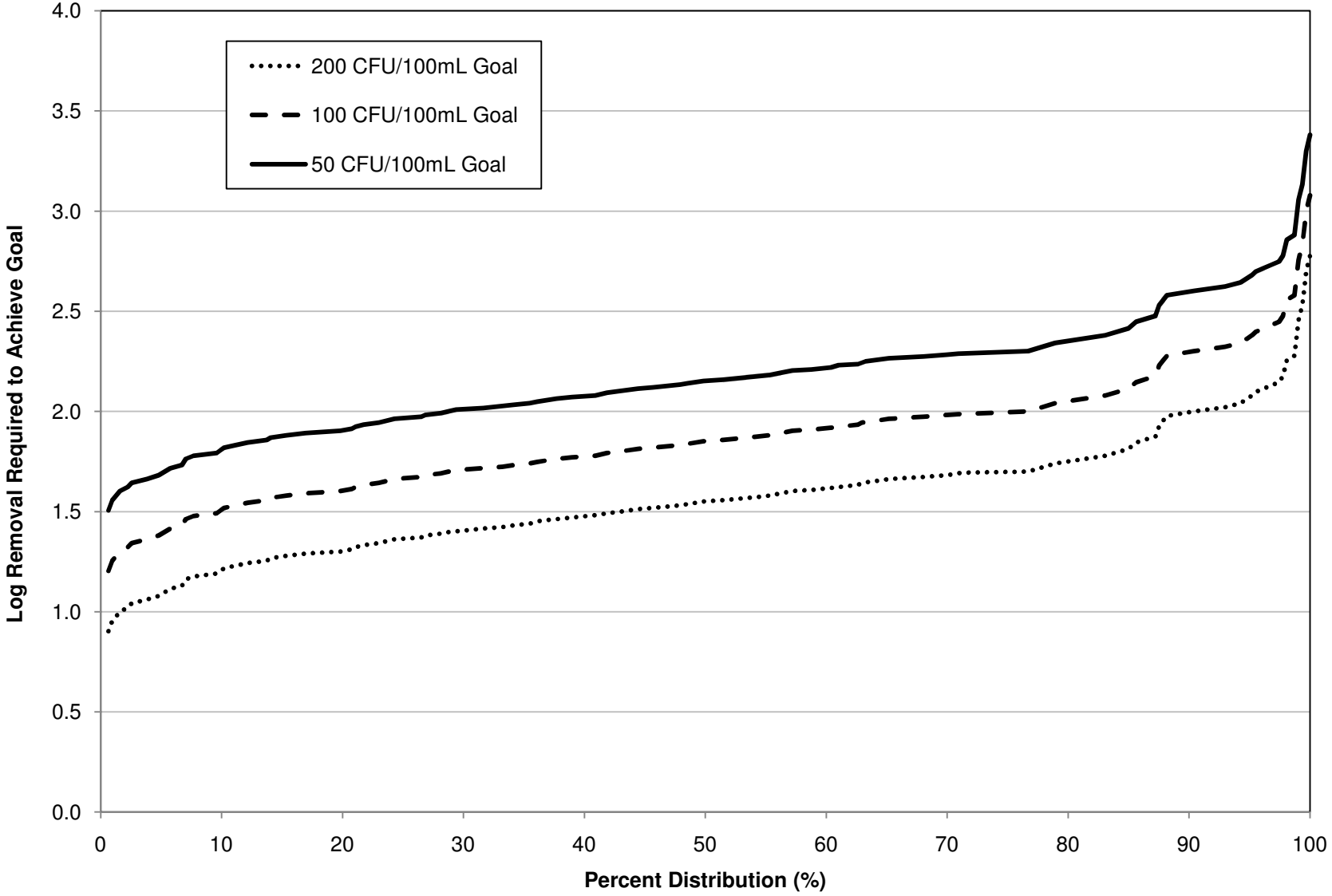


FIGURE 5: FINAL EFFLUENT ULTRAVIOLET TRANSMITTANCE AND HOURLY PLANT FLOW AT THE CALUMET WATER RECLAMATION PLANT FROM 12/3/11 THROUGH 2/1/12

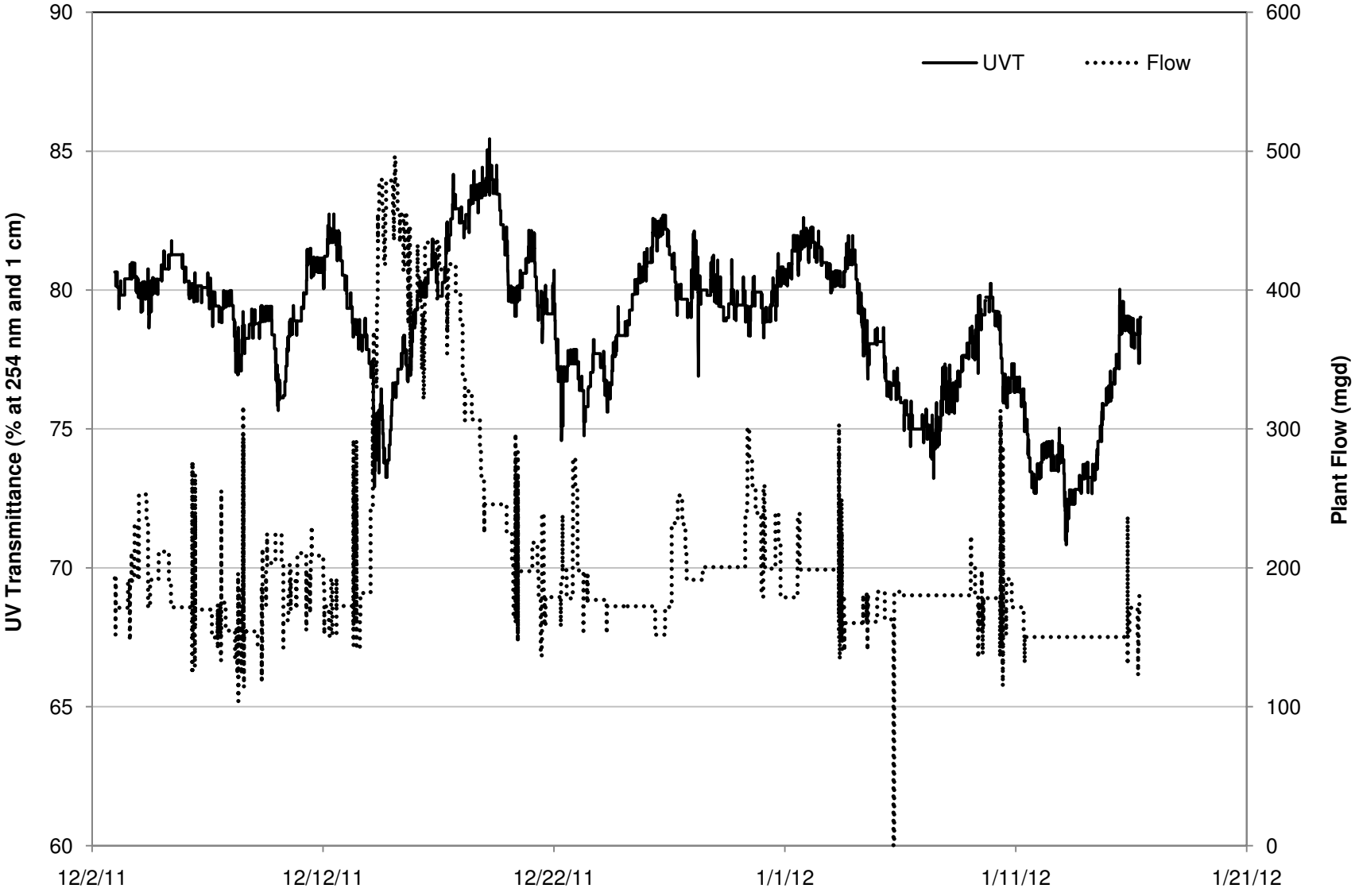


FIGURE 6: FECAL COLIFORM COUNTS AFTER IRRADIATION AT VARIOUS ULTRAVIOLET IRRADIATION DOSES USING FINAL EFFLUENT FROM THE CALUMET WATER RECLAMATION PLANT

