Addressing Maryland's Non-Tidal Bacteria Impairments

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Acknowledgements

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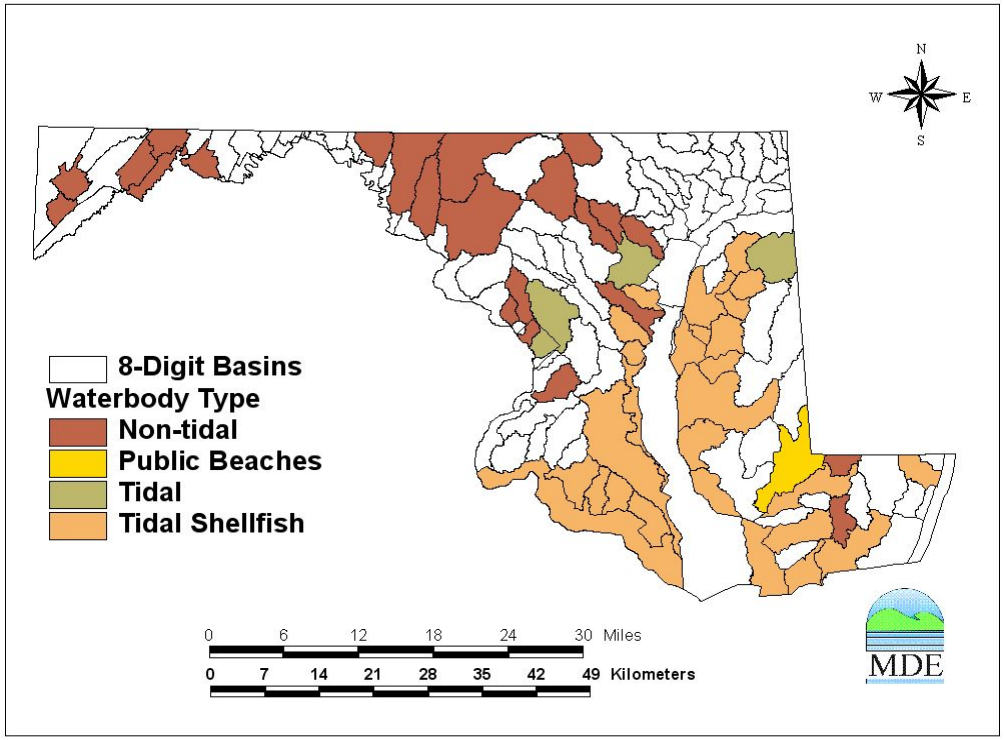
- MDE TMDL Development program
- Salisbury University
- Virginia Department of Environmental Quality
- Virginia Shellfish Workgroup
- Environmental Protection Agency Region III
- Price Associates
- Americas Clean Waters

Maryland's 303(d) Bacteria Listings

Waterbody Type	Listing Year	# of Listings
Non-tidal Total =22	1996	3
	1998	0
	2002	18
	2004	1
Tidal Total = 4	1996	1
	1998	2
	2002	0
	2004	1
Tidal Shellfish Area Total = 73	1996	52
	1998	14
	2002	0
	2004	7
Beaches = 1	1998	1



Bacteria Water Quality Standards

TABLE 1 COMAR 26.08.02.03-3

Water Quality Criteria Specific to Designated Uses.

A. Criteria for Use I, III and IV Waters - Water Contact Recreation and Protection of Aquatic Life

(2) Assessment of Areas Not Designated as Beaches.

If five samples taken over 30 days are not available to assess a water body segment for the purpose of assessment for the National Water Quality Inventory Report (305(b) Report) for the List of Impaired Waters (303(d) List), **a geometric mean of sequential monitoring results may be used as long as at least five sample results are available. The single sample maximum shall apply only at beach areas.**

(COMAR Section 26.08.02.03-3)

	Steady State Geometric Mean Indicator Density
Indicator	
Freshwater	
Enterococci	33 MPN/100ml
E. coli	126 MPN/100ml
Marine water	
Enterococci	35 MPN/100ml

