Total Maximum Daily Loads for Indicator Bacteria in the Houston Metropolitan Area

Contract No. 582-6-70860
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2nd Quarterly Report

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INTRODUCTION

Twenty-seven segments in the general Houston Metropolitan Area (see Table 1) are considered impaired water bodies for contact recreation because they do not meet indicator bacteria (*Escherichia coli* (*E. coli*)) water quality standards. These segments are in a number of watersheds in the San Jacinto River basin including, Greens Bayou Watershed, Halls Bayou Watershed, Hunting Bayou Watershed, Brays Bayou Watershed, Sims Bayou Watershed, and the general Houston Ship Channel Watershed.

For the purpose of TMDL development, the project has been subdivided into five sub-projects; Greens Bayou Watershed – Bacteria, Halls Bayou Watershed – Bacteria, Brays Bayou Watershed – Bacteria, Sims Bayou Watershed, and Eastern Houston – Bacteria. The Eastern Houston watershed contains all of the bacteria impaired segments in the Houston Ship Channel and Houston Ship Channel/Buffalo Bayou watersheds. All of these segments are fresh water bodies with contact recreation use and they drain into the tidally influenced Houston Ship Channel and Houston Ship Channel/Buffalo Bayou segments with non-contact recreation use.

Greens Bayou (segment 1016) was placed on the Texas Clean Water Act 303(d) List in 1996 and the remaining 26 segments were listed in 2002. All of these segments were placed on the 303(d) list for not meeting contact recreation water quality standards. The purpose of this study is to provide the Texas Commission on Environmental Quality (TCEQ) with the information and assistance necessary for the preparation of a Total Maximum Daily Load (TMDL) for the indicator bacteria (*E. coli*) impairments.

The information gathered under this project will be used to develop the TMDL allocations. First, the TMDL allocations identify how much indicator bacteria (E. coli) the water bodies can assimilate and maintain the contact recreation standard (load capacity). Second, the TMDL allocations identify how much reduction is needed to the sources of indicator bacteria (E. coli) to reach the contact recreation standard. Reductions are identified for two broad categories of indicator bacteria sources, those sources that are covered by permits referred to as the waste load allocation (WLA) and those sources that are not covered by a permit referred to as the load allocation (LA). This relationship is referred to as the TMDL equation and it is expressed as: LC = LA + WLA.

In 2000, the State of Texas adopted new bacteria standards for contact recreation. The *E. coli* indicator bacteria standard was adopted for contact recreation in place of the existing fecal coliform indicator bacteria. For fecal coliform, no sample should exceed 400 colony-forming units (cfu) per 100 mL for contact recreation. In addition, the geometric mean should be less than 200 cfu/100 mL. For *E. coli*, no sample should exceed 394 cfu/ 100 mL and the geometric mean should be less than 126 cfu/100 mL (30 Texas Administrative Code 307.7(b)(A)).

The overall objective of this project is to establish the TMDL allocation equation for the segments listed above.

There are five tasks for WO 582-6-70860-23:

1. Administer Project;
2. Participate in Public/Advisory Group Process;
3. Development of TMDLs for Contact Recreation Segments;
4. Complete analyses for 5c Segments; and
5. Preparation of Technical Guidance Documents

This report describes the progress for the period from December 1, 2008 through February 28, 2009 for the metro project.

TASK PROGRESS

TASK 1 Administer Project

UH administered all aspects of the project during the quarter.

TASK 2 Participate in Public/Advisory Group Process

Numerous meetings were set-up by TCEQ and HGAC for the Bacteria Implementation Group (BIG) during the past quarter. The projected team attended and supported all the meetings that were held.

TASK 3 Development of TMDLs for Contact Recreation Segments

Draft Technical Guidance Documents for Brays and Greens Bayous submitted in FY08 were revised multiple times based on comments received from TCEQ. Comments forwarded by TCEQ during the first quarter of 2009 included development of graphic tools for calculating waste load allocations and load allocations for various water quality standards for all metro watersheds. These comments were addressed and the information was included in the draft guidance documents for Brays and Greens currently being reviewed by TCEQ.