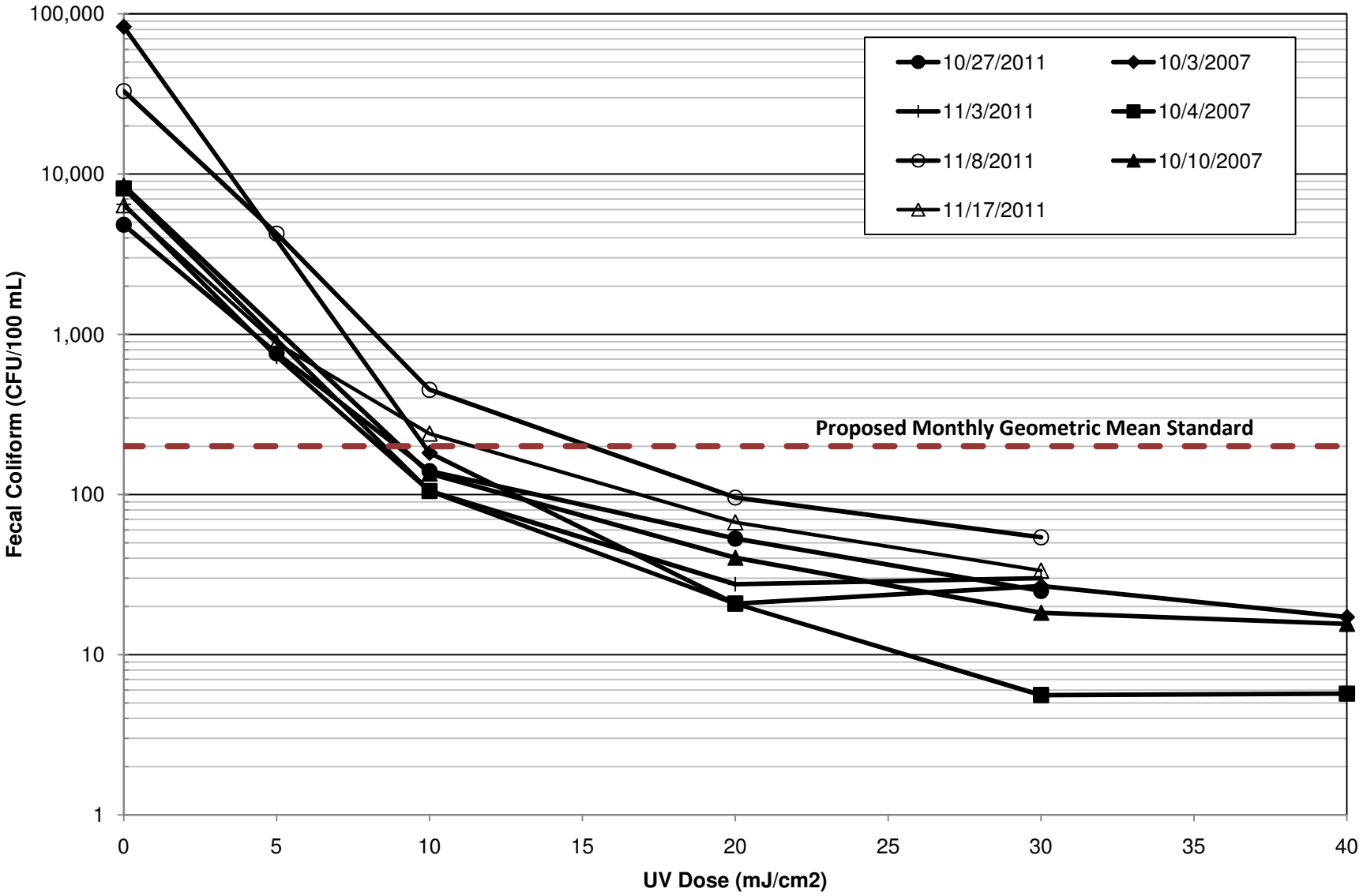


FIGURE 7: LOG INACTIVATION OF FECAL COLIFORM FOR VARIOUS ULTRAVIOLET IRRADIATION DOSES USING FINAL EFFLUENT FROM THE CALUMET WATER RECLAMATION PLANT

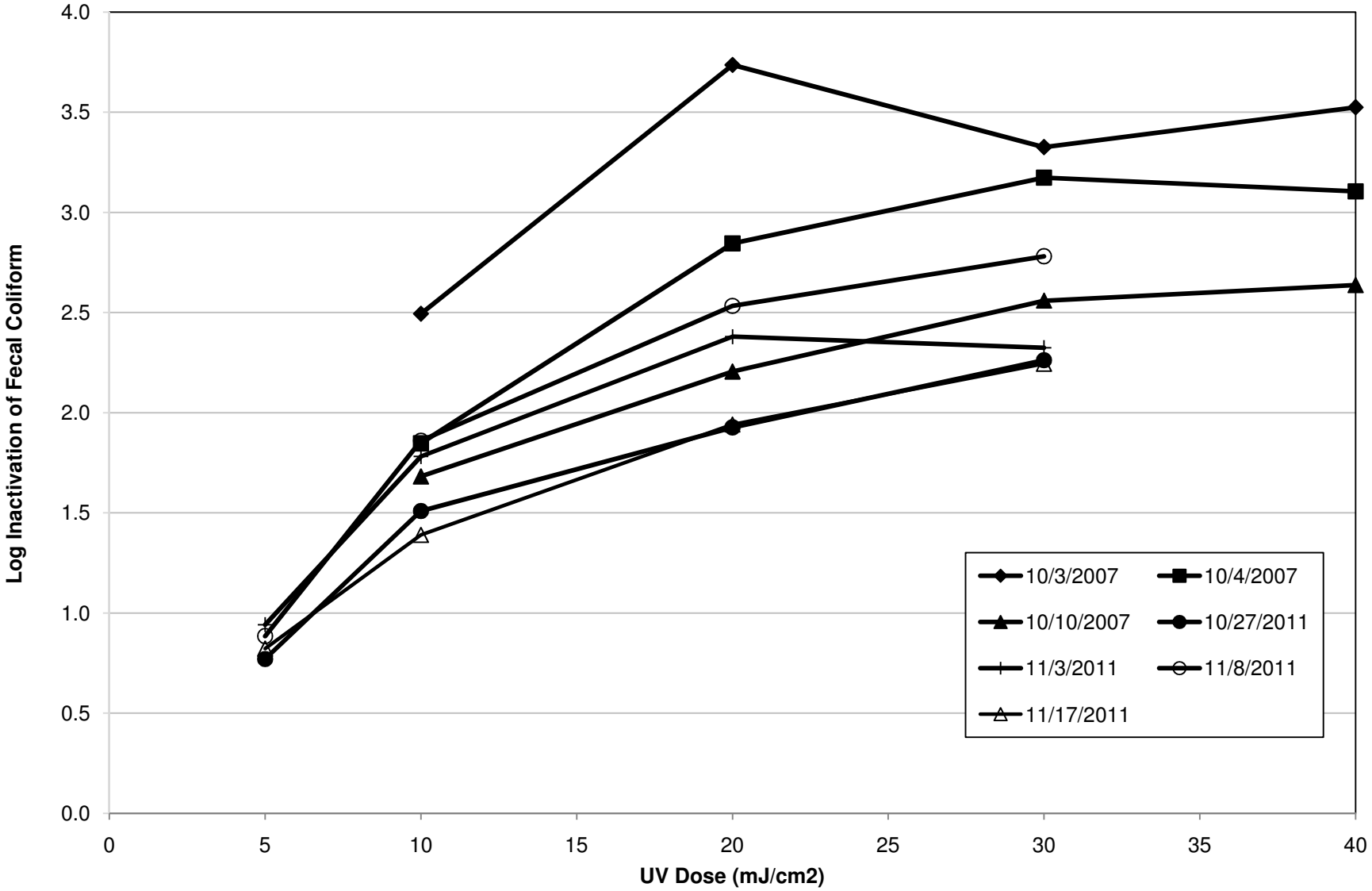
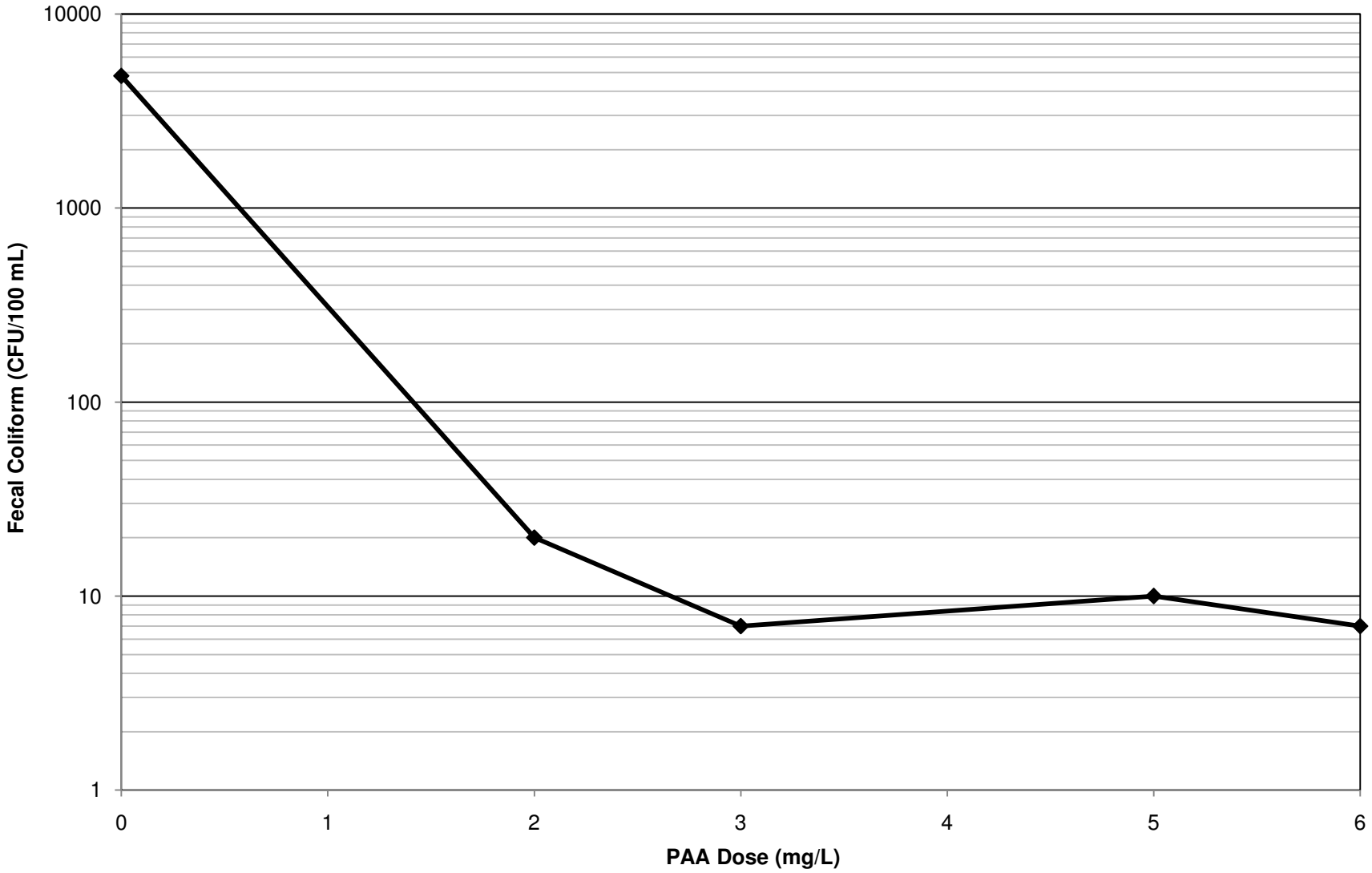