TMDL Methodology Development Objectives

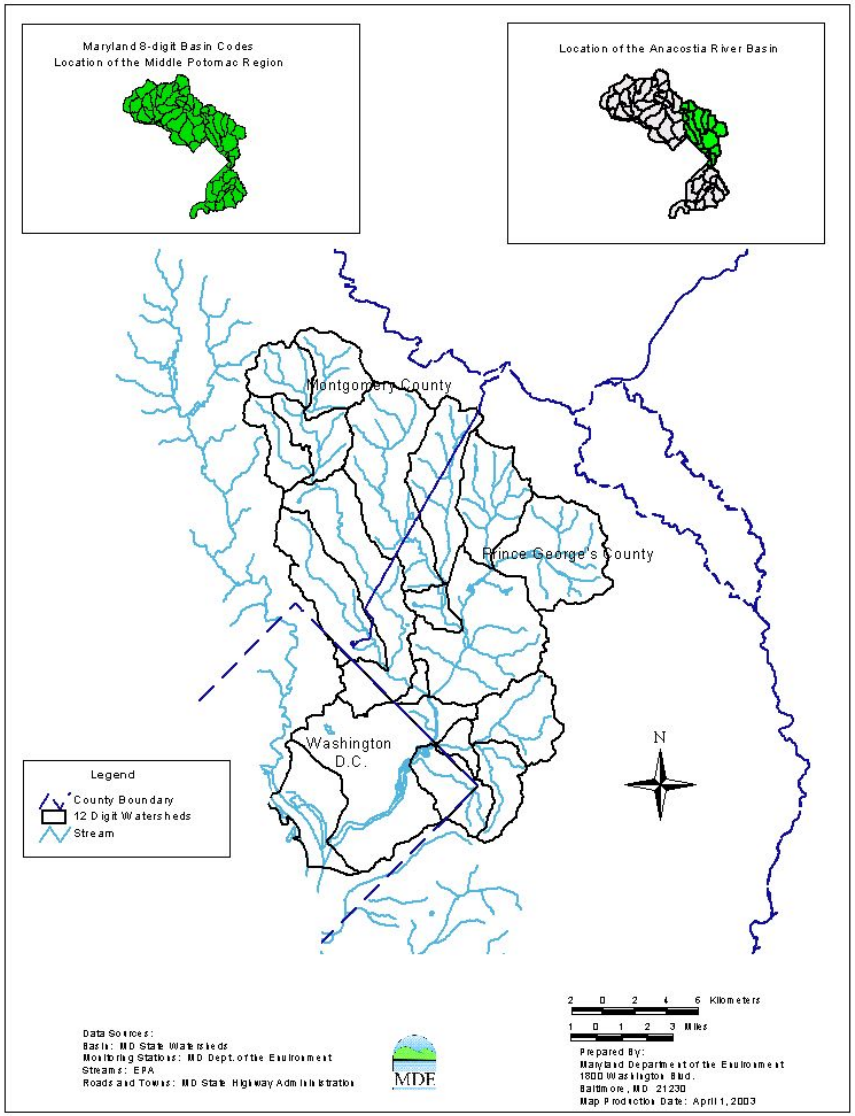
- **Balance of model complexity vs. data availability vs. cost**
  - Scale of available data
  - Uncertainty in bacteria source estimation
  - Cost in terms of staff and contractual
- **Estimation of assimilative capacity**
  - Load
  - Downstream waters
- **Estimation of Sources**
  - Reliability
- **Scenario development**
  - Maximum practicable reductions
- **Provide guidance for future implementation efforts**
  - Baseline conditions source estimates
  - Presentation tools

TMDL Methodology

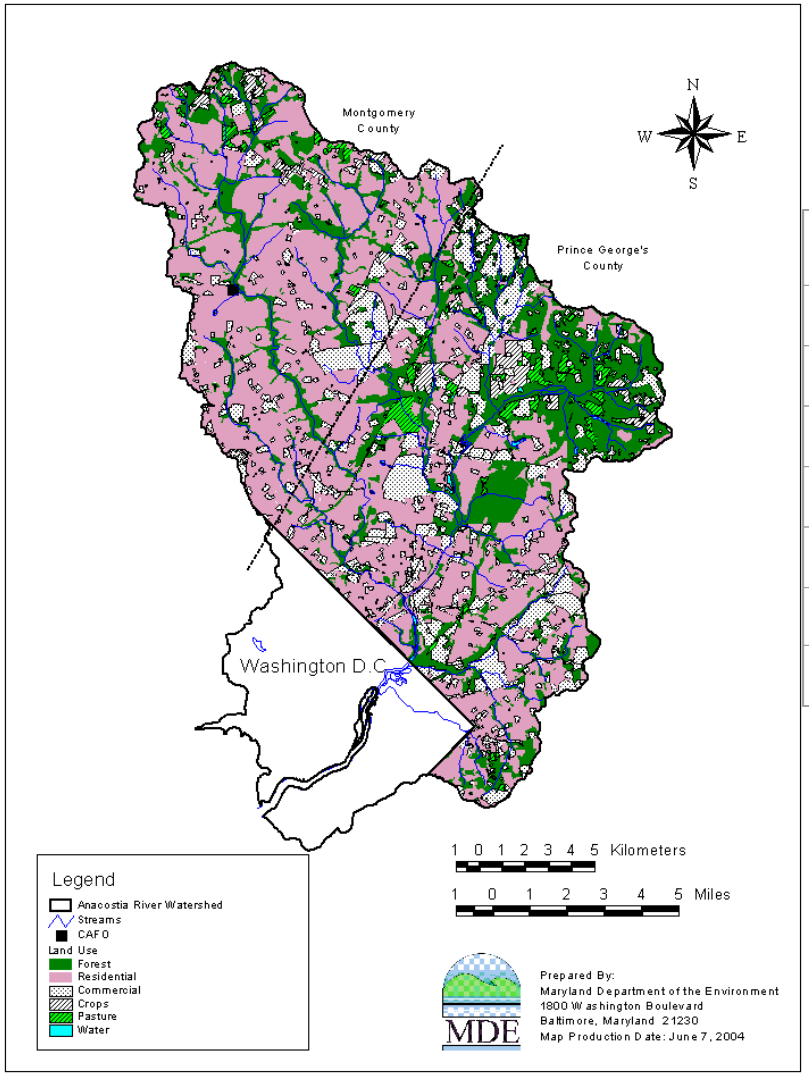
- **Loads**
  - Load Duration Curve
  - Accounts for hydrologic variation
  - Watershed specific zones for potential bacteria delivery
  - Reduces potential bias from monitoring design
- **Sources**
  - Bacteria Source Tracking
  - Summary of sources
    - Hydrologic variation
- **Scenarios**
  - Identify maximum practicable reductions
  - Clear and concise objective
  - Repeatable

