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Memorandum

DATE: June 3, 2011

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PROJECT: Battelle Contract EP-C-08-001, TO 004

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CC: Fran Mulhern, Larry Merrill, Helene Drago (EPA Region 3), Lynn McLeod (Battelle)

SUBJECT: FINAL Memo Summarizing DC Bacteria Data and Recommending a DC Bacteria Translator (Task 2)

SUMMARY

The District of Columbia (DC) Department of the Environment (DDOE) approved fecal coliform bacteria total maximum daily loads (TMDLs) for a total of 24 impaired segments in 2003 and 2004. These TMDLs require translation from fecal coliform to E. coli bacteria expressed as a daily load because of a change in the water quality criteria and a court ruling on the daily expression of TMDLs, both of which occurred after 2004. LimnoTech and Battelle are conducting the first phase of this work to evaluate the existing receiving water bacteria monitoring data to determine if a sufficient amount of fecal coliform and E. coli data are available to develop a scientifically defensible "translator" from fecal coliform to E. coli bacteria. A "translator" is a mathematical equation that allows one parameter to be translated into another in a consistent and scientifically defensible way. In this case, a translator is needed in order to express the existing fecal coliform TMLD allocations as E. coli for compliance purposes.

This memorandum summarizes all the work completed to develop a DC bacteria translator, including:

1. Summary of the bacteria TMDLs approved for DC waters;
2. Review of translator methods used in other states;
3. Summary of the existing available fecal coliform and E. coli data collected in DC waters;
4. Summary of the current DC monitoring strategies and relevant reports;
5. Data gaps
6. Options for development of a bacteria translator for DC waters; and
7. The chosen DC bacteria translator equation.

The approved bacteria TMDLs were developed using models to estimate the conditions for which receiving waters would meet the DC water quality standard for fecal coliform (200 MPN/100mL). Though the models for each TMDL varied, the types of input data (precipitation, stormwater bacteria event mean concentrations, etc.) and the endpoint were common across watersheds. These common elements will make it fairly simple to translate annual allocations from fecal coliform to E. coli with the use of the translator developed under this project.

Bacterial translators from three states (Ohio, Oregon, and Virginia) were reviewed in order to provide guidance for the development of a DC-specific translator. Similarities between the methods used to develop the translators in these states included use of large datasets of paired bacteria data (defined as water quality samples collected at the same site, and at the same time, that are analyzed for both E. coli and fecal coliform bacteria), use of statewide datasets (with the exception of Ohio, which separated

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datasets by region), and application of similar QA criteria to determine the acceptability of the data used in the analyses. These three factors (large sets of paired bacteria data; statewide datasets; and use of rigorous QA on the data) were determined to be important guidelines in assessing the data available in DC receiving waters for use in developing a DC-specific translator.

DC data were compiled to determine if they are sufficient to develop a DC-specific translator. Individual E. coli and fecal coliform bacteria measurements and paired bacteria data collected in DC waters and adjacent waters in Virginia were compiled from DDOE, the Maryland Department of the Environment (MDE), and the Virginia Department of Environmental Quality (VDEQ). There are 127 measurements of paired bacteria data available for analysis of a relationship for a DC-specific bacteria translator, and this amount of data was deemed to be sufficient for development of the DC-specific translator. The correlation between log-normalized E. coli and fecal coliform data was strong (R^2=0.83), and produced a quantitative relationship similar to that developed by VDEQ for their state-wide bacteria translator. The major data gap identified is a lack of paired bacteria data collected in the tributary waters of DC, where translation for many of the 24 bacteria TMDLs is needed.

Based on assessment of the currently available information, there are two options available for developing an approach to translating fecal coliform loads to E. coli in DC. One option is to use the VDEQ bacteria translator equation based on its current use in both Maryland and Virginia, and its similarity to the equation that expresses the relationship between E. coli and fecal coliform data in DC. This option reinforces use of a regionally consistent bacteria translator across the Washington, DC Metropolitan Area. A second option is to use the DC-specific equation with the understanding that it is based on a less robust amount of paired bacteria data, and that collection of additional paired bacteria data over time would be valuable in verifying the accuracy and precision of the relationship.

The translator equation preferred by EPA, DDOE and LimnoTech staff involved in this analysis is the one developed based on paired bacteria data collected in DC waters. This equation is

$$\text{Log}_2(\text{E. coli}) = 0.8906[\text{Log}_2(\text{Fecal coliform})]-0.1725.$$

It is recommended that this equation be used to convert bacteria loads from fecal coliform to E. coli in the 24 approved bacteria TMDLs in DC.

1 SUMMARY OF DC BACTERIA TMDLS

TMDLs for fecal coliform bacteria were approved by EPA Region 3 for 24 impaired segments of DC waters during 2003-2004. The segments were, in most cases, grouped so that the methodology used to model bacteria loads and future conditions are shared among segments (Table 1). In general, monitoring data from the DC's stormwater program (fecal coliform, TSS, pH, temperature, conductivity, and dissolved oxygen) and stormwater flow data from either the stormwater program or USGS gages, when available, was used to estimate loads from the stormwater system. Flow and event mean concentration data from DC Water's combined and separate sewer system outfalls were used to determine the contribution of bacteria to receiving waters from sewer systems,. Other inputs to the models included precipitation data (from Reagan National Airport's weather station), upstream loads from contributing waterbodies (e.g., segments in Maryland), and direct overland runoff (e.g., from waterfowl and park areas).

A variety of bacteria models were employed across the various DC watershed TMDLs (including the DC Small Tributaries model, MOUSE, TAM/WASP, EFDC, and HSPF), but they all had a common endpoint (or TMDL water quality target) of meeting the 30-day geometric mean criteria of 200 MPN/100mL, the DC water quality standard for fecal coliform in Class A waters in place at that time (DDOE 2004).

Models were applied to simulate scenarios associated with specific percent reductions in bacteria loads that were adjusted until the model output provided 0 percent exceedance of the bacteria water quality standard. Allocations and percent reductions in fecal coliform average annual load required to meet this water quality standard varied according to watershed and segment. Appendix Table A-1 provides a more detailed summary of the type of data, time period, model inputs, allocations, and percent reduction in fecal coliform average annual loads used to develop the TMDLs.

Table 1. DC Bacteria TMDLs

Impaired Waterbody	Watershed	Date TMDL Received EPA Approval	Reference
Fort Chaplin Run	Anacostia River	8/28/2003	DDOH 2003a
Fort Davis Tributary			
Fort DuPont Creek			
Fort Stanton Tributary			
Hickey Run			
Watts Branch			
Nash Run			
Popes Branch			
Texas Avenue Tributary			
Anacostia River			
Kingman Lake	Anacostia River	10/31/2003	DDOH 2003b
Lower Rock Creek	Rock Creek	2/28/2004	DDOH 2004a
Upper Rock Creek			
Battery Kemble Creek	Potomac River	10/6/2004	DDOH 2004b
Dalecarlia Tributary			
Foundry Branch			
Lower Potomac River			
Middle Potomac River			
Upper Potomac River			
Chesapeake and Ohio Canal	Potomac River	12/15/2004	DDOH 2004c
Oxon Run	Anacostia River	12/15/2004	DDOH 2004d
Tidal Basin	Potomac River	12/15/2004	DDOH 2004e
Washington Ship Channel			

2 REVIEW OF TRANSLATOR METHODS

A review of translator methods employed by other states was undertaken in order to identify guidelines for development of a DC-specific translator equation. Three states, Ohio, Oregon and Virginia, have documentation on the development and use of bacteria translators.

2.1 Ohio (OEPA 2006)

The Ohio Environmental Protection Agency (OEPA) compiled fecal coliform and E. coli data from their Northeast, Central, Southwest, and Southeast Districts. The Northwest District of EPA sampled E. coli much less frequently than the other districts so its data was not included in the analysis for developing the translator. The following data were deleted from the dataset of over 6,000 pairs of data per QA/QC procedures: all non-detects (for either fecal coliform or E. coli in a pair of data), values which were too high to be quantified by the analytical laboratory, data with problems noted by the lab (e.g., holding time violated), data outside of the recreation season (May 1-Oct 15), and data not collected in a stream (e.g., data collected at outfalls). Ohio developed two translators: one for the Northeast District, and one for the rest of the state. This was done for two reasons: 1) a different laboratory was used for the Northeast District, and 2) the resulting translator equations were statistically different between the Northeast District and the rest of the state.