TABLE 2: UVT AND OTHER WATER QUALITY PARAMETERS MEASURED IN THE CALUMET WATER RECLAMATION PLANT'S FINAL EFFLUENT SAMPLES USED IN COLLIMATED BEAM TESTS*

Parameter	10/3/07	10/4/07	10/10/07	10/27/11	11/3/11	11/8/11	11/17/11
Initial Fecal Coliform (CFU/100 mL)	83,182	8,153	8,468	4,825	6,475	33,000	6,375
UVT_{254} (%)	70.5	70.0	72.5	70.1	71.3	70.5	71.6
Total Phosphorus (mg/L)	NA	NA	NA	6.05	6.74	3.91	5.78
Total Kjeldahl Nitrogen (mg/L)	NA	NA	NA	1.42	1.53	1.69	1.71
COD (mg/L)	NA	NA	NA	30	45	27	32
Suspended Solids (mg/L)	NA	NA	NA	5	5	5	7
Total Dissolved Solids (mg/L)	NA	NA	NA	564	508	540	624
Hardness (mg/L as $CaCO_3$)	NA	NA	NA	274	289	229	294

* NA: Parameter not analyzed

FIGURE 8: FECAL COLIFORM CONCENTRATION VERSUS PERACETIC ACID (PAA) DOSE USING FINAL EFFLUENT FROM THE CALUMET WATER RECLAMATION PLANT, 20-MINUTE CONTACT TIME



Calumet WRP. As this was the first time PAA was tested using effluent from one of the Metropolitan Water Reclamation District of Greater Chicago's plants, the contact time and PAA doses were rather conservative. If additional testing of PAA is needed in the future, testing will include evaluation of the dose-response at varying contact times. Based on these results and the results for the North Side WRP presented below, a dose of 2 mg/L of PAA with a contact time of 15 minutes will be used when comparing disinfection alternatives.

2.7. Ozone Dose

Ozone dose-response data is not available for the Calumet WRP. However, unlike PAA, there is a greater amount of information available in the literature regarding ozone dosing. Pilot testing of ozone systems are typically done at a WRP prior to installation, as a number of variables impact ozone dosage, such as wastewater quality, transfer efficiency, and contact time. Based on the literature, typical ozone doses range between 2 and 15 mg/L of ozone with contact times ranging from 1 to 30 minutes (Paraskeva and Graham, 2002). Other studies suggest that a transferred dose of 4 to 6 mg/L is typically required to meet a coliform standard of 200 MPN/100mL in nitrified effluent (Tchobanoglous 2003) and an *E. coli* standard of 100 CFU/100mL in secondary effluent (Paraskeva and Graham 2006). The applied dose would be higher and dependent on the transfer efficiency of the system. Liberti et al. (2000) evaluated the effect of various ozone doses and contact times applied to un-nitrified secondary effluent with additional treatment including flocculation, clarification, and filtration. To achieve total coliform less than 200 CFU/100 mL, an ozone dose of 13 mg/L with a 10 minute contact time was needed. Blatchley et al. (2011) determined the ozone dose response for a filtered secondary effluent. They concluded that a minimum applied dose of 7.5 to 8.0 mg/L was required to comply with a 125 CFU/100 mL *E. coli* standard. Tests done by Gesuale et al (2010) showed an applied dose of 3 to 5 mg/L of ozone was required to achieve a 4-log inactivation of thermotolerant coliform in a biologically treated, domestic wastewater. The required dose varied based on the organic content of the wastewater. As there is some variability in typical ozone doses found in the literature, a some what conservative applied ozone dose of 8 mg/L will be used along with a 10 minute contact time when comparing disinfection alternatives.

2.8. Chlorine Dose

Chlorine dose-response data is not available for the Calumet WRP, but there is also a significant amount of information available regarding chlorine dosage for disinfection. The 10 State Standards and the Illinois Recommended Standards for Sewage Works both recommend a chlorine dose of 6 mg/L for the type of effluent at the Calumet WRP, unfiltered and nitrified, secondary effluent. The chlorine doses applied at the District's Egan, Kirie, and Hanover Park WRPs, which utilize chlorination for disinfection, were reviewed. The Egan WRP adds sodium hypochlorite (NaOCl) upstream of sand filters, and during 2009 and 2011 applied an average chlorine dose of 4.7 mg/L. The Kirie WRP adds NaOCl to unfiltered effluent, downstream of finishing tanks, which provide additional settling time. The average chlorine dose applied from 2007 to 2011 was 1.4 mg/L. The Hanover Park WRP has had two different dosing locations, upstream and downstream of sand filters. The average chloride dose applied during 2007 through 2008 upstream of sand filters was 8.7 mg/L. The average chlorine dose applied during 2009 to 2011 downstream of sand filters was 3.3 mg/L. The difference in dosage at the plants can be attributed to differences in effluent water quality. Based on recommended standards, a chlorine dose of 6 mg/L with 15 minute contact time will be used when comparing alternatives.