Example Watershed – Anacostia River

Location Map



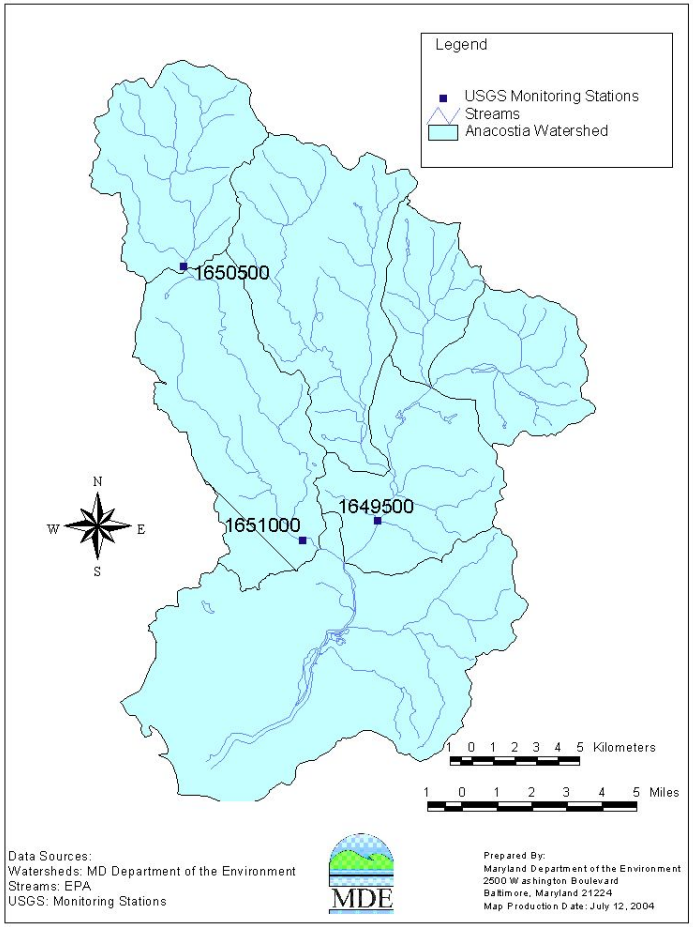
Anacostia – General Setting



Land Use Distribution

Land Type	Acreage	Percentage
Urban	65,094.1	70.2
Forest	22,229.4	24.0
Agriculture	5,031.2	5.4
Wetlands	47.2	0.1
Water	320.1	0.3
Totals	**92,721.9**	**100.0**