The data were first log-transformed and then correlated using a Type 2 regression in order to enable OEPA to convert back and forth between E. coli and fecal coliform values (and avoid one variable being dependent and one being independent). A simple linear regression was ruled out for this reason. For the Northeast District, the translator equation is:

$$\text{E. coli} = 0.667(\text{fecal coliform})^{1.034}$$

For the rest of the state the translator equation is:

$$\text{E. coli} = 0.403(\text{fecal coliform})^{1.028}$$

2.2 Oregon (Cude 2005)

The Oregon Department of Environmental Quality (ODEQ) collected paired bacteria data in Oregon streams between February 1996 and December 1999 from stations in their ambient monitoring network. Censored or estimated data were removed, leaving 614 pairs of data from 105 stations. The data were first log-transformed (using base 10) and then analyzed in order to determine whether spatial location or data quality is a significant factor. The model that included "high quality" and all ambient data had the best fit. The resulting translator equation is:

$$\text{E. coli} = 0.531(\text{fecal coliform})^{1.06}$$

2.3 Virginia (VDEQ 2003)

VDEQ had a dataset of 493 paired samples from their statewide monitoring network. The membrane filtration method was used to analyze fecal coliform. Screening of data included removing samples that did not meet the cell density requirement of 20 to 60 CFUs or when reported as high outliers (Too Numerous to Count, TNTC). During development of the translator, VDEQ consulted with several academic reviewers to consider four pools of data as options for the basis of the translator: 1) all paired E. coli/fecal coliform monitoring data, 2) all monitoring data with combined analyses (from the same plate), 3) EPA bacteria criteria (instead of using actual data, use the ratio of 200 CFU fecal coliform: 126 MPN E. coli as the basis for the translator), and 4) all paired bacteria data, but on a site-specific basis (develop many site-specific translators). Option 1 was the overwhelmingly favored method due to its simplicity and inclusiveness of the largest group of data.
The data were log-transformed (base 2) and the resulting translator equation is:

$$\text{Log}_2(\text{E. coli}) = 0.9191[\text{Log}_2(\text{Fecal coliform})] - 0.0172$$

2.4 Maryland (Thomas Thornton, MDE, pers. comm.)

MDE was also contacted concerning their use of a bacteria translator. MDE indicated that they have not developed their own state translator and, instead, use the VDEQ translator. However, MDE has not developed or translated any TMDLs with the translator at the time this memo was written. Instead, they used the VDEQ translator to translate wastewater treatment plant (WWTP) effluent concentrations from E. coli to fecal coliform in the shellfish TMDLs, because the water quality standard for protection of shellfish is expressed in fecal coliform. Newer WWTP permits and monitoring data are expressed in E. coli.

2.5 Discussion

The translators reviewed from Ohio, Oregon and Virginia had some common elements that can be used as guidance for developing the DC translator. First, they were developed based on a large set of paired bacteria data collected from a diversity of land uses and waterbodies over a wide enough time period to account for inter- and intra-annual environmental variability. Second, development of the translators used similar QA/QC methods to remove data that exceeded or fell below detection limits or was marked for QA issues by the analytical laboratory. Third, all paired bacteria data for the state was combined to develop one translator to be used across the state. The one exception to this was in Ohio, where a separate translator was developed for the Northeast District of Ohio EPA. This exception was due to the use of different analytical laboratories and because there was a statistically significant difference in the equations used to translate fecal coliform to E. coli in the Northeast District, as compared to the rest of the state. These common elements were used as guidelines when evaluating the bacteria dataset available for DC waters to determine whether it is sufficient to develop an equation to translate fecal coliform TMDLs to E. coli.

3 REVIEW OF DC DOCUMENTS, PLANS AND GUIDANCE

This section provides a review of relevant DDOE documents, plans and guidance used in order to evaluate 1) what type of bacteria data was collected (and collection methodology), and 2) if the data collected is sufficient to develop a bacteria translator equation. . The documents summarized below are:

- Triennial Review of the District of Columbia's Water Quality Standards(DDOE 2010a)
- District of Columbia Water Quality Monitoring and Assessment Strategy (DDOE 2004a)
- Draft NPDES Permit No. DC0000221 Authorization to Discharge under the National Pollutant Discharge Elimination System Municipal Separate Stormwater System Permit
- (DDOE 2004b)
- The District of Columbia Water Quality Assessment 2010 Integrated Report to the Environmental Protection Agency and U.S. Congress Pursuant to Sections 305(b) And 303(d) Clean Water Act (DDOE 2010c)

3.1 Triennial Review of the District of Columbia's Water Quality Standards (DDOE 2010a)

All waters in DC with the exception of wetlands have primary contact recreation (Class A) as a designated use, although none of the waters in DC are listed for primary contact recreation as a current use (defined as "the use that is generally and usually attained based upon the water quality in the waterbody" (p. 27)). Bacteria criteria for Class A waters are currently based on E. coli, although the fecal coliform standard is also provided for comparison (Table 2).

Table 2. DC Bacteria Water Quality Standards

Basis	E. coli (MPN/100mL)	Fecal Coliform (MPN/100mL)
Geometric Mean[1] (Maximum 30 day geometric mean for 5 samples)	126	200
Single Sample Value	410	

3.2 District of Columbia Water Quality Monitoring and Assessment Strategy (DDOE 2004a)

The most recent version of the DC Water Quality Monitoring and Assessment Strategy was completed in 2004. A revised version is currently being drafted, but monitoring activities since 2004 have followed the 2004 version of the strategy (George Onyullo, DDOE, *pers. comm.*). The fecal coliform data provided by DDOE for 2005-2007 largely follow what is stated in the monitoring strategy in terms of frequency of sampling, and number and distribution of monitoring locations (Table 3). There are two exceptions that highlight the difference between the fecal coliform data provided by DDOE and the monitoring strategy: 1) DDOE provided data collected at seven stations that were not in the monitoring strategy; and 2) the data from twelve stations (all tributaries) were not collected at the frequency stated in the strategy.

The monitoring strategy does not include any mention of E. coli or paired bacteria data, since fecal coliform was the standard bacteria indicator for water quality at the time the strategy was published, and there were no requirements for collecting E. coli data as well. Thus, it is not possible to comment on the sufficiency of DC's monitoring strategy with respect to the collection of E. coli or paired bacteria data. The following evaluation is based on the assumption that E. coli replaced fecal coliform in the monitoring strategy starting in 2008. E. coli data is available from fewer than half the stations (23) where fecal coliform was collected (54) prior to 2008. The frequency and distribution (mix of mainstem and tributaries) of stations seems to follow the monitoring strategy with respect to bacteria sampling in general, though there is a much lower frequency of samples collected at tributary stations.

Table 3. Frequency of Fecal Coliform Monitoring at DC Water Quality Stations

Type of Station	# Stations	Frequency
Anacostia and Potomac Rivers	26	Bimonthly or monthly, depending on station
Tributaries	37	Quarterly (27 stations every year, 10 stations every 5 years)

Storage and accessibility of bacteria were also evaluated. According to the DC monitoring strategy, the bacteria data are supposed to be reported to EPA STORET and the Chesapeake Bay Program every six months. However, a search of EPA STORET did not reveal any bacteria data from DDOE. The Chesapeake Bay Program database was queried and did not include any E. coli data from any agency, though fecal coliform data is available from DDOH (District Department of Health; DDOE's predecessor) up until December 2006.

In summary, it is difficult to evaluate the adherence of the data collected by DDOE to the monitoring strategy mostly due to the change in the bacteria indicator from fecal coliform to E. coli in 2008. It is understandable that it takes time to transition monitoring protocols and data management. Other factors

[1] The geometric mean criterion shall be used for assessing water quality trends and for permitting. The single sample value criterion shall be used for assessing water quality trends only.

which make it challenging to evaluate the data are the age of the monitoring strategy, and the availability of bacteria data in public databases.

3.3 Draft NPDES Permit (DDOE 2004b)

DDOE was issued a NPDES stormwater permit on August 19, 2004, with an expiration date of August 18, 2009. Although a new permit has not been issued yet, a draft of the new permit was provided by DDOE, and this review evaluates that version. E. coli appears on the list of required parameters, in order to

> "Make wet weather loading estimates…from the MS4 to receiving waters. Number of samples, sampling frequencies and number and locations of sampling stations must be adequate to ensure data are statistically significant and interpretable" (p. 27).