3.0. North Side Water Reclamation Plant Data

3.1. Historic Flows

The historic daily average flows at the North Side WRP ranged from 141 to 501 MGD from 2005 through 2010. The frequency at which the different flows occurred is shown in Figure 9. The frequency of hourly flows during 2005 through 2010 is shown in Figure 10. The highest hourly flow during this time was 527 MGD. Based on the historic data, a maximum flow of 530 MGD and average flow of 240 MGD will be used when estimating costs of disinfection alternatives at the North Side WRP.

3.2. Water Quality Data

A summary of water quality parameters of interest from 2005 through 2010 is given in Table 3. The summary includes the ranges, averages, and standard deviations of all the data from the six year period. The ranges, averages, and standard deviations were also calculated for data only from the proposed disinfection season, March 1 through November 30, for the six years, but the data is not presented due its being very similar to the summary of all the data. These data are from the routine sampling conducted at the plant. The exception is the absorbance data which were from special sampling conducted every two weeks in 2006. The FC and ultraviolet (UV) transmittance data is provided in more detail in a later section.

3.3. Fecal Coliform Data

The frequency of FC data from the North Side WRP during 2005 through 2010 is shown in Figure 11. The FC data were from grab samples collected every Tuesday during the six years. During this time, four out of 313 samples had FC greater than or equal to 100,000 CFU/100 mL. Figure 12 represents the percent distribution of the log removals that would have been required to meet various disinfection goals using the 2005 through 2010 FC data. The three disinfection goals considered were 200, 100, and 50 CFU/100 mL.

3.4. UV Transmittance Data

UV absorbance at a wavelength of 254 nm and with a 1-cm path length was measured using the plant's daily composite sample once every two weeks during 2006. The UV absorbance was converted to UVT and is summarized below in Table 3. Since the 2006 data was limited to only 27 data points and the results were for the daily composite, a UVT sensor was installed in the final effluent of the North Side WRP. A summary of the available data to date is shown in Figure 13. The UVT will continue to be monitored and an updated summary of the data will be documented.

3.5. UV Dose-Response Data

Collimated beam tests were completed in August and September 2007 for the North Side WRP in order to establish a UV dose-response curve. Additional tests were completed in November 2011. Figure 14 shows the resulting FC after irradiating samples with various UV doses from the 2007 and 2011 testing. Figure 15 shows the same results in terms of log inactivation of FC. The UVT and other water quality data from the samples used in the collimated beam tests are listed in Table 4. A conservative UV dose typically used when designing UV disinfection systems is 40 mJ/cm^2. The Illinois Environmental Protection Agency