TASK 4 Complete Analyses for 5c Segments

The data gathered in FY08 for 5c segments have been analyzed, tabulated and graphed. The results are presented in Appendix A.

TASK 5 Preparation of Technical Guidance Documents

As mentioned in Task 2 above, additional comments were received from TCEQ during the first quarter that necessitated revising the guidance documents. This was done for

Greens and Brays and the guidance documents for the two bayous are currently being reviewed by TCEQ.

Table 1. Metro Segments

TMDL Project Name	Segment Number	Segment Name
Eastern Houston - Bacteria	1006F	Big Gulch Above Tidal
	1006H	Spring Gully Above Tidal
	1007F	Berry Bayou Above Tidal
	1007G	Kuhlman Gully Above Tidal
	1007H	Pine Gully Above Tidal
	1007I	Plum Creek Above Tidal
	1007K	Country Club Bayou
	1007M	Unnamed Non-Tidal Tributary of Hunting Bayou
	1007O	Unnamed Non-Tidal Tributary of Buffalo Bayou
	1007R	Hunting Bayou Above Tidal
Greens Bayou Watershed – Bacteria	1016	Greens Bayou Above Tidal
	1016A	Garners Bayou
	1016B	Unnamed Tributary of Greens Bayou
	1016C	Unnamed Tributary of Greens Bayou
	1016D	Unnamed Tributary of Greens Bayou
Halls Bayou Watershed – Bacteria	1006D	Halls Bayou below US 59
	1006E	Halls Bayou above US 59
	1006I	Unnamed Tributary of Halls Bayou
	1006J	Unnamed Tributary of Halls Bayou
Brays Bayou Watershed – Bacteria	1007B	Brays Bayou Above Tidal
	1007C	Keegans Bayou above tidal
	1007E	Willow Waterhole Bayou Above Tidal
	1007L	Unnamed Non-Tidal Tributary of Brays Bayou
	1007P	Brays Bayou Above Tidal
Sims Bayou Watershed – Bacteria	1007D	Sims Bayou Above Tidal
	1007N	Unnamed Non-Tidal Tributary of Sims Bayou
	1007Q	Sims Bayou Above Tidal

Appendix A
Preliminary Data Gathering And Analysis Report For 5c Segments in Metro Area

Introduction

The 5c impaired segment list in the Houston metro area is comprised of four major segments including 1005, 1006, 1007, and 1007A. Segment 1007A does not have any data associated with it in the TCEQ Surface Water Quality Monitoring Database, and thus was excluded from the analysis. Some data for the segment have been retrieved from paper sources and are currently being analyzed and incorporated into this database.

The TCEQ Surface Water Quality Monitoring Database includes information on water temperature, total suspended solids, specific conductance, and indicator pathogen concentrations over a general period of record from 1973 to 2008. The records are not a continuous data set i.e. there are intermittent periods without collected data for many of the parameters. By forming data tables using indicator pathogen concentrations as the discerning parameter, statistical tests could be applied to the historical data and correlations between the data could be structured. Statistical analyses were undertaken for each of the 55 stations including the minimum, maximum and geometric mean values of indicator bacteria concentrations over the period of record. The standard deviation of each data set as well as the 95% prediction confidence interval was calculated to give a basic understanding of the data that were gathered.

Table 1 below shows the water quality standards for both contact and non-contact recreation.

Table 1. Water Quality Standards for Contact and Non-Contact Recreation

Contact Recreation	Fecal Coliform	Single Sample	394	cfu/100mL
		Geomean	605	cfu/100mL
	Enterococci	Single Sample	89	cfu/100mL
		Geomean	35	cfu/100mL
Non-Contact Recreation	Enterococci	Geomean	168	cfu/100mL

Bacteria Concentrations

Table 2 below shows the descriptive statistics for the fecal coliform data for all stations within all the segments while Table 3 contains the Enterococci bacteria statistical analysis for the three segments.