However, because the draft permit has no specific requirements for monitoring bacteria levels in receiving water bodies, its applicability to this project is minimal.

3.4 2010 Integrated Report (DDOE 2010c)

For the 2010 reporting cycle of the Integrated Report, use support decisions were made using data collected from 2008-2009. E. coli data is supplied in a statistical summary report for 45 stations throughout DC. However, because there is no reporting of paired bacteria data in the Integrated Report, it is of minimal use to the development of a bacteria translator equation.

4 REVIEW OF AVAILABLE BACTERIA DATA FROM DC WATERS

A review of available bacteria data is central to the development of an understanding of bacteria in DC waters and how a translator can be developed. This section focuses on fecal coliform, E. coli, and paired fecal coliform/E. coli data. Paired bacteria data is defined as water quality samples collected at the same site, and at the same time, that are analyzed for both E. coli and fecal coliform bacteria. The time period of this data summary is limited to between January 1, 2005 and the present.

4.1 Non-paired Bacteria Data

4.1.1 Fecal coliform

Fecal coliform data has been collected in DC waters by DC agencies for several decades. DDOE provided fecal coliform data collected between 2005 and 2007 at 54 stations throughout DC. The Chesapeake Bay Program's database was queried for bacteria data, but there was not any additional data available from other agencies or for a different time period than what was already compiled. MDE also occasionally collects bacteria data in DC waters. The data summarized in Table 4 represents MDE (queried from EPA's STORET database) and DDOE data collected in DC waters. Fecal coliform data collected in the absence of paired E. coli data does not have any specific value in developing a bacteria translator, however it is available for certain applications, such as determining compliance with water quality standards once the translator is developed (and fecal coliform values are translated to E. coli).

Table 4. Summary of Available Fecal Coliform Data

Period	Number of Stations	Number of Measurements	Source
2007	55	315	DDOE, MDE
2006	56	377	DDOE, MDE
2005	54	263	DDOE

4.1.2 E. coli

E. coli data has been collected in DC waters since 2005. The standard indicator for bacteria was officially changed to E. coli from fecal coliform in 2008 (DDOE 2008). DDOE provided E. coli data and additional data was obtained through a search of EPA's STORET database and VDEQ's water quality database. No E. coli data is available for any agency in the Chesapeake Bay Program's database. E. coli data from DDOE is available for a limited time period, mostly in 2008, for 23 stations. At 17 of these 23 stations, E. coli was analyzed from water samples once per month. Monitoring at the remaining stations resulted in three to five samples for E. coli for these locations in 2008. There is no corresponding (paired) data for fecal coliform for any of these DDOE stations during this time period. MDE data was retrieved from STORET. MDE collected this data at four stations (Figure 1) between 2005 and 2007, for a total of 93 measurements. Finally, VDEQ has E. coli data for twelve measurements taken at one tidal Potomac station between 2005 and 2008. All E. coli samples were analyzed using the membrane filtration method.

A summary of readily available E. coli data is presented in Table 5. E. coli data collected in the absence of paired fecal coliform data does not have any specific value in developing a bacteria translator.

Table 5. Summary of Available E. coli Data

Period	Number of Stations	Number of Measurements	Data Source
2010	2	2	DDOE
2009	18	32	DDOE
2008	24	217	DDOE, VDEQ
2007	3	29	MDE, VDEQ
2006	3	33	MDE, VDEQ
2005	2	40	MDE, VDEQ

4.2 Paired Fecal Coliform and E. coli Data

Paired fecal coliform and E. coli data is available from three agencies mentioned above: DDOE, covering 20 stations spread across DC; MDE, covering four Anacostia River watershed stations; VDEQ, from one tidal Potomac station

4.2.1 DDOE 2007-2010

Paired E. coli/fecal coliform throughout DC were provided by DDOE for July-August 2010 and April-May 2007. Screening of the data for data quality for all datasets led to the elimination of several observations: values that were estimated because they fell below or exceeded detection limits (e.g., <1 or >160,000), values estimated outside of standard methods, or values with any other quality issues noted by the analytical lab. The resulting dataset consists of 24 pairs of E. coli/fecal coliform data from 20 stations (Figure 1).

All data are expressed in most probable number (MPN) per 100 mL, indicating that the samples were analyzed using the multiple tube fermentation method. This is a different method than that used to analyze fecal coliform by MDE and VDEQ. Since MPN is a statistical reporting method, there tends to be more variability associated with it and results average slightly higher than those reported using the membrane filtration method (reported in CFU). This is not a result of human or laboratory error, but a consequence of the probabilistic basis for calculating MPN (Gronewald and Wolpert 2008). Since a direct equation providing a conversion between CFU and MPN is not available, it is assumed that they are roughly equivalent measurements for this data summary.

It is important to evaluate the range of concentrations of both fecal coliform and E. coli data in the paired samples in order to determine if samples were collected in a wide range of conditions. Fecal coliform concentrations ranged from 20 to 33,000 MPN/100mL, and had a median of 388 MPN/100mL. E. coli concentrations ranged from 1 to 8,704 MPN/100mL, and had a median of 202 MPN/100mL (Table 6, Figure 2). This is an acceptably large range of data.

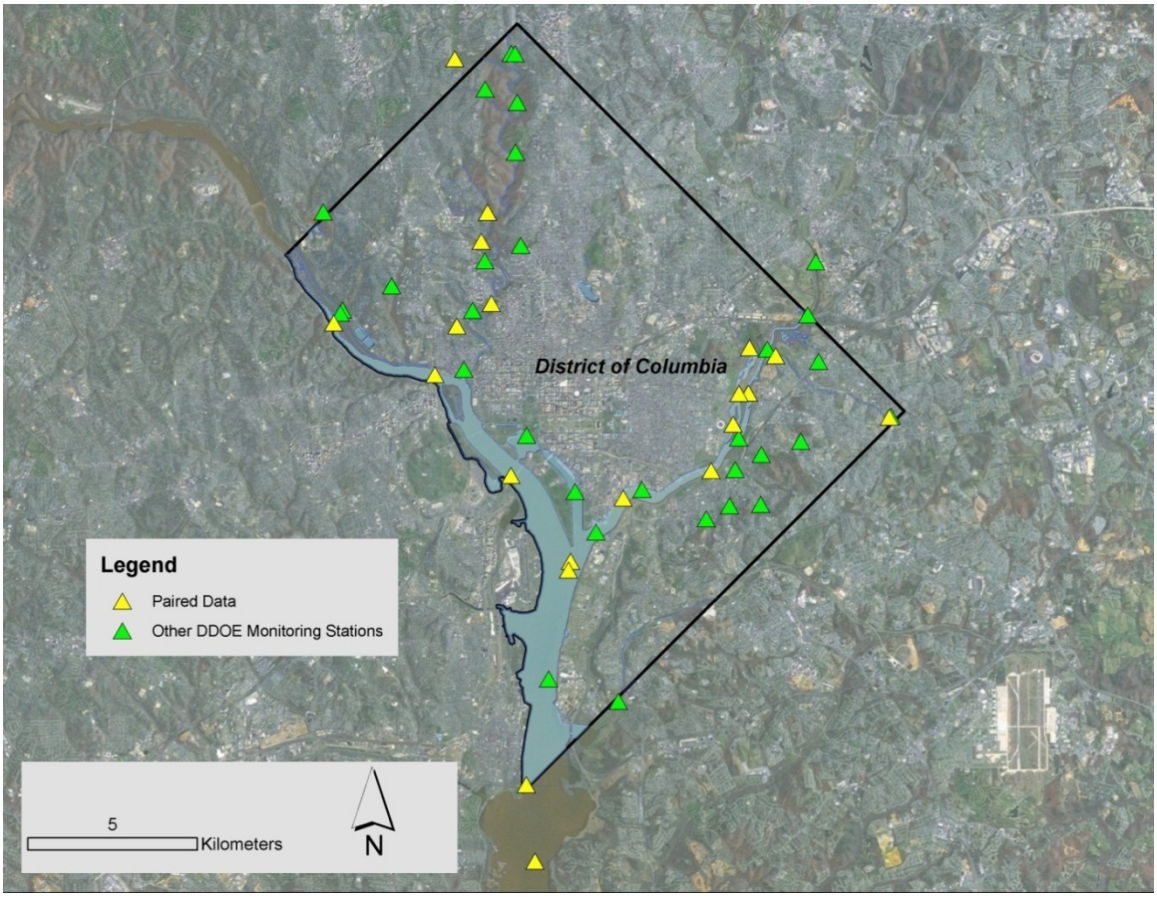

Figure 1. District Department of the Environment Monitoring Sites for Bacteria.