Hydrology

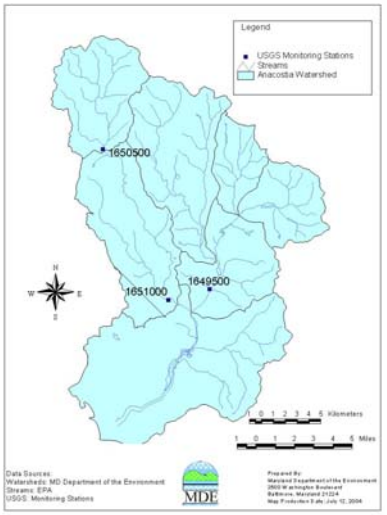


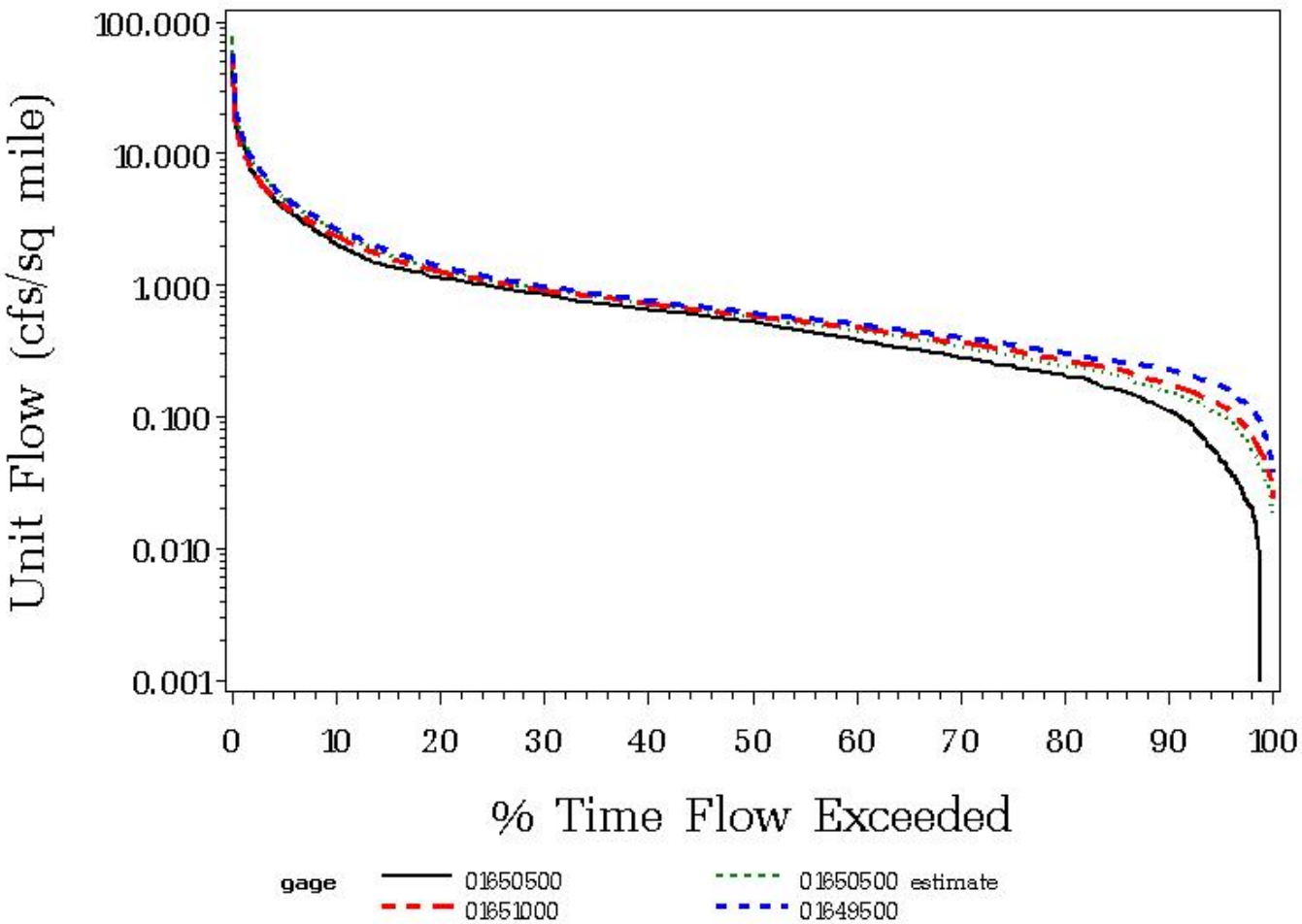
- 3 Active USGS gages

USGS Gage #	Dates used	Description
01649500	Oct 1, 1988 to Sep 30, 2003	
01651000	Oct 1, 1988 to Sep 30, 2003	
01650500	Nov 27, 1997 to Sep 30, 2003	
01650500 (estimate)	Oct 1, 1988 to Sep 30, 2003	Estimated flow based on USGS Gage 0165100 using MOVE.1 (Hirsch, 1982)