It can be seen that Segment 1005 is the least impacted segment of the three compared within this study. Segment 1005 has a relatively low percentage of samples exceeding fecal standard levels and approximately half of the total station geometric means are above the 35 cfu/100mL standard for Enterococci. Segment 1006 and Segment 1007 are adversely affected by bacterial loading, and the 35 cfu/100ml standard is exceeded by all but one of the 1006 stations and all of the 1007 stations.

Table 2. Fecal Coliform Statistical Summary for 1005, 1006 and 1007

			Fecal								
Segment	**Station ID**	**Period of Record**	**Geomean**	**Median**	**Min**	**Max**	**95 % Confidence**	**Sample Size (n)**	**Standard Deviation**	**# of Samples >395cfu/100ml**	**% of Samples > 395cfu/100ml**
1005	11252	1987 - 1995	35	20	5	4000	91	213	591	18	8.5
	11254	1999 - 2004	38	40	1	6000	235	57	793	3	5.3
	11258	1973 - 1995	123	105	10	12000	1747	196	10913	51	26.0
	16618	1999 - 2004	52	40	1	1000	60	58	202	5	8.6
	16619	2000 - 2004	92	119	1	4000	180	56	601	6	10.7
	16621	2001 - 2004	82	70	10	9100	367	61	1280	7	11.5
1006	11264	1973 - 2004	302	275	10	43000	622	246	4352	105	42.7
	11266	1973 - 1974	922	1440	90	3900	1069	7	1262	5	71.4
	11271	1973 - 2004	886	900	1	145000	2177	267	15871	184	68.9
	11272	1987 - 1995	1027	1050	10	26000	2559	24	5593	18	75.0
	11273	1993 - 1995	723	390	230	3400	1372	5	1369	2	40.0
	11274	1976 - 1977	5663	23000	200	1600000	272980	13	439119	10	76.9
	11275	1973 - 1995	3208	2050	10	249000	22976	50	72484	44	88.0
	11276	1973 - 1975	3597	4100	200	92000	17091	16	30500	13	81.3
	11277	1987 - 2001	560	460	36	400000	18640	48	57617	26	54.2
	11278	1976 - 1977	9877	13000	10	2400000	439813	14	734197	12	85.7
	11279	1973 - 2001	1561	1700	3	160000	3717	161	21039	119	73.9
	16617	1999 - 2001	203	190	10	9200	415	59	1423	20	33.9
	16664	1999 - 2004	48391	120000	330	200000	24490	66	88765	65	98.5
1007	11173	1983 - 1983	-	-	-	-	-	-	-	-	-
	11283	1999 - 2004	395	400	1	20700	1157	59	3966	31	52.5
	11284	1973 - 1995	7566	8000	10	480000	10235	194	63602	183	94.3
	11287	1973 - 1995	2109	2000	4	241000	4711	207	30241	168	81.2
	11292	1973 - 2004	2166	1950	1	450000	7705	262	55645	202	77.1
	11293	1973 - 1999	23363	33000	53	1100000	76059	41	217280	37	90.2
	11294	1975 - 1994	1591	2250	10	800000	13754	192	85025	138	71.9
	11295	1977 - 1988	10933	13500	10	570000	15787	90	66821	86	95.6
	11296	1975 - 1995	8188	7600	10	1300000	24619	122	121317	119	97.5
	11298	1973 - 2001	1595	1400	10	1609000	35936	104	163505	70	67.3
	11299	1983 - 1995	1822	1350	10	1200000	42011	65	151112	46	70.8
	11300	1987 - 1993	1573	800	10	116000	15441	21	31569	13	61.9
	11301	1983 - 1983	-	-	-	-	-	-	-	-	-
	11302	1976 - 2001	670	370	10	240000	8831	87	36751	43	49.4
	11303	1973 - 1976	69	20	10	37000	6349	13	10213	2	15.4
	11304	1999 - 2001	905	690	36	36000	3639	29	8744	21	72.4
	11305	1973 - 1980	12410	20000	2	790000	46420	49	144971	44	89.8
	11306	1987 - 2001	2435	2000	10	200000	12853	49	40140	39	79.6
	11307	1973 - 1995	24991	23500	900	3390000	374284	22	783236	22	100.0
	11309	1973 - 2001	11620	8500	63	240000	23834	63	84400	60	95.2
	14368	1993 - 1993	-	-	-	-	-	-	-	-	-
	14369	1993 - 1993	-	-	-	-	-	-	-	-	-
	14370	1993 - 1993	-	-	-	-	-	-	-	-	-
	14371	1993 - 1993	-	-	-	-	-	-	-	-	-
	15841	1999 - 2001	2345	2200	120	35000	3731	38	10261	35	92.1
	15860	1999 - 1999	2415	2200	1800	3800	694	6	759	6	100.0
	15861	1999 - 1999	1814	2750	45	47000	7447	14	12432	10	71.4
	16620	1999 - 2004	364	350	1	17500	941	58	3197	29	50.0
	16680	1999 - 2001	2026	1300	63	180000	7357	65	26461	58	89.2