Table 6. Summary Statistics of Fecal Coliform and E. coli from DDOE Paired Bacteria Data

Statistics	Fecal Coliform (MPN/100mL)	E. coli (MPN/100mL)
Min	20	1
Max	33,000	8,704
Median	388	202

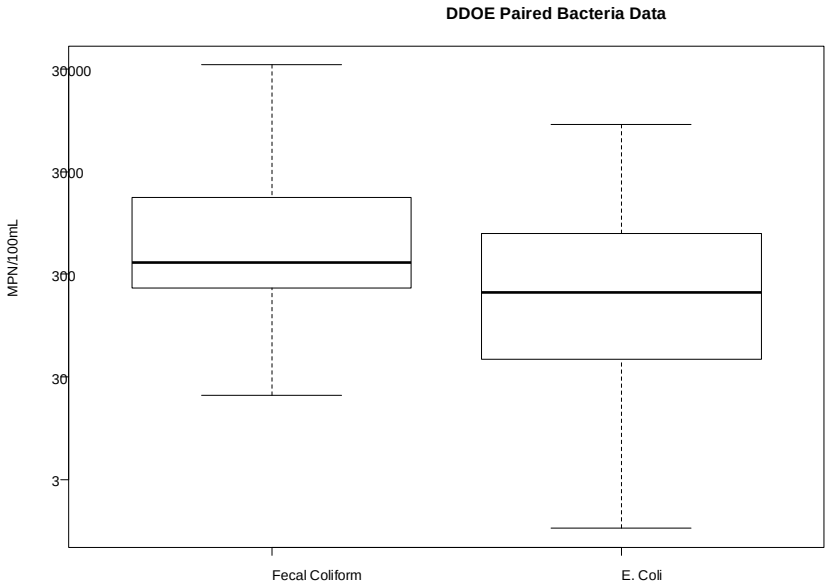

Figure 2. Box and Whisker Plots of DDOE Paired Bacteria Data. Note Log Scale.

On 3 of the 9 days sampled in 2008-2010, more than 0.1 inches of rain (daily total) was recorded at National Airport. These samples likely represent data collected in wet weather conditions. In general, the DDOE dataset appears to represent a good mix of wet and dry weather conditions (See Appendix A, Table A-2).

The relationship between DDOE's transformed (log base 2, to be consistent with the VDEQ translator method and previous analyses) E. coli and fecal coliform data (shown in blue) was explored and was weak (R^2=0.25; Figure 3).

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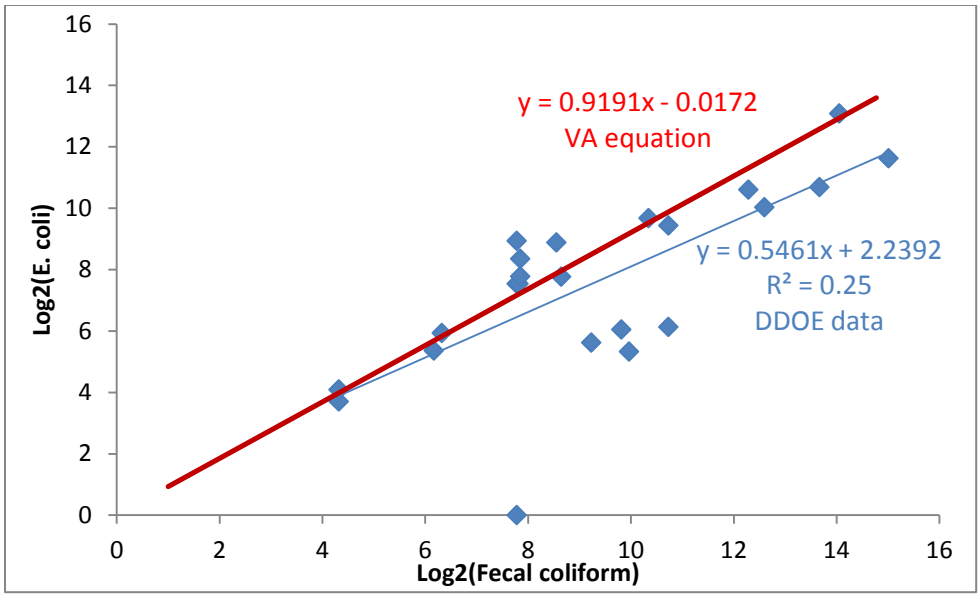

Figure 3. Log-Transformed DDOE Paired Bacteria Data Compared to the VDEQ Translator Equation.

4.2.2 Maryland Department of the Environment, 2005 - 2007

A search of EPA's STORET database for all bacteria data collected within DC produced the paired bacteria data collected from MDE. MDE analyzed water quality samples for bacteria that were collected at four stations in the Anacostia River watershed within DC waters (Figure 4) approximately every two weeks for the time periods of June-October 2005 and 2006; and July-October 2007. There are 93 paired samples in total, collected at one station in 2005 (Station CA), two stations in 2006 (Stations DC OUT and WA) and at two stations in 2007 (Stations SA and CA). Fecal coliform was analyzed using the membrane filtration method, and the data are expressed in colony forming units (CFU). Fecal coliform concentrations ranged from 2 to 160,000 CFU/100mL, with a median of 100 CFU/100mL (Table 7, Figure 5), The corresponding E. coli concentrations ranged from 2 to 48,000 MPN/100mL, with a median of 87 MPN/100 mL. This is an acceptably large range of both fecal coliform and E. coli data.

Table 7. Summary Statistics of Fecal Coliform and E. coli from MDE Paired Bacteria Data

Statistic	Fecal Coliform (CFU/100mL)	E. Coli (MPN/100mL)
Min	2	2
Max	160000	48000
Median	100	87