FIGURE 9: FREQUENCY DISTRIBUTION OF DAILY AVERAGE FLOWS AT THE NORTH SIDE WATER RECLAMATION PLANT FROM 2005 THROUGH 2010

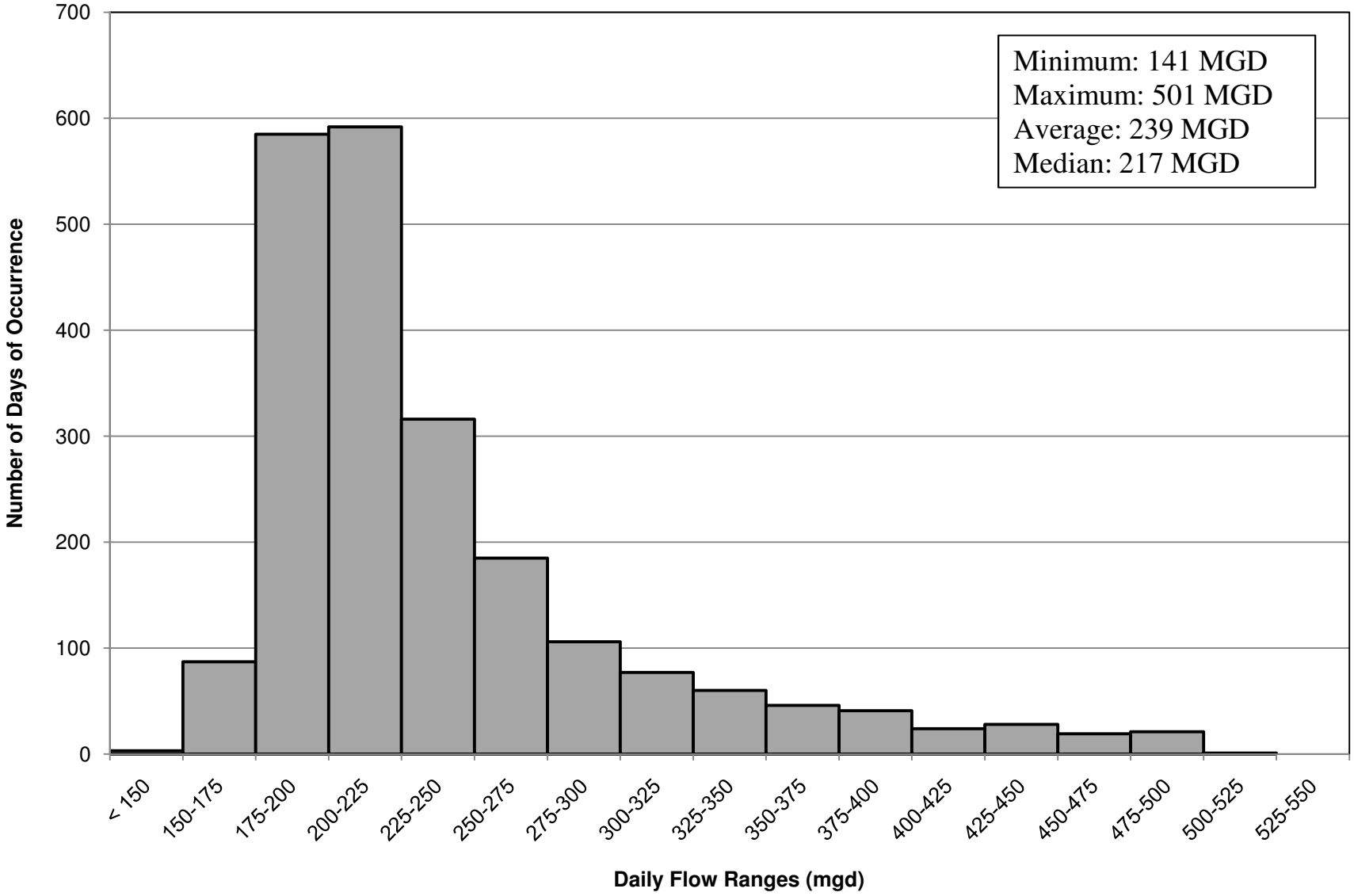


FIGURE 10: FREQUENCY DISTRIBUTION OF HOURLY FLOWS AT THE NORTH SIDE WATER RECLAMATION PLANT DURING 2005 THROUGH 2010

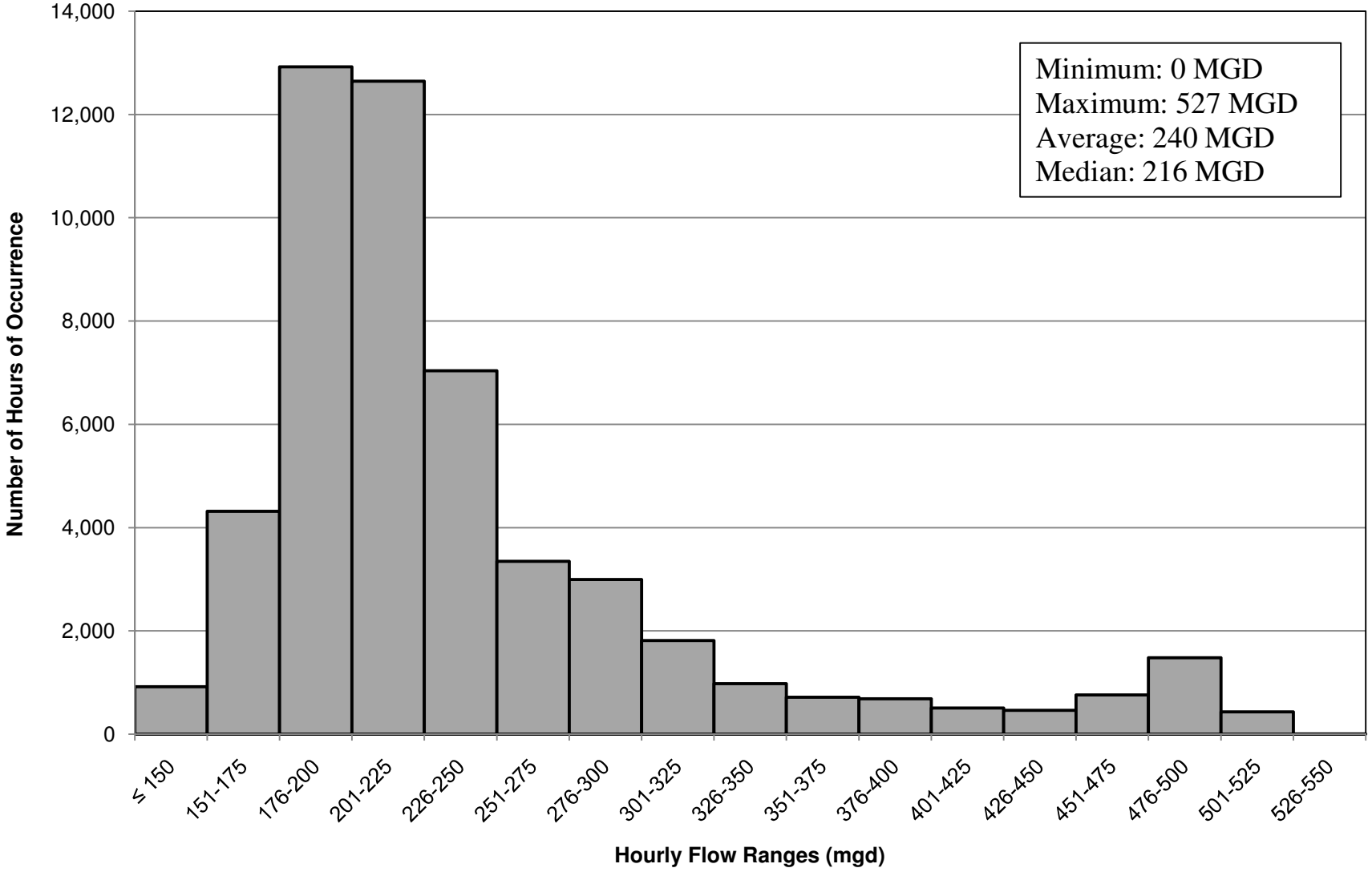


TABLE 3: SUMMARY OF WATER QUALITY DATA FROM THE NORTH SIDE WATER RECLAMATION PLANT'S FINAL EFFLUENT

Parameter	Minimum	Maximum	Average	Standard Deviation
Ammonia Nitrogen[1] (mg/L)	< 0.03	7.25	0.45	0.55
Suspended Solids[1] (mg/L)	< 2	34[6]	6	3
5-Day Biochemical Oxygen Demand[1] (mg/L)	< 2	52[6]	6	4
Total Organic Carbon[2] (mg/L)	2	14	5	1
Nitrate[1] (mg/L)	< 0.02	12.11	8.30	1.76
Nitrite[1] (mg/L)	< 0.003	2.67	0.28	0.30
pH[1] (pH units)	6.4	7.6	7.1	0.1
Iron, Total[1] (mg/L)	< 0.04	0.82	0.07	0.03
Magnesium, Total[3] (mg/L)	10.2	41.5	21.6	4.6
Calcium, Total[3] (mg/L)	32	110	60	11
Hardness[3] (mg/L as CaCO3)	123	446	238	46
Fecal Coliform[2] (CFU/100 mL)	660	200,000	15,672	22,028
UV_{254} Transmittance[5] (%)	67.3	81.7	77.9	3.3

[1] Daily composite; measured every day
[2] Daily composite; measured every Tuesday
[3] Daily composite; measured every Tuesday and Thursday
[4] Daily composite; measured the first Tuesday of every month
[5] Daily composite; measured the second and fourth Monday of every month in 2006
[6] One daily composite with higher SS of 85 mg/L and BOD_5 of 68 mg/L, which were measured in the same sample; elevated effluent concentrations, which are most likely due to a sampling problem, occurred during dry weather; daily composites from individual batteries all had SS less than 10 mg/L on this day; BOD_5 was not measured.

FIGURE 11: FREQUENCY DISTRIBUTION OF FECAL COLIFORM DATA FROM 2005 THROUGH 2010 AT THE NORTH SIDE WATER RECLAMATION PLANT

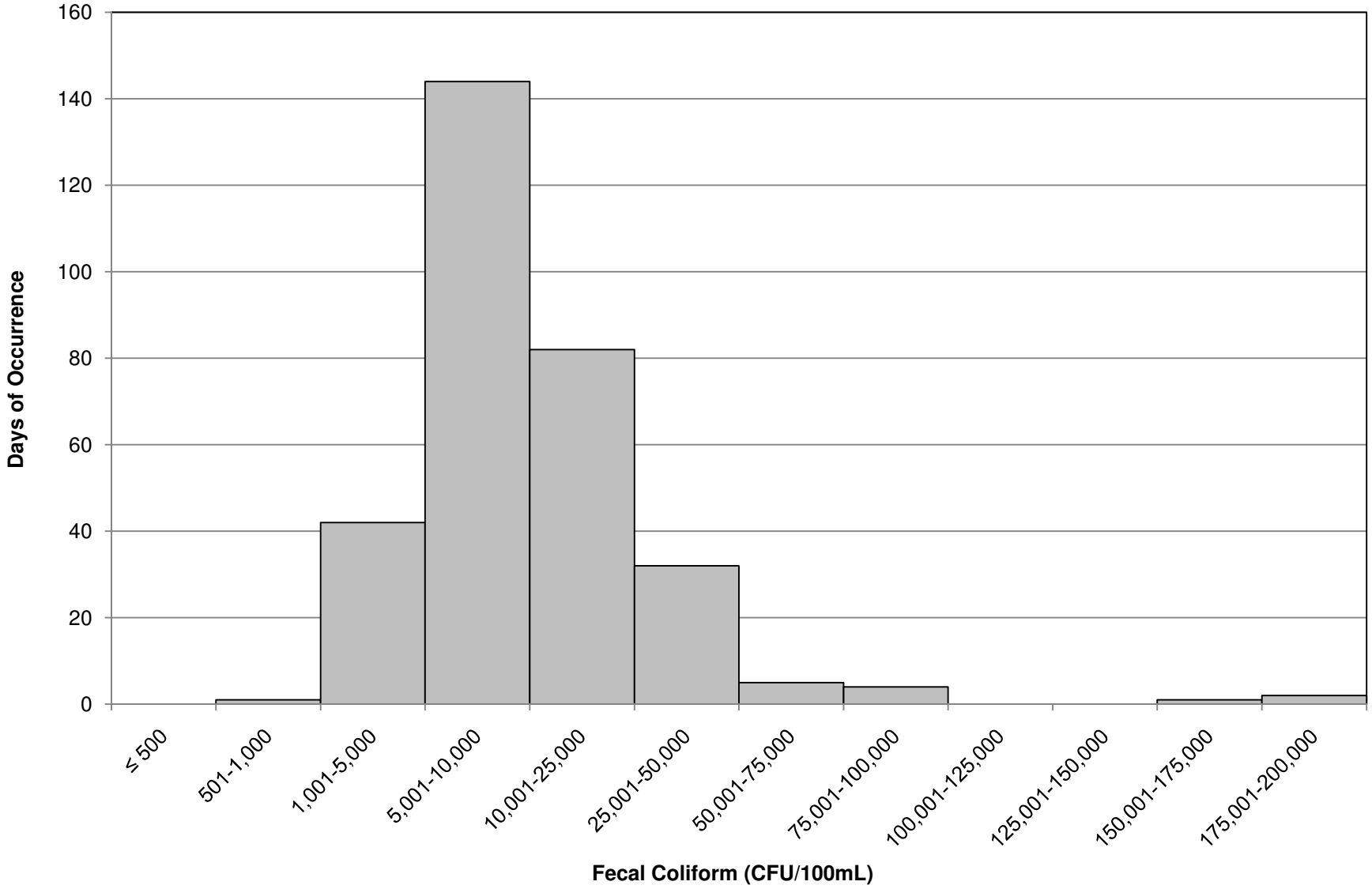


FIGURE 12: PERCENT DISTRIBUTION OF LOG INACTIVATIONS REQUIRED FOR MEETING VARIOUS DISINFECTION GOALS USING FECAL COLIFORM DATA FROM THE NORTH SIDE WATER RECLAMATION PLANT FROM 2005 THROUGH 2010