Table 3. Enterococci Statistical Summary for 1005, 1006 and 1007

	Enterococci													
Segment	Station ID	Period of Record	Geomean	Median	Min	Max	95 % Confidence	Sample Size (n)	Standard Deviation	# of Samples >89cfu/100ml	% of Samples > 89cfu/100ml	Geomean > 35 cfu/100mL	# of Samples >168cfu/100ml	% of Samples > 168cfu/100ml
1005	11252	2000 - 2008	25	10	10	3873	298	29	716	5	17.2	NO	4	23.2
	11254	2003 - 2007	39	20	10	24000	1160	47	3548	13	27.7	YES	9	32.5
	11258	2000 - 2008	36	20	10	4611	374	28	882	7	25.0	YES	5	20.0
	15897	2001 - 2006	44	15	10	950	350	6	383	2	33.3	YES	2	6.0
	16195	2002 - 2007	31	10	10	5794	1618	8	2041	1	12.5	NO	1	8.0
	16618	2003 - 2007	23	10	10	340	22	44	65	5	11.4	NO	3	26.4
	16619	2004 - 2007	37	36	10	1200	62	44	184	11	25.0	YES	3	12.0
	16621	2005 - 2007	24	20	10	550	28	45	85	5	11.1	NO	2	18.0
1006	11264	2000 - 2008	41	31	10	2382	105	71	394	13	18.3	YES	11	60.1
	11271	2000 - 2008	80	63	10	24000	757	74	2904	32	43.2	YES	22	50.9
	11273	2000 - 2008	42	20	10	2282	221	27	513	8	29.6	YES	5	16.9
	11275	2000 - 2000	-	-	-	-	-	-	-	-	-	YES	-	-
	11617	2003 - 2007	62	52	10	10000	496	45	1485	16	35.6	YES	13	36.6
	16664	2004 - 2007	172	130	10	22000	2368	23	5067	15	65.2	YES	10	15.3
	16981	2002 - 2008	55	92	10	2602	260	22	545	11	50.0	YES	7	14.0
	17154	2002 - 2007	44	52	10	400	67	15	115	6	40.0	YES	2	5.0
	18322	2004 - 2008	27	20	10	405	56	16	100	2	12.5	NO	1	8.0
	18363	2001 - 2008	123	96	10	7700	766	27	1775	15	55.6	YES	8	14.4
1007	11283	2000 - 2007	94	86	10	5500	382	45	1145	22	48.9	YES	15	30.7
	11284	2000 - 2008	48	31	10	4884	446	29	1071	9	31.0	YES	6	19.3
	11287	2000 - 2008	58	41	10	3255	293	29	704	11	37.9	YES	7	18.5
	11292	2000 - 2008	84	58	10	11000	553	72	2094	29	40.3	YES	21	52.1
	11296	2000 - 2008	107	73	10	3448	363	27	841	13	48.1	YES	10	20.8
	11298	2004 - 2007	88	52	10	8100	737	25	1644	10	40.0	YES	9	22.5
	11299	2000 - 2008	97	86	10	7701	642	27	1489	13	48.1	YES	9	18.7
	11300	2000 - 2008	183	144	10	24192	2942	29	7069	16	55.2	YES	13	23.6
	11302	2000 - 2008	60	31	10	14136	1099	48	3398	11	22.9	YES	9	39.3
	11304	2001 - 2007	94	63	10	11000	1349	19	2623	7	36.8	YES	5	13.6
	11306	2000 - 2008	67	41	10	24000	1313	49	4100	15	30.6	YES	10	32.7
	15841	2004 - 2007	136	110	10	11000	1077	23	2304	14	60.9	YES	11	18.1
	16620	2003 - 2007	129	120	10	11000	702	45	2102	25	55.6	YES	17	30.6
	16660	2005 - 2007	180	114	10	14000	2099	16	3747	9	56.3	YES	7	12.4
	18362	2001 - 2008	63	36	10	12033	1076	28	2539	7	25.0	YES	7	28.0