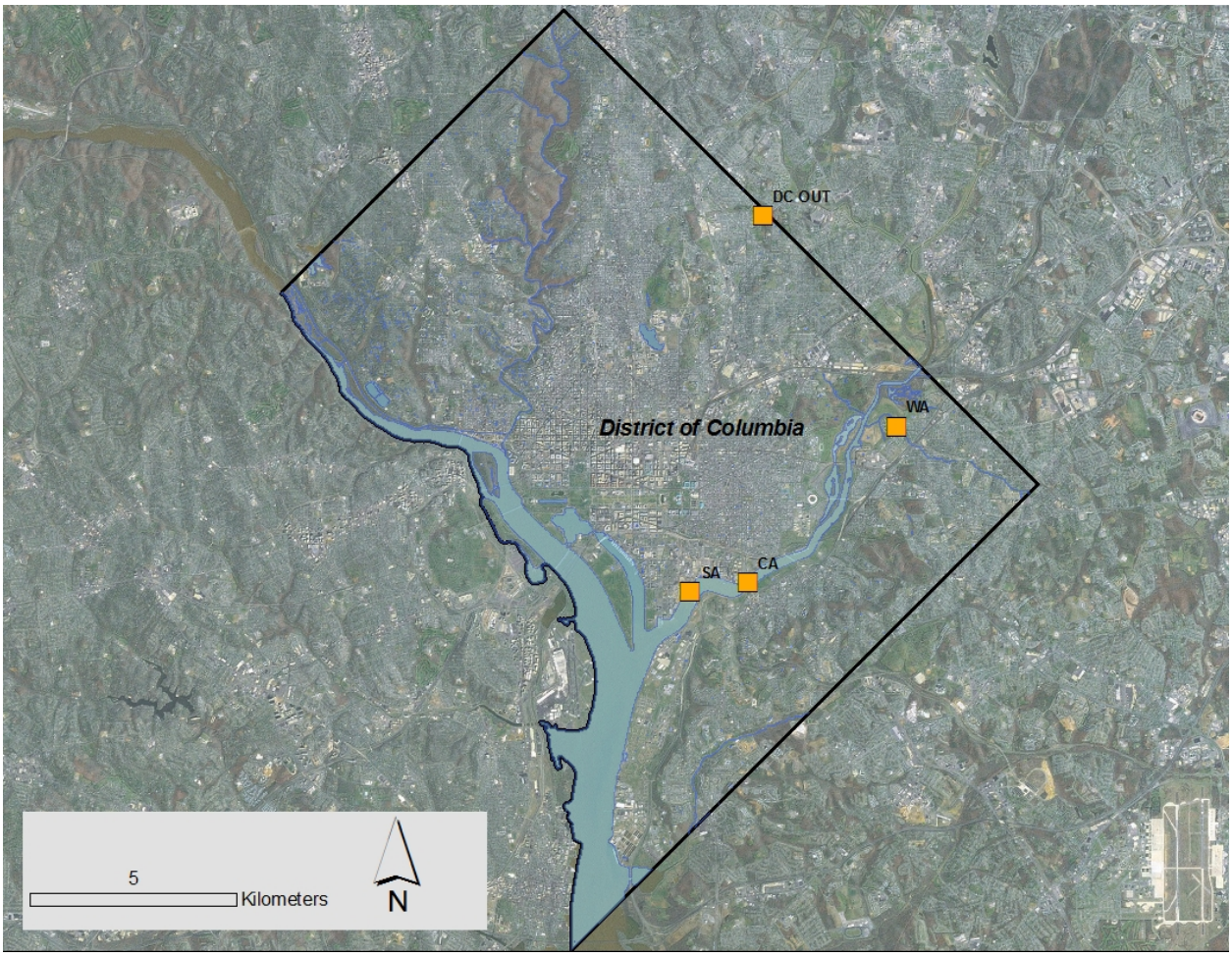

Figure 4. MDE Paired Bacteria Monitoring Sites in the District of Columbia.

On 12 of the days sampled in 2005-2007, there was more than 0.1 inches of rain recorded at National Airport. These samples are considered to be collected in wet weather conditions, so the MDE dataset appears to represent a good mix of wet and dry weather conditions (See Appendix A, Table A-2).

The relationship between the log-transformed (to base 2) fecal coliform and E. coli data for this dataset (shown in green) in Figure 6 shows a high degree of correlation (R^2=0.89). It is also quite similar to the relationship developed by VDEQ for their bacteria translator (shown in red in Figure 6).

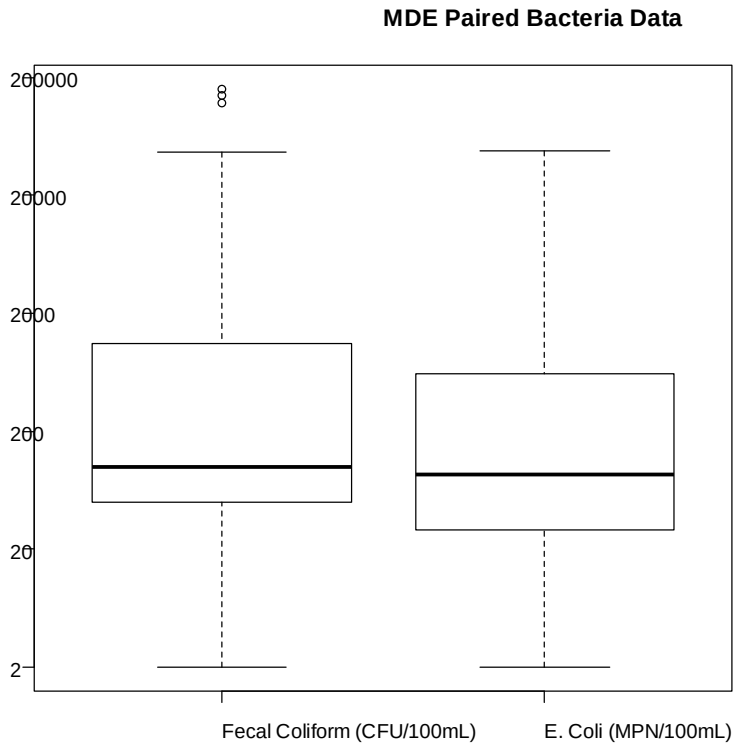

Figure 5. Box and Whisker Plots of MDE Paired Bacteria Data. Note log scale and different units for fecal coliform (CFU/100mL) and E. coli (MPN/100mL).

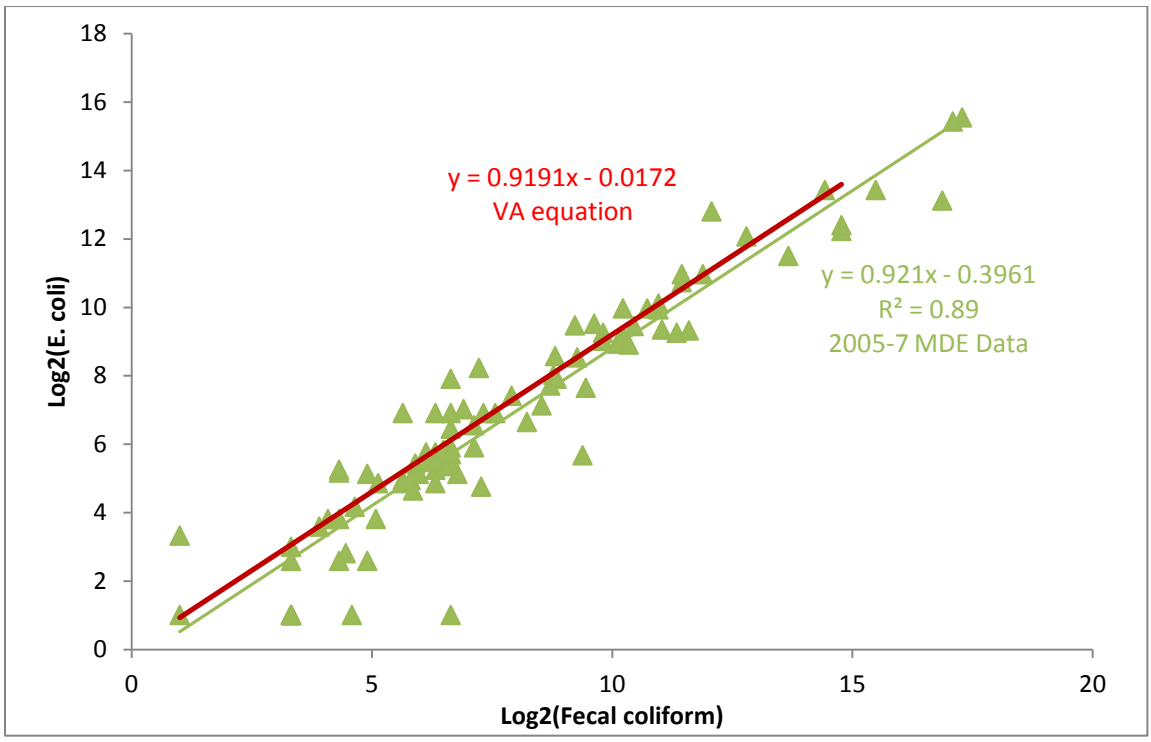

Figure 6. Regression of Paired MDE Bacteria Data with VDEQ Translator Regression

4.2.3 VDEQ 2005-2008

A search of VDEQ's water quality database for all bacteria data collected within the tidal influence of DC waters produced ten measurements of paired bacteria data collected between 2005 and 2008 at a tidal Potomac station in the Hunting Creek Embayment (Station 1AHUT000.01, Figure 7). Like MDE, VDEQ analyzed fecal coliform using the membrane filtration method, and the data are expressed in CFU/100mL. Fecal coliform concentrations ranged from 75 to 1,300 CFU/100mL, with a median of 375 CFU/100mL; and E. coli had a range of 25 to 1,400 MPN/100mL, with a median of 315 MPN/100 mL (Table 8). Two of the twelve days sampled occurred during wet weather conditions (See Appendix A, Table A-2). Although this is not an ideal mix of wet and dry weather, it is still acceptable since both weather conditions are met (though not equally distributed), especially considering the small number of samples.