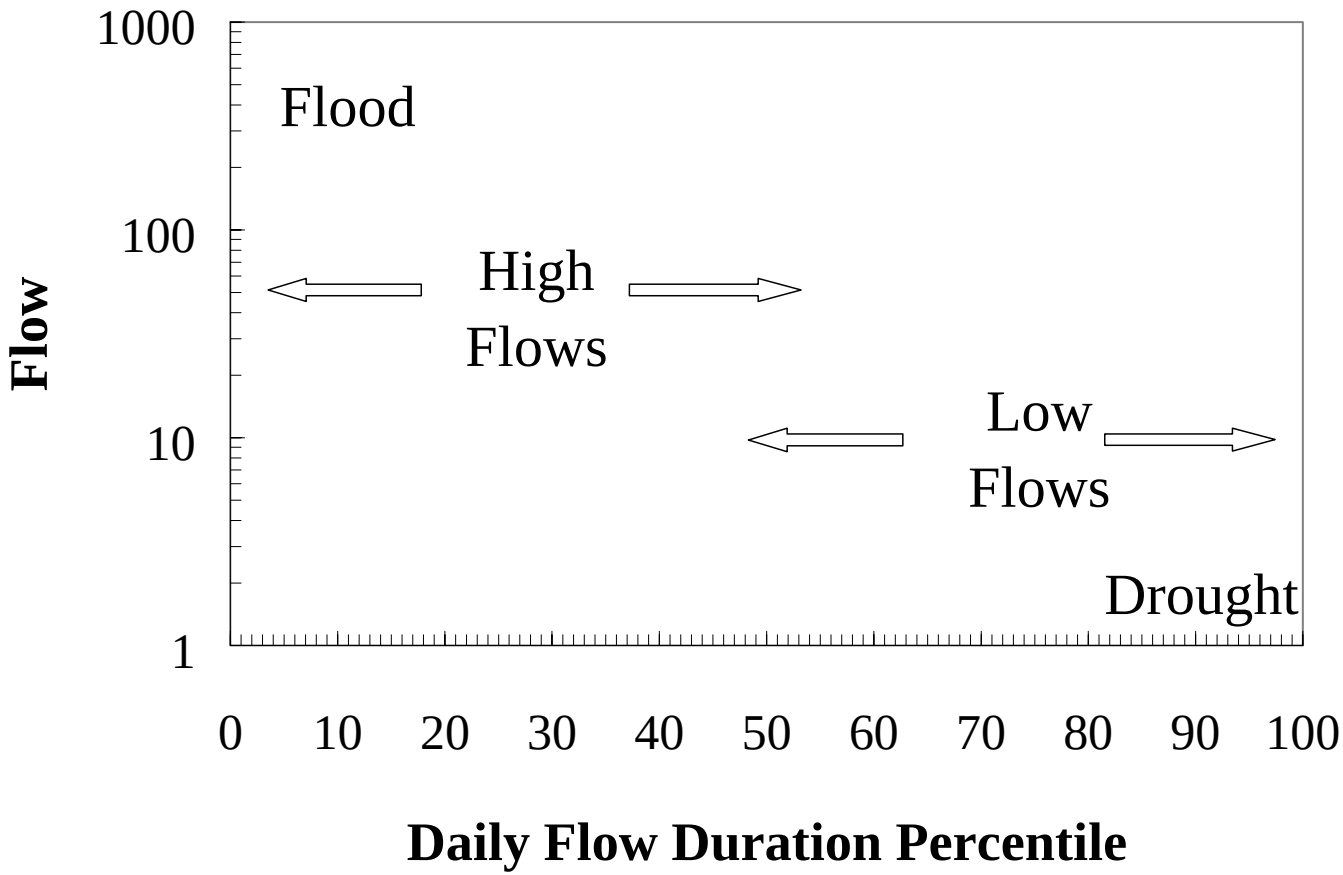
Daily Flow Duration Curve

Anacostia River



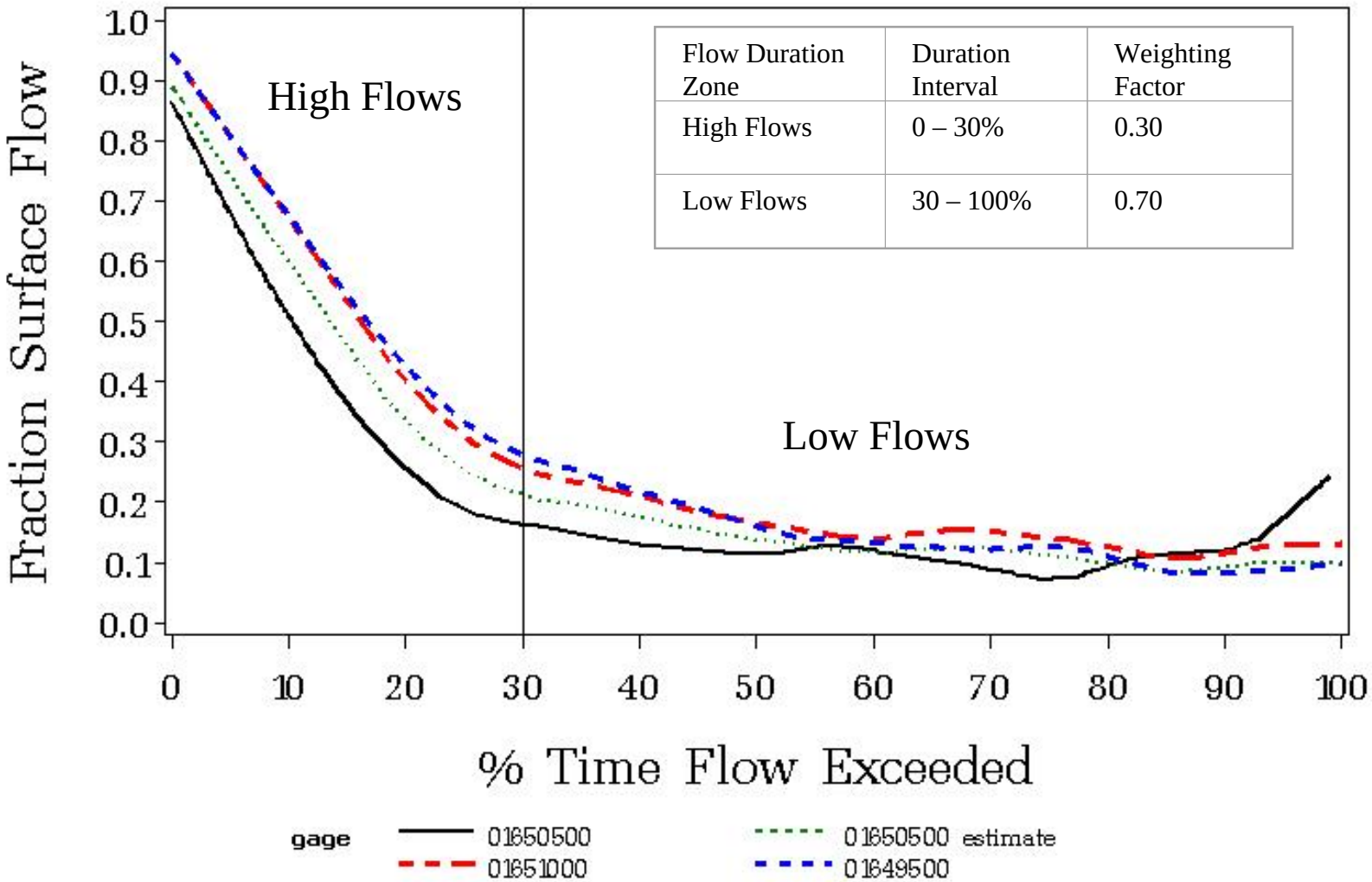


Flow Duration Zones



Hydrograph Separation (Zones)