Seasonal Analysis

The seasonal effects on indicator bacteria in the 5c segments were explored using t-tests assuming unequal variance between the data sets in different seasons. To accomplish this, the month in which the sample was taken was tagged with a season identifier, 0, 1, or 2, which depicts the season as cool, neutral, or warm, respectively as shown in Table 4.

Table 4. Tag associated with Months identifying them as cool (0), neutral (1) or warm (2)

Month	Number	Code
Jan	1	0
Feb	2	0
Mar	3	1
Apr	4	1
May	5	2
Jun	6	2
Jul	7	2
Aug	8	2
Sep	9	2
Oct	10	1
Nov	11	0
Dec	12	0

The classification of the various months shown above was then correlated to the indicator pathogen concentrations to determine if there were differences between the various months. The relationship was considered to be significant (SIG) if the p-value was less than 0.10 and considered not significant (NOT) if the p-value was greater than or equal to 0.10. Similar tables are located within Appendix A for the stations within Segments 1006 and 1007.

The results are shown in Table 5 below for Segment 1005. It can be seen that 3 of the 6 stations for Segment 1005 and 5 of the 6 for enterococci were significantly correlated with the time of yr in which they were collected.

Table 5. Significance of seasonality, days since precipitation, and specific conductance for Segment 1005

	Seasonality				Wet / Dry				Specific Conductance Correlation			
	Fecal		Enterococci		Fecal		Enterococci		Fecal		Enterococci	
1005	11252	SIG	11252	SIG	11254	NOT	11252	NOT	11252	SIG	11252	SIG
	11254	NOT	11254	SIG	16618	NOT	11254	SIG	11254	SIG	11254	SIG
	11258	SIG	11258	SIG	16619	NOT	11258	NOT	11258	SIG	11258	SIG
	16618	SIG	16618	SIG	16621	SIG	16618	SIG	16618	SIG	16618	SIG
	16619	NOT	16619	SIG			16619	NOT	16619	SIG	16619	SIG
	16621	NOT	16621	NOT			16621	NOT	16621	SIG	16621	SIG
	# Sig	3	# Sig	5	# Sig	1	# Sig	2	# Sig	6	# Sig	6
	% Sig	50	% Sig	83.33333	% Sig	25	% Sig	33.33333	% Sig	100	% Sig	100

Number of Days Since Rain

Similarly, an analysis was conducted to determine if the number of days since a rain event prior to sampling would have an impact on indicator bacteria concentrations. For this analysis, rain within four days of a sample collection was considered a 'wet' sample while samples collected on days that have not seen rain in at least five days were considered to be 'dry' samples. As storm water events have commonly been associated with increased contaminant levels, the large data set seemed to provide the opportunity for this type of analysis.

The results shown in Table 5 for Segment 1005 do not support a correlation between wet and dry conditions and pathogen indicators.