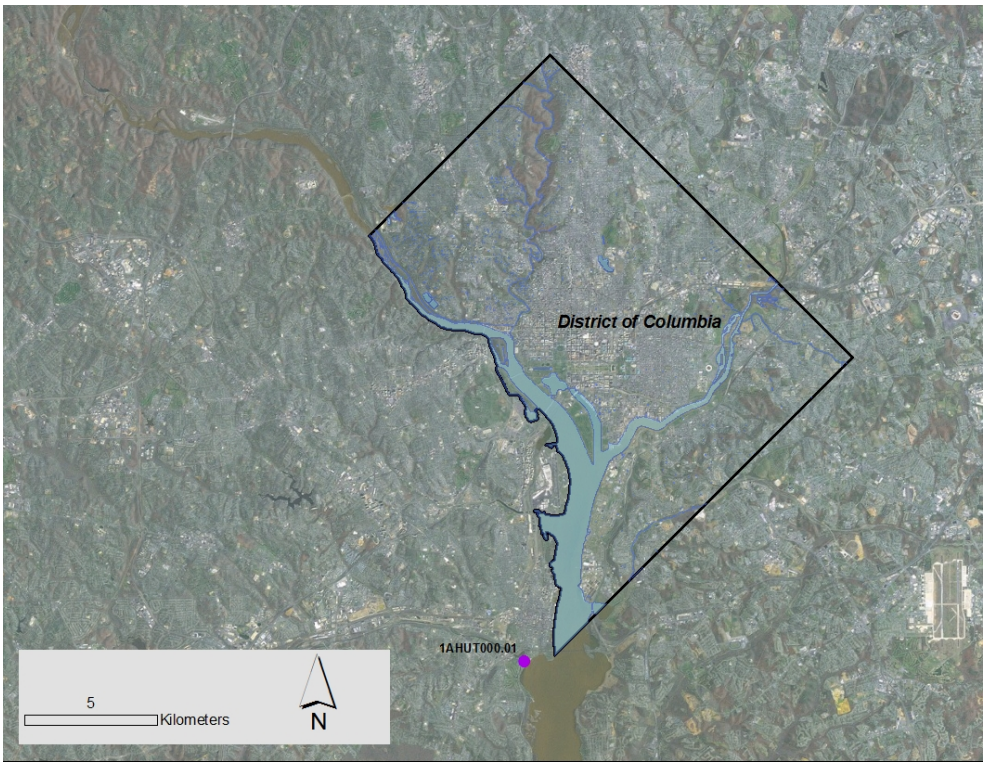

Figure 7. VDEQ Monitoring Station with Paired Bacteria Data within the Tidal Influence of DC Waters.

Table 8. Summary Statistics of Fecal Coliform and E. coli from VDEQ Paired Data

	Fecal coliform (CFU/100mL)	E. coli (MPN/100mL)
Min	75	25
Max	1300	1400
Median	375	315

4.2.4 All DC Paired Bacteria Data

In summary, the available paired bacteria data for DC waters includes data collected over the spring, summer and fall months over five years (though months are not consistent for each year) from three agencies, at 28 different stations throughout DC for a total of 127 discrete paired measurements. The best temporal coverage of paired bacteria data (in terms of frequency of collection) is 2005-2007 (MDE). As

demonstrated in Figure 8, when the MDE, VDEQ, and DDOE paired datasets are all combined to represent all paired data readily available in DC waters since 2005 (shown in purple), the correlation (on the transformed dataset) was found to be strong (R^2=0.83), and the resulting equation is similar to the VDEQ bacteria translator equation (shown in red).

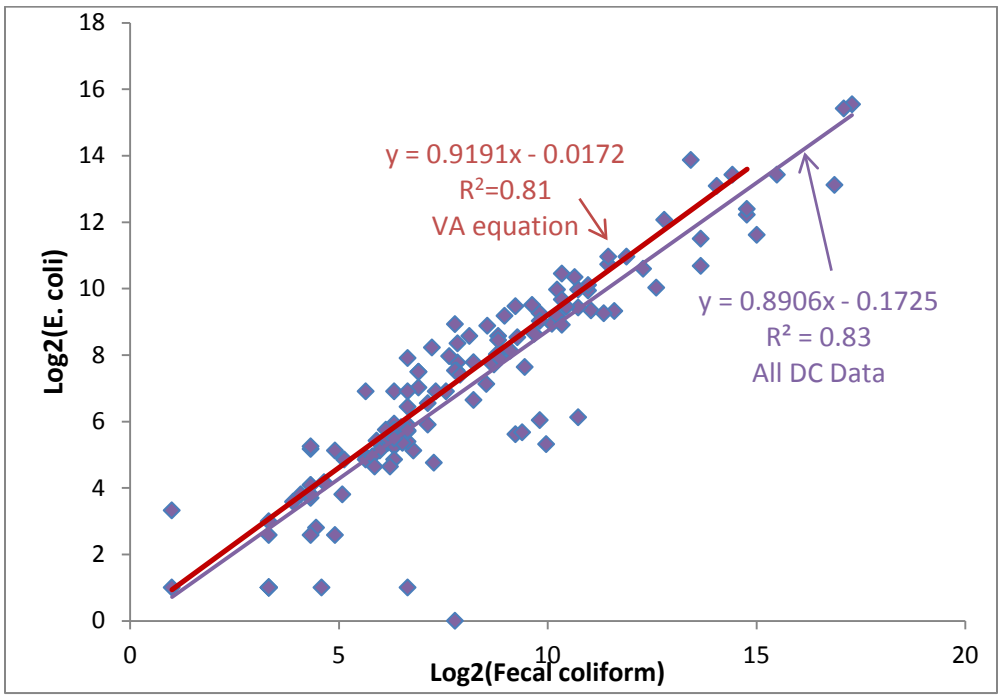

Figure 8. All Combined, Log-Transformed DC Data (DDOE, MDE and VDEQ Datasets) Compared to the VDEQ Bacteria Translator Regression.

5 IDENTIFICATION OF DATA GAPS

There are two data gaps that were identified. First, no paired bacteria data are available for 2009. Second, the DDOE data for tributaries is weak. This is the most important data gap to address since 17 of the 24 waterbodies impaired by bacteria are tributaries.

6 RECOMMENDATION ON WHETHER EXISTING PARIED DATA IS SUFFICIENT FOR TRANSLATOR DEVELOPMENT

The available paired bacteria data for DC waters includes data collected mostly during the recreation season (June to October) over 5 years (though months are not consistent for each year) from three agencies, at 28 different stations throughout DC for a total of 127 paired measurements. Consultations with agencies that have developed translators in other states suggest that the minimum amount of data needed for a new translator includes 20-30 pairs of data per station collected over about 2-3 years. Only one MDE station (Station CA) fits these guidelines (Table 9). It is also important to have stations that represent the range of land use and water quality conditions in the state, and for sample collection times to be representative of typical inter-annual variability (season, wet/dry weather, etc.).

DC is entirely urbanized and, collectively, all of the stations are representative of DC urban waters. In addition, inter-annual variability is good with wet and dry weather conditions represented, as well as most of the months in which contact recreation takes place (months in which data was collected varies by location, with May having the least number of samples taken).

Table 99. Paired Bacteria Data by Station.

Station	# Paired Samples Per Station
1AHUT000.01	10
ANA08	1
ANA14	1
ANA21	2
ANA29	1
CA	49
DC OUT	16
KNG01	1
KNG02	1
PMS01	1
PMS10	1
PMS21	1
PMS29	2
PMS44	1
PMS51	1
RCR01	2
RCR09	1
SA	12
TBR01	1
TD001	1
THR01	2
TMH01	1
TWB01	1
TWB06	1
WA	16

There are some exceptions to the acceptability of the data to consider, though they are minor. First, the laboratories that were used to analyze the VDEQ and MDE data are unknown, but it is assumed there are at least two different laboratories involved, and a third, when considering DDOE's data. Faced with a similar issue of different laboratories, Ohio EPA chose to develop separate translators. However, the small amount of paired bacteria data available for DC and the small size of DC preclude the development of more than one translator equation from being a practical option. Second, DDOE's laboratory used a different analytical method for their fecal coliform analysis than the other two states (Maryland and Virginia). Since there is an absence of a translator between the units (CFU and MPN), it is assumed that they are equivalent. Third, the available paired bacteria data for DC waters do not meet all of the guidelines mentioned in Section 2 for paired bacteria datasets, but there are extenuating circumstances. The geographic area of DC is very small and entirely urbanized. The number of stations where paired bacteria data is available is good but there is often only one set of paired bacteria data at individual stations. Collectively, all stations represent urban conditions. The seasonal distribution of paired bacteria data across the spring, summer and fall is satisfactory, as is the mix of wet and dry weather data. The use of different analytical methods might be viewed as a problem in regard to the comparability of the data, or it might be viewed as unimportant since the correlation coefficient is rather good.