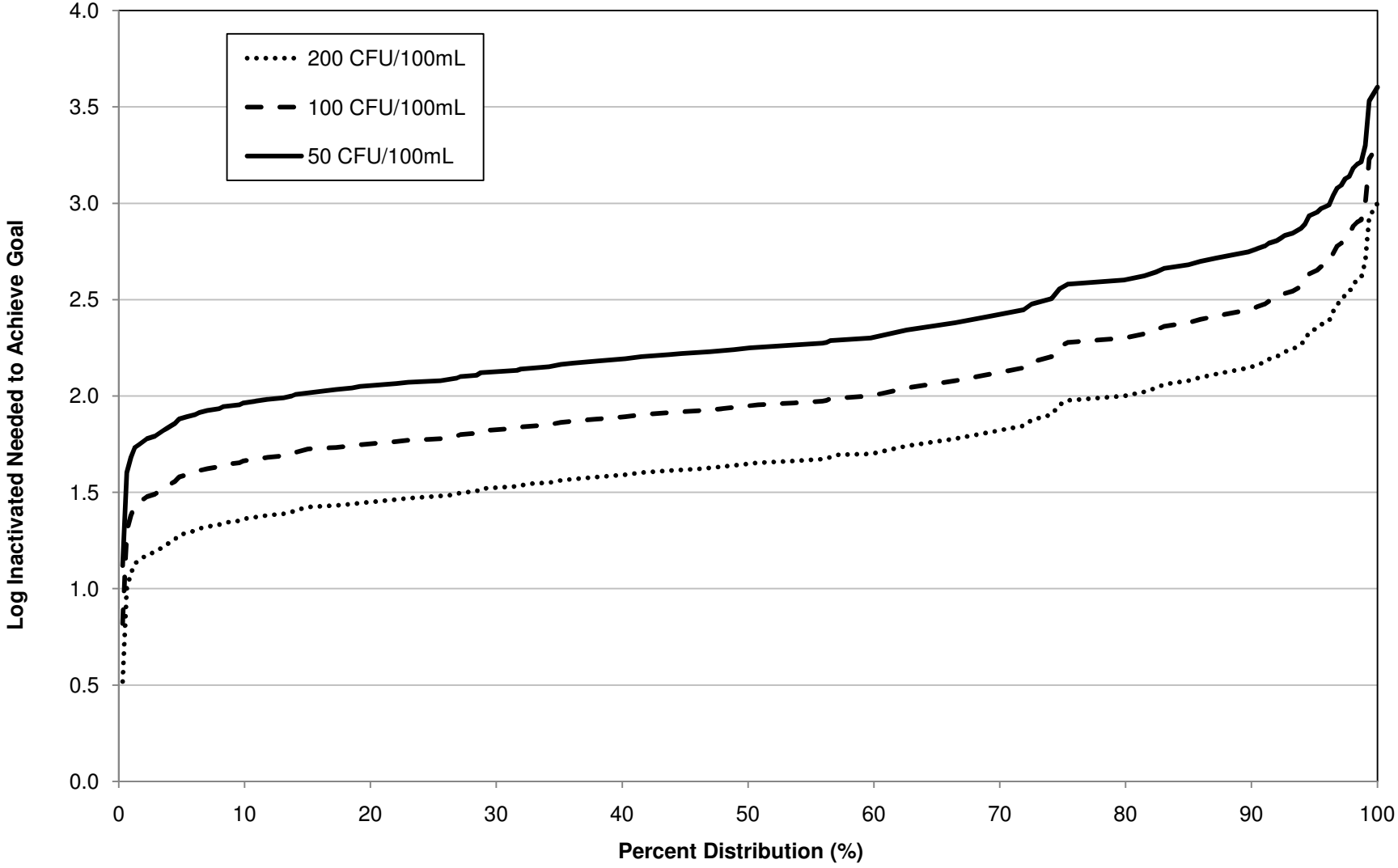


FIGURE 13: FINAL EFFLUENT ULTRAVIOLET TRANSMITTANCE AND HOURLY FLOW DATA AT THE NORTH SIDE WATER RECLAMATION PLANT FROM 11/14/2011 THROUGH 2/1/2012

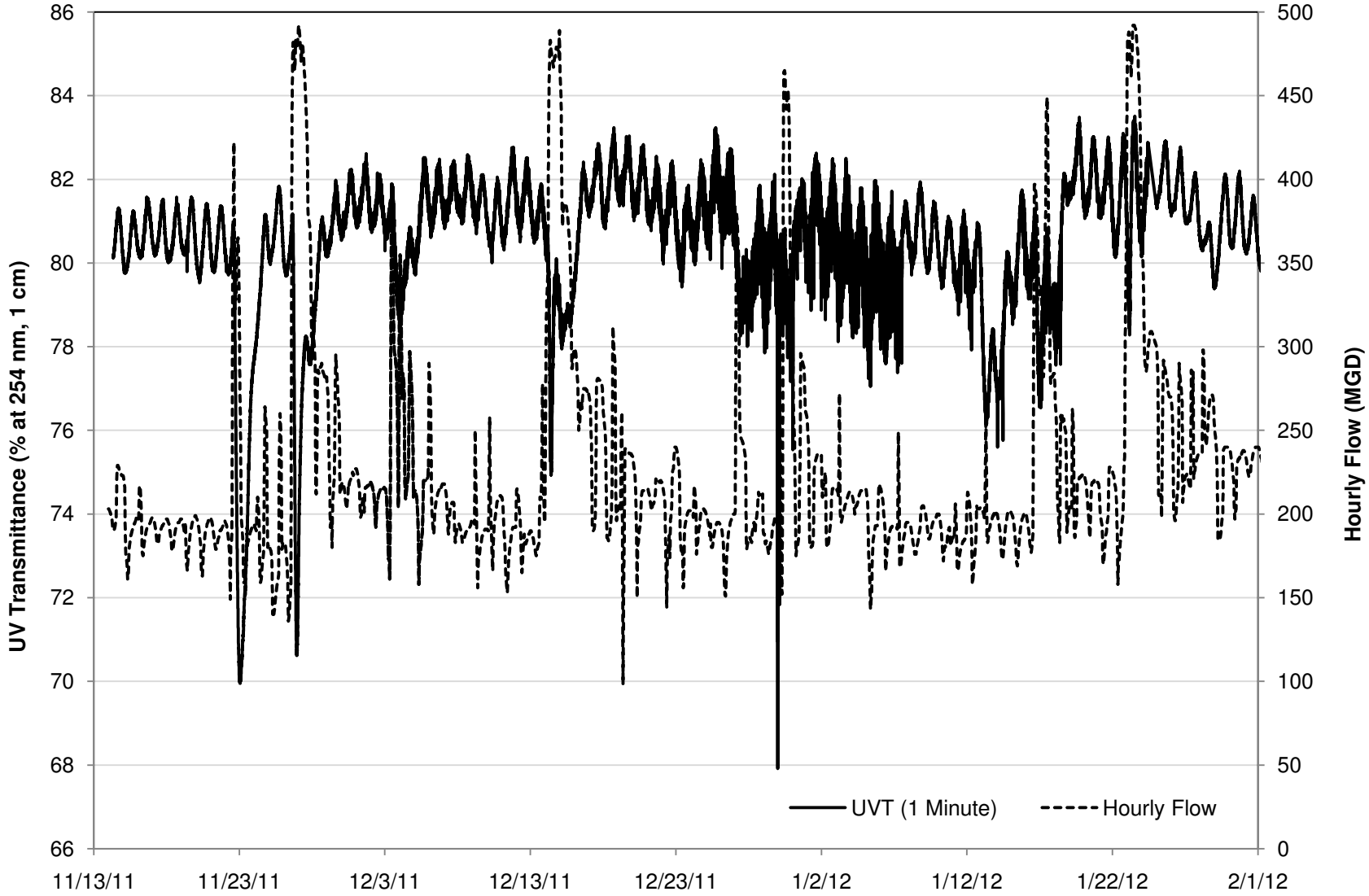


FIGURE 14: FECAL COLIFORM AFTER IRRADIATION AT VARIOUS ULTRAVIOLET IRRADIATION DOSES USING FINAL EFFLUENT FROM THE NORTH SIDE WATER RECLAMATION PLANT