Salinity

All segments showed a high correlation between specific conductivity and pathogen concentrations, a finding that has been reported in the literature as well. As salinity is directly related to the specific conductance of the flowing water, and Enterococci thrive in saline environments while fecal coliforms die.

Temporal Analysis

To gage the change in indicator pathogens over time , the fecal coliform dataset was divided into two data series, pre- 1990 data then post-1990 data. These datasets were subsequently compared to each other for stations that had data during both time periods. The results are summarized in Table 6. By assuming the post-1990 geometric means to be lower than the pre-1990 geometric means, the findings were recorded as a % reduction in indicator pathogen concentrations. Note that negative reductions indicate an increase in the geometric mean concentration for that particular station.

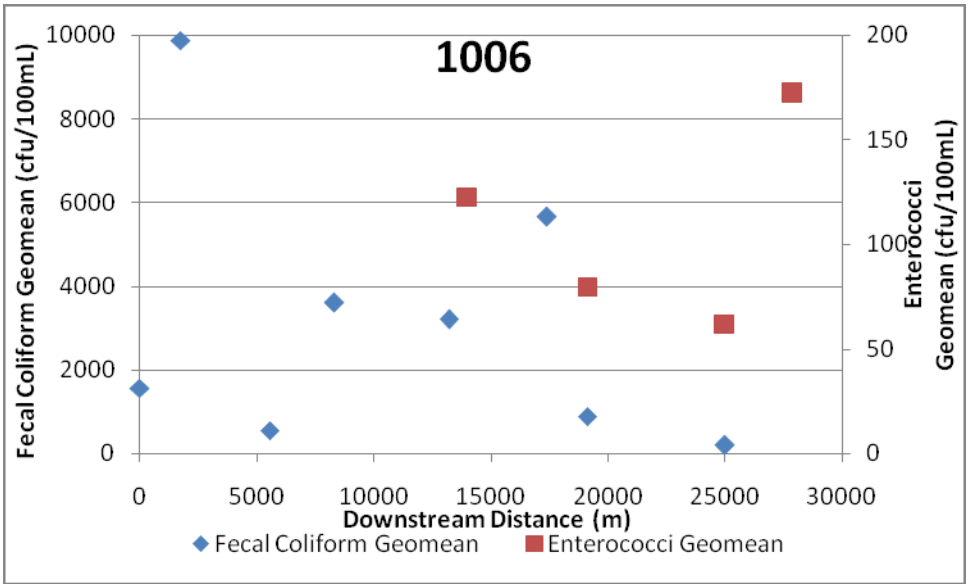
Table 6. Comparative reduction of indicator pathogen concentration relative to 1990

	Matched Stations			
	Station ID	Pre 1990	Post 1990	% Reduction
1005	11252	34	47	-28
	11258	124	122	1
1006	11264	385	192	100
	11271	1191	484	146
	11277	920	415	121
	11279	5536	352	1472
1007	11284	9025	2774	225
	11287	2305	1165	98
	11292	3782	706	436
	11294	1698	1011	68
	11296	9242	5647	64
	11298	2708	561	382
	11302	477	935	-49

By focusing on the final column in Table 6, it can be concluded that the stations within each segment have a relatively close reduction factor to the other stations within their segment. Also, Segments 1006 and 1007 appear to see high reduction rates indicating an improvement in water quality post-1990 in the segments. Segment 1005, however, seems to have remained relatively unchanged and may even be slightly worse than its pre-1990 state.

Spatial Changes

In addition to the previous findings, an analysis was undertaken to determine if the concentrations of indicator bacteria were changing spatially throughout the segments. Using distance-delineating techniques in ArcGIS 9.3, the flow length distance between each station along each segment was calculated and the geometric means were plotted along with the relative distance downstream from the furthest upstream station. Figure 1 shows the geometric mean concentration of the indicator pathogens with respect to the downstream distance for the three segments. As can be seen from Figure 1, the results were mixed with no distinct spatial pattern for any of the segments.