On a qualitative basis, and despite the caveats described above, the available paired bacteria data collected in DC waters by three agencies is sufficient for the development of a DC-specific translator equation. The favorable correlation coefficient between the E. coli and fecal coliform data collected in DC waters and the similarity of the DC-specific translator equation to the VDEQ equation support the

adequacy of the data. The collection of additional paired bacteria data in the future, particularly paired bacteria data from DC tributaries, would be valuable in verifying the accuracy and precision of the DC-specific translator equation.

7 RECOMMENDED TRANSLATORS FOR DC

A translator equation is needed to convert the existing DC bacteria TMDLs from fecal coliform to E. coli. Linear regression analysis was conducted using all of the DC paired bacteria data, with log-transformed E. coli values regressed against log-transformed fecal coliform values. The least-squares best fit equation is:

$$Log_2(\text{E. coli}) = 0.8906[Log_2(\text{Fecal coliform})] - 0.1725$$

This regression represents a DC-specific translator equation. The regression was tested for the significance of its slope using the software package Minitab, and the slope was found to be significant with $p<0.001$. This indicates a less than one in one thousand chance that the observed correlation is due to random chance. A test was also performed to determine whether or not the regression line obtained from the DC data is significantly different from the given VA regression line. Joint confidence intervals were constructed using the t-distribution for the slope and intercept of the DC regression line. It was found that the VA model parameters were within the confidence interval bounds with joint $p>0.85$; thus the equations are not significantly different. In other words, under the assumption that the true regression lines are exactly the same, the observed difference in the regression line estimated from data could be expected to occur with greater than 85 percent probability based on sampling uncertainty alone. Detailed results of the statistical analysis are provided in Appendix B.

There are two recommended options for moving ahead with a translator for DC bacteria TMDLs:

1) Use the DC-specific translator equation
2) Use the VDEQ translator equation

Since the two equations are not significantly different at the 85% confidence level, there is little difference between the two choices, and either one could provide a sufficient level of confidence to translate fecal coliform load allocations to E. coli.

It was agreed on the April 12, 2011 conference call among EPA, DDOE and LimnoTech participants that the DC-specific translator equation is the preferred translator to be used to translate the TMDL annual allocations for each impaired waterbody, evaluate compliance with the E. coli water quality standard (126 MPN/100mL), simulate additional reductions in loads through modeling (if necessary) to achieve compliance, and finally, express the annual allocations in terms of daily loads.

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APPENDIX A

Table A-1. Summary of Data, Models, Allocations, and % Reductions Used to Develop DC Bacteria TMDL

See separate file “Appendix_A-1_TMDL_Summary.pdf”

Table A-2. Paired Bacteria Data Detail. Wet weather is defined as when daily rainfall is greater than 0.1 in.

Station	Waterbody	Watershed	Date	Fecal Coliform[2]	E coli (MPN/100mL)	Weather	Source
ANA08	Anacostia River	Anacostia River	7/13/2010	5000	1553	Wet	DDOE
ANA14	Anacostia River	Anacostia River	7/13/2010	1700	691	Wet	DDOE
ANA21	Anacostia River	Anacostia River	8/24/2010	72	41	Dry	DDOE
ANA21	Anacostia River	Anacostia River	7/13/2010	600	49	Wet	DDOE
ANA29	Anacostia River	Potomac River	4/10/2007	220	1	Dry	DDOE
KNG02	Kingman Lake	Anacostia River	8/16/2010	220	185	Dry	DDOE
KNG01	Kingman Lake	Anacostia River	7/19/2010	6200	1046	Wet	DDOE
PMS10	Potomac River	Potomac River	7/12/2010	80	61	Wet	DDOE
PMS21	Potomac River	Potomac River	8/23/2010	1700	70	Dry	DDOE
PMS29	Potomac River	Potomac River	7/12/2010	20	13	Wet	DDOE
PMS29	Potomac River	Potomac River	8/23/2010	900	66	Dry	DDOE
PMS44	Potomac River	Potomac River	8/23/2010	1000	40	Dry	DDOE
PMS51	Potomac River	Potomac River	7/12/2010	20	17	Wet	DDOE
PMS01	Potomac River	Potomac River	7/12/2010	20	17	Wet	DDOE
RCR01	Rock Creek	Potomac River	8/17/2010	400	218	Dry	DDOE
RCR09	Rock Creek	Rock Creek	7/20/2010	230	326	Dry	DDOE
RCR01	Rock Creek	Potomac River	8/17/2010	226	185	Dry	DDOE
TBR01	Broad Branch	Rock Creek	7/20/2010	17000	8704	Dry	DDOE
TMH01	Melvin Hazen	Rock Creek	8/17/2010	230	219	Dry	DDOE
THR01	Hickey Run	Anacostia River	8/16/2010	376	473	Dry	DDOE

[2] Units for fecal coliform samples analyzed by MDE and VDEQ are in CFU/100mL, but are expressed in MPN/100mL for samples collected by DDOE (due to methodology). They are treated as equivalent since no translator between the two methods is readily available.

THR01	Hickey Run	Anacostia River	7/19/2010	33000	3148	Wet	DDOE
TWB01	Watts Branch	Anacostia River	7/19/2010	13000	1640	Wet	DDOE
TWB06	Watts Branch	Anacostia River	8/16/2010	220	488	Dry	DDOE
DC OUT	DC Stormwater Pipe Outfall	Anacostia River	6/20/2006	3800	2000	Wet	MDE
DC OUT	DC Stormwater Pipe Outfall	Anacostia River	6/27/2006	160000	48000	Wet	MDE
DC OUT	DC Stormwater Pipe Outfall	Anacostia River	7/11/2006	50	31	Wet	MDE
DC OUT	DC Stormwater Pipe Outfall	Anacostia River	7/25/2006	2	10	Dry	MDE
DC OUT	DC Stormwater Pipe Outfall	Anacostia River	8/1/2006	10	2	Dry	MDE
DC OUT	DC Stormwater Pipe Outfall	Anacostia River	8/8/2006	100	60	Dry	MDE
DC OUT	DC Stormwater Pipe Outfall	Anacostia River	8/15/2006	10	8	Dry	MDE
DC OUT	DC Stormwater Pipe Outfall	Anacostia River	8/22/2006	10	2	Dry	MDE
DC OUT	DC Stormwater Pipe Outfall	Anacostia River	8/29/2006	10	2	Wet	MDE
DC OUT	DC Stormwater Pipe Outfall	Anacostia River	9/12/2006	10	2	Dry	MDE
DC OUT	DC Stormwater Pipe Outfall	Anacostia River	9/19/2006	100	2	Dry	MDE
DC OUT	DC Stormwater Pipe Outfall	Anacostia River	9/26/2006	10	2	Dry	MDE

DC OUT	DC Stormwater Pipe Outfall	Anacostia River	10/3/2006	2	2	Dry	MDE
DC OUT	DC Stormwater Pipe Outfall	Anacostia River	10/17/2006	140000	44000	Wet	MDE
DC OUT	DC Stormwater Pipe Outfall	Anacostia River	10/24/2006	20	36	Dry	MDE
DC OUT	DC Stormwater Pipe Outfall	Anacostia River	10/31/2006	10	2	Dry	MDE
SA	Anacostia River	Anacostia River	7/12/2007	2800	1700	Dry	MDE
SA	Anacostia River	Anacostia River	7/19/2007	15	12	Wet	MDE
SA	Anacostia River	Anacostia River	7/26/2007	24	2	Dry	MDE
SA	Anacostia River	Anacostia River	8/2/2007	22	7	Dry	MDE
SA	Anacostia River	Anacostia River	8/9/2007	34	14	Wet	MDE
SA	Anacostia River	Anacostia River	8/16/2007	20	6	Wet	MDE
SA	Anacostia River	Anacostia River	8/23/2007	900	610	Dry	MDE
SA	Anacostia River	Anacostia River	9/13/2007	190	120	Dry	MDE
SA	Anacostia River	Anacostia River	9/20/2007	50	29	Dry	MDE
SA	Anacostia River	Anacostia River	9/27/2007	17	14	Dry	MDE
SA	Anacostia River	Anacostia River	10/4/2007	25	18	Dry	MDE
SA	Anacostia River	Anacostia River	10/25/2007	11000	15000	Wet	MDE
WA	Watts Branch	Anacostia River	6/20/2006	28000	4800	Wet	MDE
WA	Watts Branch	Anacostia River	6/27/2006	28000	5400	Wet	MDE
WA	Watts Branch	Anacostia River	7/11/2006	2000	980	Wet	MDE
WA	Watts Branch	Anacostia River	7/25/2006	2100	650	Dry	MDE
WA	Watts Branch	Anacostia River	8/1/2006	790	730	Dry	MDE