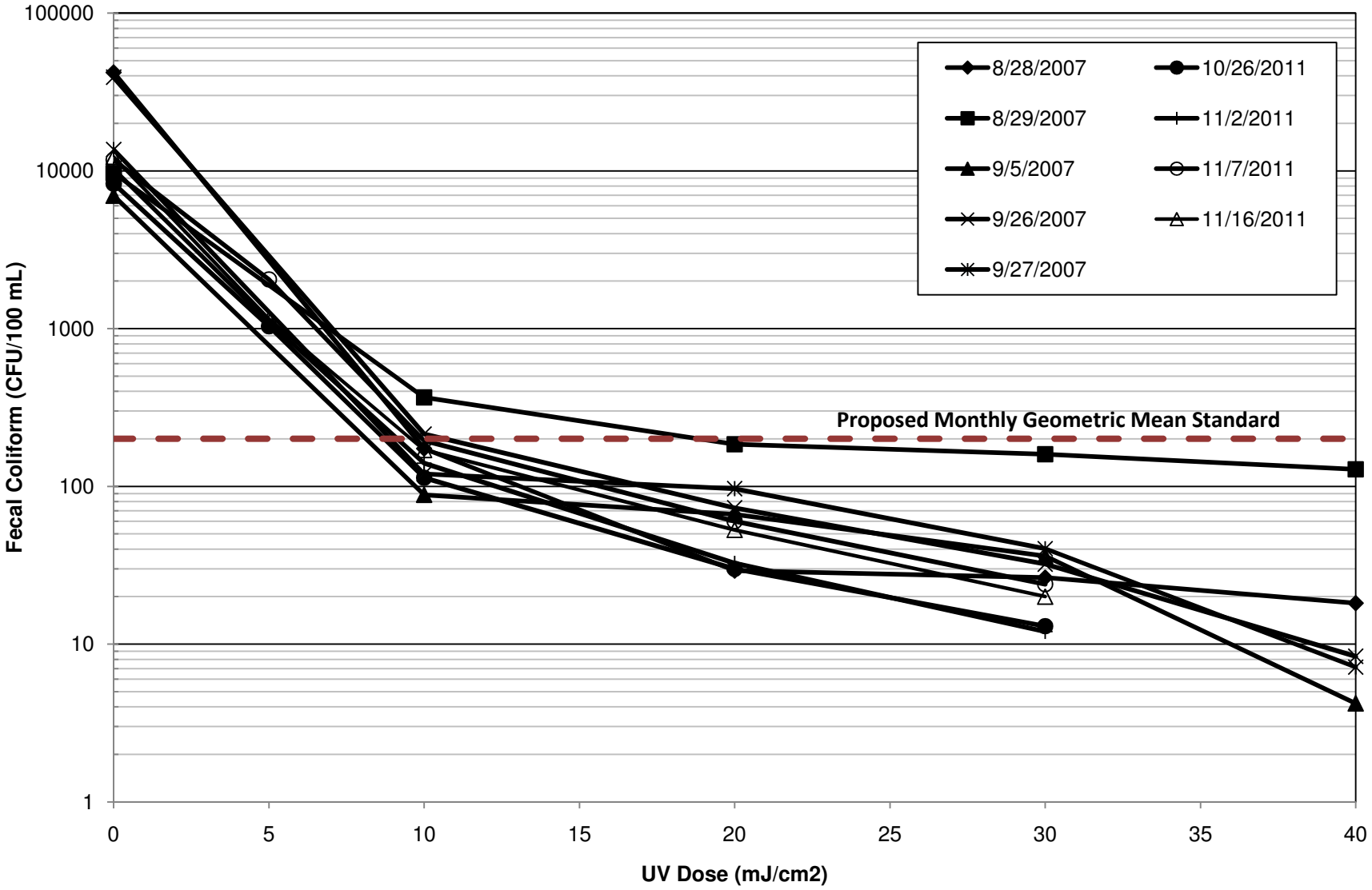


FIGURE 15: LOG INACTIVATION OF FECAL COLIFORM FOR VARIOUS ULTRAVIOLET IRRADIATION DOSES USING FINAL EFFLUENT FROM THE NORTH SIDE WATER RECLAMATION PLANT

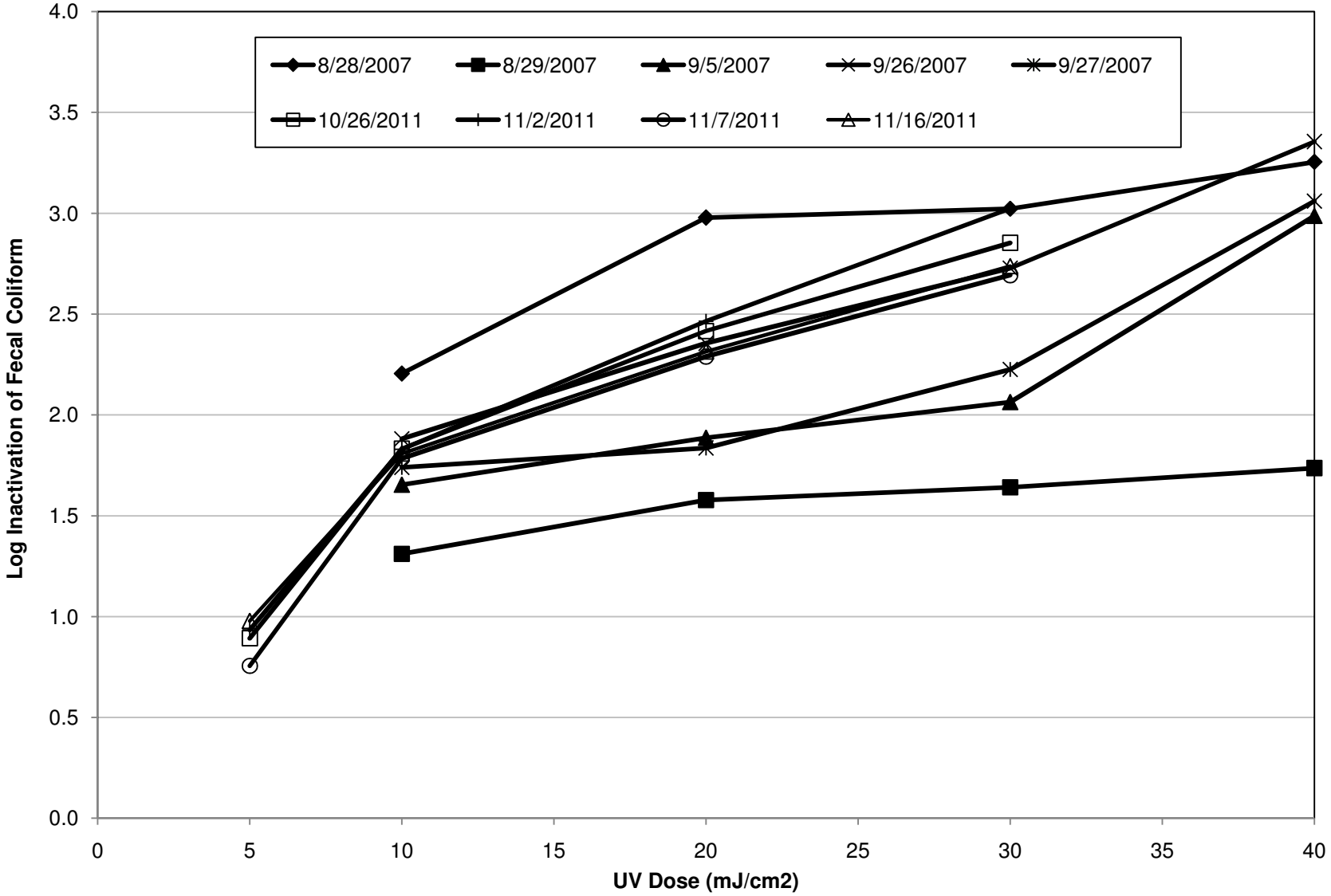


TABLE 4: UVT AND OTHER WATER QUALITY DATA MEASURED IN THE NORTH SIDE WATER RECLAMATION PLANT'S FINAL EFFLUENT SAMPLES THAT WERE USED IN THE COLLIMATED BEAM TESTS*