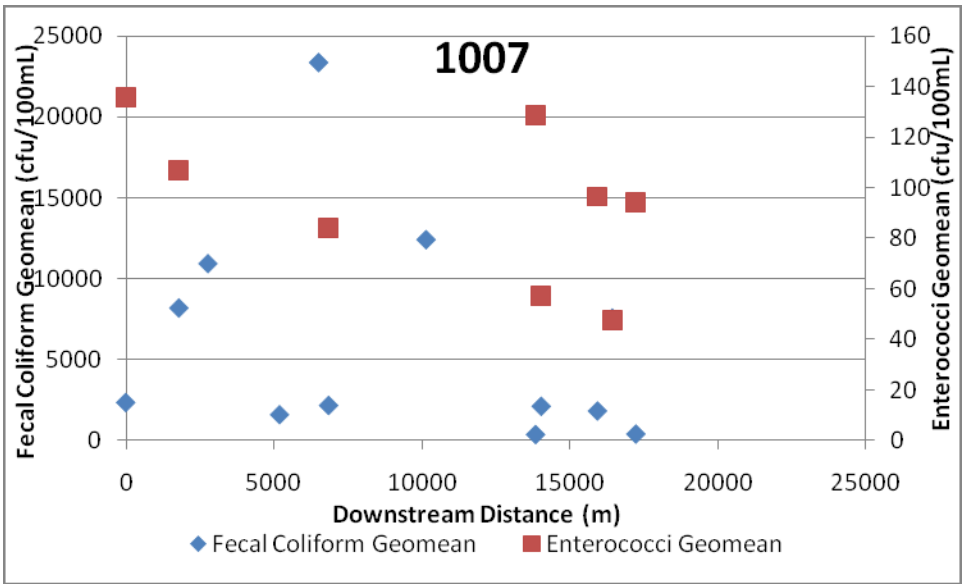


Figure 1: Indicator pathogen geometric mean values with distance for Segments 1005, 1006, and 1007

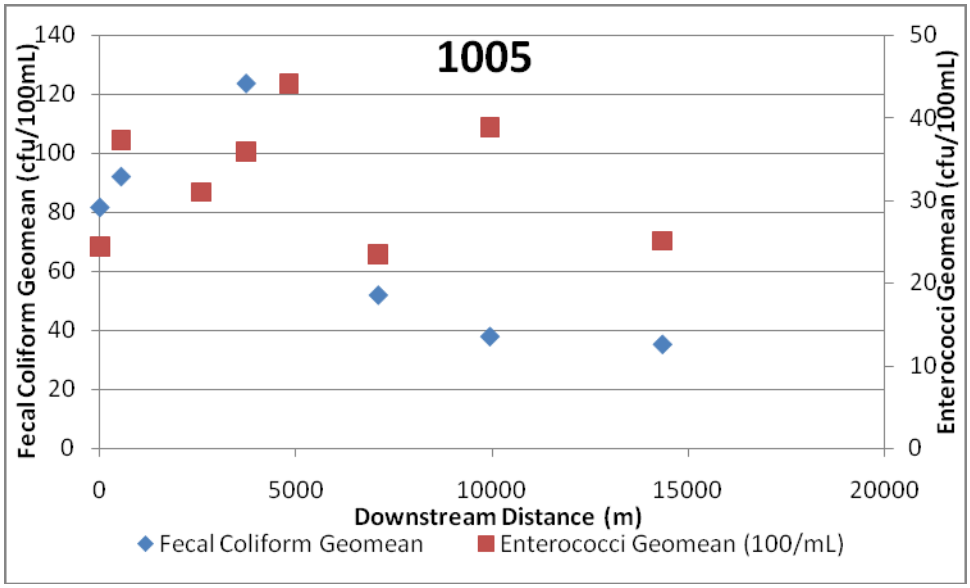


Figure 1: Indicator pathogen geometric mean values with distance for Segments 1005, 1006, and 1007