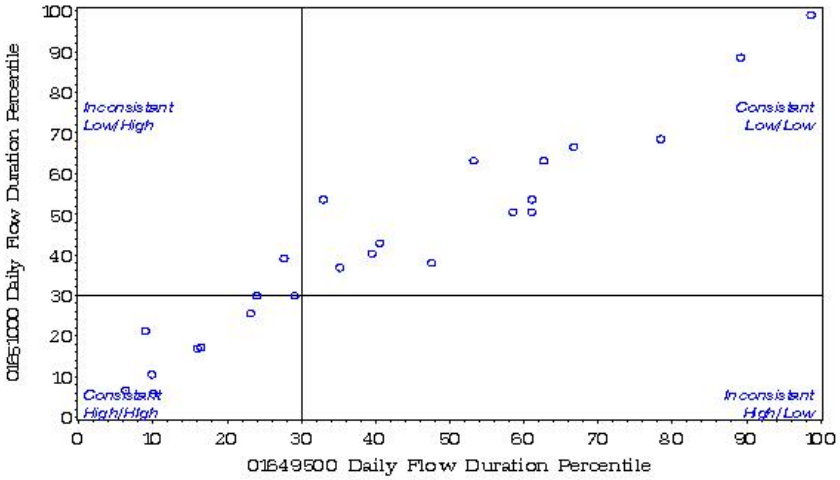
Anacostia River

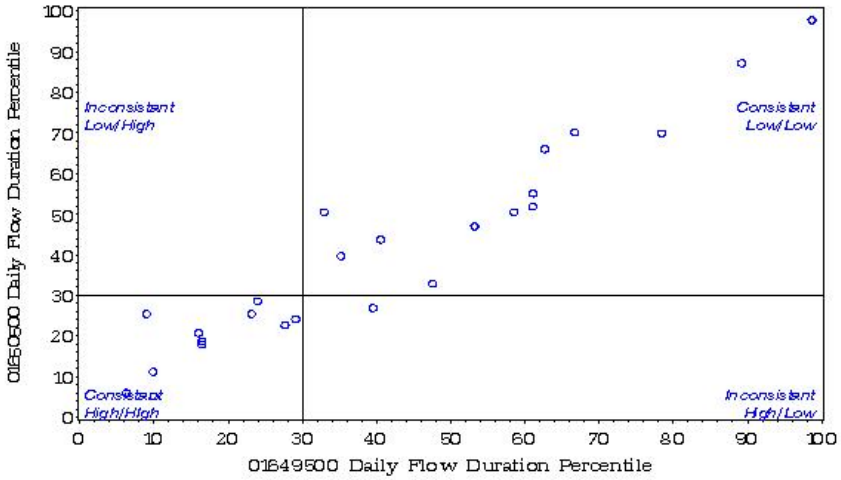


Flow Duration Zone	Duration Interval	Weighting Factor
High Flows	0 – 30%	0.30
Low Flows	30 – 100%	0.70