Parameter	8/29/07	8/30/07	9/5/07	9/26/07	9/27/07	10/26/11	11/2/11	11/7/11	11/16/11
Initial Fecal Coliform (CFU/100 mL)	42,000	9,681	6,937	39,234	13,649	8,300	10,250	11,750	12,250
UVT_{254} (%)	76.0	78.0	77.0	59.0	74.0	79.2	78.0	78.1	78.7
Total Phosphorus (mg/L)	NA	NA	NA	NA	NA	1.36	2.07	2.16	1.90
Total Kjeldahl Nitrogen (mg/L)	NA	NA	NA	NA	NA	1.24	1.73	2.35	1.51
COD (mg/L)	NA	NA	NA	NA	NA	<25	32	<25	<25
Suspended Solids (mg/L)	NA	NA	NA	NA	NA	2	5	4	4
Total Dissolved Solids (mg/L)	NA	NA	NA	NA	NA	366	474	566	496
Hardness (mg/L as $CaCO_3$)	NA	NA	NA	NA	NA	229	219	215	233

* NA: Parameter not analyzed

requires a minimum of three months of pilot testing if a design UV dose less than 40 mJ/cm^2 is to be used. The collimated beam tests show that a lower dose may be sufficient to meet the proposed FC standard. However, due to the uncertainty of whether or not pilot testing will be completed, a calculated UV dose of 40 mJ/cm^2 will be used when comparing disinfection alternatives.

3.6. PAA Dose-Response Data

Preliminary dose-response testing was conducted by PERAGreen Solutions. The testing was completed on November 17, 2011, in the Environmental Monitoring and Research Laboratory at the Stickney WRP. Various concentrations of PAA were added to aliquots of a final effluent sample from the North Side WRP. The PAA concentrations used were 1.25, 2.5, 3.75, and 5 mg/L. The PAA was allowed to react for 15 minutes, after which sodium thiosulfate was added to quench the PAA. FC was measured in the aliquots following the 15-minute contact time. Figure 16 shows the preliminary dose-response for PAA using final effluent from the North Side WRP. Additional testing of PAA will be conducted as needed in the future.

The PAA testing for the North Side WRP effluent was completed following review of the testing results from the Calumet WRP. Based on the Calumet WRP results, the doses and contact times used for the North Side WRP testing were less conservative. Future testing, if needed, will be more comprehensive, including ranges of both contact times and doses. Based on these results, a PAA dose of 2 mg/L and contact time of 15 minutes will be used when comparing disinfection alternatives.

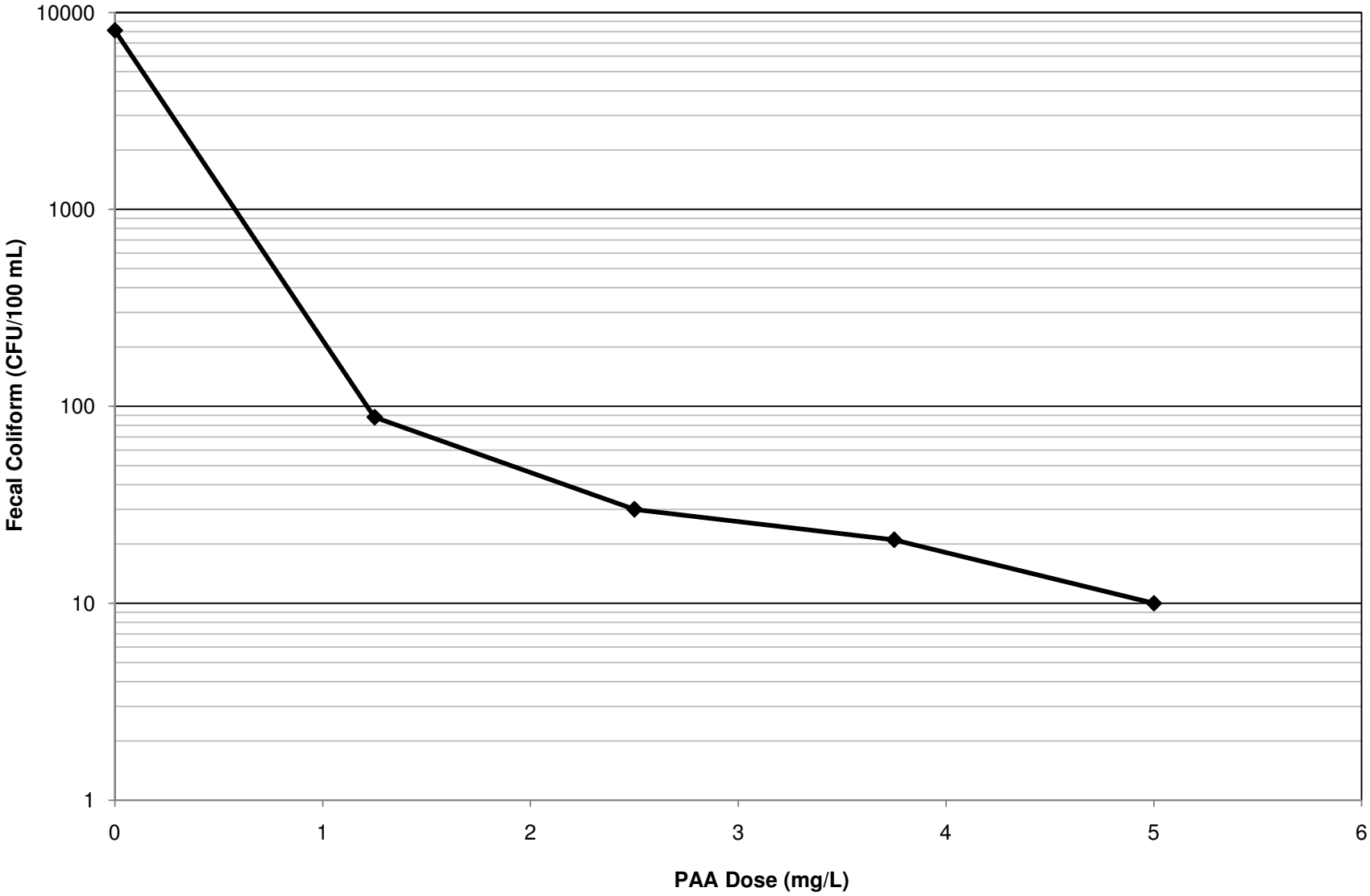
3.7. Ozone Dose

Similar to the Calumet WRP, ozone dose-response data is not available for the North Side WRP. Based on the literature presented in the Calumet WRP Ozone Dose-Response section, a some what conservative applied ozone dose of 8 mg/L will be used along with a 10 minute contact time when comparing disinfection alternatives.

3.8. Chlorine Dose

Chlorine dose-response data is also not available for the North Side WRP. A chlorine dose of 6 mg/L is recommended by the Ten State Standards and the Illinois Recommended Standards for Sewage Works. Typical chlorine doses at the District's Kirie, Egan, and Hanover Park WRPs, as presented above in the Calumet WRP Chlorine Dose-Response section, ranged from 1.4 to 8.7 mg/L over the last few years. A chlorine dose of 6 mg/L will be used along with a 15 minute contact time when comparing disinfection alternatives.

FIGURE 16: FECAL COLIFORM CONCENTRATION VERSUS PERACETIC ACID (PAA) DOSE USING FINAL EFFLUENT FROM THE NORTH SIDE WATER RECLAMATION PLANT, 15-MINUTE CONTACT TIME



4.0. References

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