WA	Watts Branch	Anacostia River	8/8/2006	13000	2900	Dry	MDE
WA	Watts Branch	Anacostia River	8/15/2006	1100	490	Dry	MDE
WA	Watts Branch	Anacostia River	8/22/2006	440	260	Dry	MDE
WA	Watts Branch	Anacostia River	8/29/2006	620	370	Wet	MDE
WA	Watts Branch	Anacostia River	9/12/2006	100	240	Dry	MDE
WA	Watts Branch	Anacostia River	9/19/2006	1200	1000	Dry	MDE
WA	Watts Branch	Anacostia River	9/26/2006	600	710	Dry	MDE
WA	Watts Branch	Anacostia River	10/3/2006	420	210	Dry	MDE
WA	Watts Branch	Anacostia River	10/17/2006	46000	11000	Wet	MDE
WA	Watts Branch	Anacostia River	10/24/2006	80	120	Dry	MDE
WA	Watts Branch	Anacostia River	10/31/2006	50	120	Dry	MDE
CA	Anacostia River	Anacostia River	6/7/2005	22000	11000	Wet	MDE
CA	Anacostia River	Anacostia River	6/8/2005	2800	2000	Dry	MDE
CA	Anacostia River	Anacostia River	6/14/2005	80	54	Dry	MDE
CA	Anacostia River	Anacostia River	6/15/2005	110	35	Dry	MDE
CA	Anacostia River	Anacostia River	6/21/2005	10	6	Dry	MDE
CA	Anacostia River	Anacostia River	6/28/2005	900	520	Wet	MDE
CA	Anacostia River	Anacostia River	7/12/2005	150	300	Dry	MDE
CA	Anacostia River	Anacostia River	7/13/2005	120	130	Wet	MDE
CA	Anacostia River	Anacostia River	7/19/2005	700	200	Dry	MDE
CA	Anacostia River	Anacostia River	7/20/2005	160	120	Dry	MDE
CA	Anacostia River	Anacostia River	7/26/2005	670	51	Dry	MDE
CA	Anacostia River	Anacostia River	7/27/2005	300	100	Wet	MDE
CA	Anacostia River	Anacostia River	8/2/2005	20	38	Dry	MDE

CA	Anacostia River	Anacostia River	8/3/2005	30	6	Dry	MDE
CA	Anacostia River	Anacostia River	8/9/2005	120000	8900	Wet	MDE
CA	Anacostia River	Anacostia River	8/10/2005	3100	640	Dry	MDE
CA	Anacostia River	Anacostia River	8/16/2005	60	43	Wet	MDE
CA	Anacostia River	Anacostia River	8/17/2005	100	120	Dry	MDE
CA	Anacostia River	Anacostia River	8/23/2005	30	35	Dry	MDE
CA	Anacostia River	Anacostia River	8/24/2005	80	38	Dry	MDE
CA	Anacostia River	Anacostia River	8/30/2005	140	94	Dry	MDE
CA	Anacostia River	Anacostia River	8/31/2005	100	42	Dry	MDE
CA	Anacostia River	Anacostia River	9/6/2005	35	29	Dry	MDE
CA	Anacostia River	Anacostia River	9/7/2005	155	27	Dry	MDE
CA	Anacostia River	Anacostia River	9/13/2005	370	140	Dry	MDE
CA	Anacostia River	Anacostia River	9/14/2005	100	52	Dry	MDE
CA	Anacostia River	Anacostia River	9/20/2005	63	35	Dry	MDE
CA	Anacostia River	Anacostia River	9/21/2005	70	54	Dry	MDE
CA	Anacostia River	Anacostia River	9/27/2005	450	380	Dry	MDE
CA	Anacostia River	Anacostia River	9/28/2005	100	87	Dry	MDE
CA	Anacostia River	Anacostia River	10/4/2005	90	57	Dry	MDE
CA	Anacostia River	Anacostia River	10/5/2005	72	45	Dry	MDE
CA	Anacostia River	Anacostia River	10/11/2005	1400	700	Wet	MDE
CA	Anacostia River	Anacostia River	10/12/2005	1200	580	Wet	MDE
CA	Anacostia River	Anacostia River	10/18/2005	240	170	Dry	MDE
CA	Anacostia River	Anacostia River	10/25/2005	2000	1100	Wet	MDE
CA	Anacostia River	Anacostia River	10/26/2005	1700	1000	Dry	MDE

CA	Anacostia River	Anacostia River	7/12/2007	2600	610	Wet	MDE
CA	Anacostia River	Anacostia River	7/19/2007	56	31	Dry	MDE
CA	Anacostia River	Anacostia River	7/26/2007	58	25	Dry	MDE
CA	Anacostia River	Anacostia River	8/2/2007	92	41	Dry	MDE
CA	Anacostia River	Anacostia River	8/9/2007	80	45	Dry	MDE
CA	Anacostia River	Anacostia River	8/16/2007	80	29	Dry	MDE
CA	Anacostia River	Anacostia River	8/23/2007	1300	480	Dry	MDE
CA	Anacostia River	Anacostia River	9/13/2007	460	240	Dry	MDE
CA	Anacostia River	Anacostia River	9/20/2007	140	60	Dry	MDE
CA	Anacostia River	Anacostia River	9/27/2007	20	14	Dry	MDE
CA	Anacostia River	Anacostia River	10/4/2007	100	53	Dry	MDE
CA	Anacostia River	Anacostia River	10/25/2007	7100	4300	Dry	MDE
1AHUT000.01	Hunting Creek	Potomac River	7/19/2005	550	280	Dry	VDEQ
1AHUT000.01	Hunting Creek	Potomac River	8/30/2005	450	350	Dry	VDEQ
1AHUT000.01	Hunting Creek	Potomac River	3/1/2007	120	180	Wet	VDEQ
1AHUT000.01	Hunting Creek	Potomac River	5/3/2007	300	220	Dry	VDEQ
1AHUT000.01	Hunting Creek	Potomac River	7/16/2007	280	380	Dry	VDEQ
1AHUT000.01	Hunting Creek	Potomac River	9/17/2007	820	400	Dry	VDEQ
1AHUT000.01	Hunting Creek	Potomac River	11/27/2007	1300	1400	Dry	VDEQ
1AHUT000.01	Hunting Creek	Potomac River	1/30/2008	500	580	Dry	VDEQ
1AHUT000.01	Hunting Creek	Potomac River	3/3/2008	75	25	Dry	VDEQ
1AHUT000.01	Hunting Creek	Potomac River	5/7/2008	120	180	Dry	VDEQ

APPENDIX B

Minitab Results for Statistical Assessment

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Regression Analysis: Log2(EC) versus Log2(FC)

The regression equation is
Log2(EC) = - 0.172 + 0.891 Log2(FC)


Predictor     Coef  SE Coef      T      P
Constant   -0.1725   0.3125  -0.55  0.582
Log2(FC)   0.89062  0.03568  24.96  0.000


S = 1.35019   R-Sq = 83.1%   R-Sq(adj) = 82.9%


Analysis of Variance

Source           DF      SS      MS       F      P
Regression        1  1135.6  1135.6  622.96  0.000
Residual Error  127   231.5     1.8
Total           128  1367.2
**********************************************************
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The two lines of output under the line which begins with "Predictor" in the output above provide the values necessary for reaching the required statistical conclusions. The p-value for the slope ("Log_2(FC)" predictor) is seen by inspection to be less than 0.001.

Discussion

The joint confidence intervals for slope and intercept were constructed using the output values "Coef" and "SE Coef". For example, at p=0.85 the interval for intercept or Constant is calculated to be (-0.4226, 0.0776) and at p=0.86 it is (-0.4199, 0.0749), based on the estimated value and standard error of -0.1725 and 0.3125, respectively. Both of these intervals contain the Virginia regression line value of -0.0172. The corresponding simultaneous intervals for slope are (0.8621, 0.9192) at p=0.85 and (0.8624, 0.9189) at p=0.86, based on the estimated value and standard error of 0.8906 and 0.0357 respectively. The interval at p=0.85 (just) contains the Virginia regression line value of 0.9191 but the interval at p=0.86 does not. Therefore the joint p-value for the VA model parameters being within the confidence interval bounds is p>0.85.