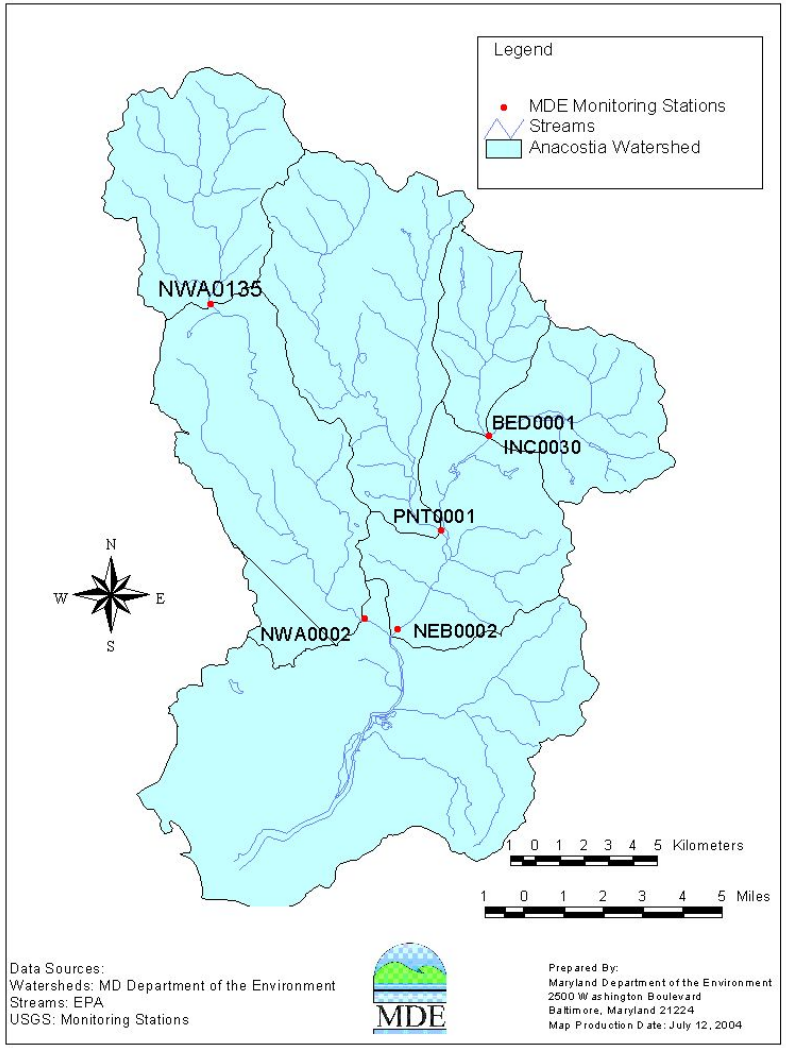
Assigning Flow Frequency to Ungaged Watersheds

- Criteria for selection
  - Proximity to watershed
  - Watershed area
  - evidence suggests that the ratio of the ungaged basin to gaged basin should be between 0.33 and 3.0 (Reis et. al., 2000)
- Cross-correlation of gages in region (n-lag model)





Anacostia River – Water Quality



- Nov 2002 to Oct 2003
- 2x per month
- enterococci

SAMPLING STATION IDENTIFIER	geometric mean MPN/100ml	High Flow	Low Flow
BED0001	346	325	355
INC0030	126	215	100
NEB0002	91	296	55
NWA0002	133	386	85
NWA0135	128	284	90
PNT0001	51	206	28

Bacteria Enumeration Results

- Samples within a specified stratum will receive their corresponding weighting factor.

- The weighted geometric mean is calculated as follows:

$$M_i = \frac{\sum_{j=1}^{n_i} \log_{10}(C_{i,j})}{n_i}$$

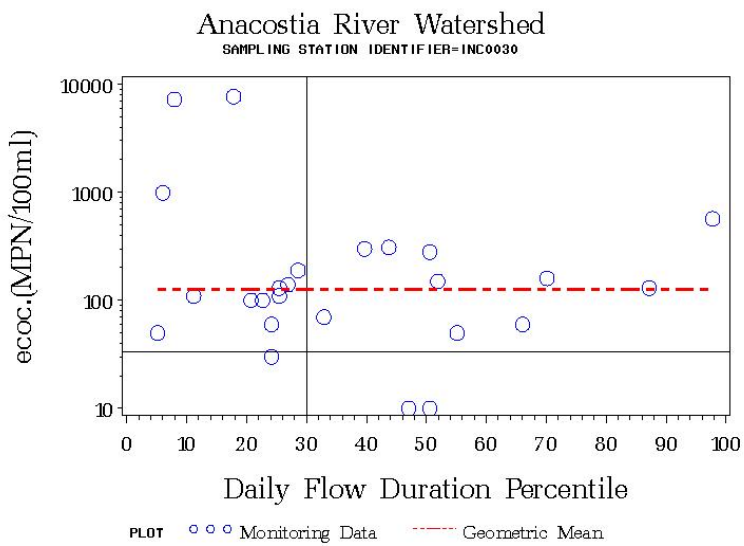
- Where

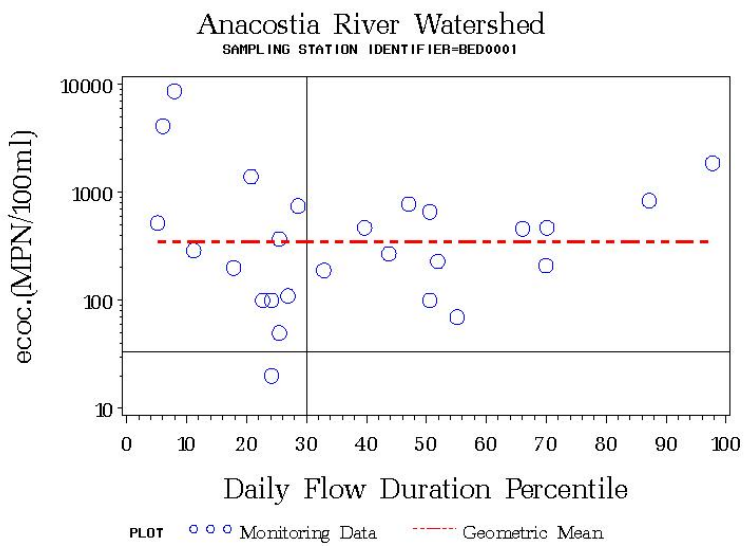
$$M = \sum_{i=1}^{2} M_i * W_i$$

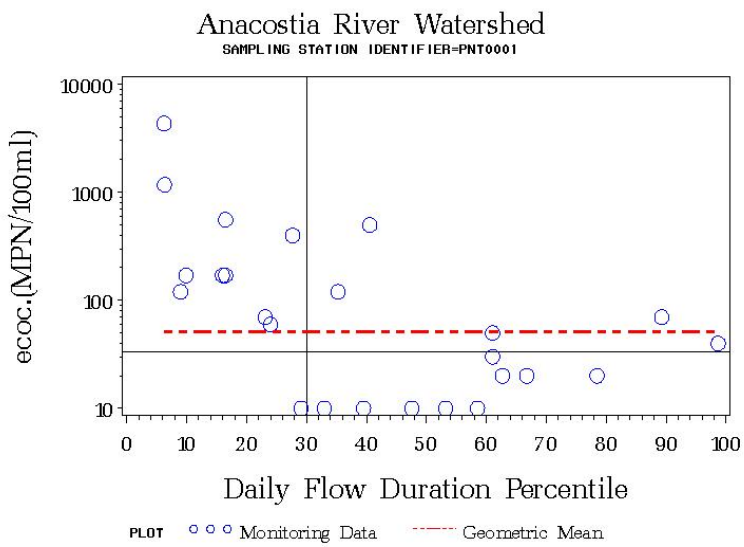
•And the Final Geometric Mean Concentration is:

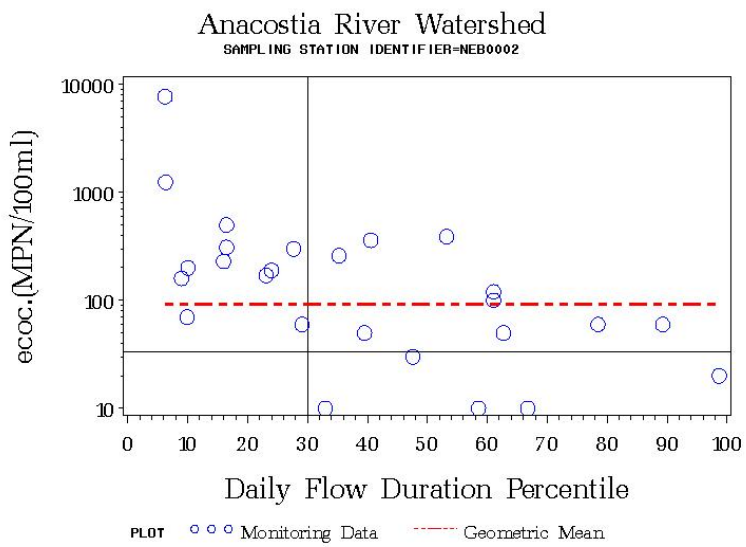
$$C_{gm} = 10^M$$

Water Quality Data – NE Branch

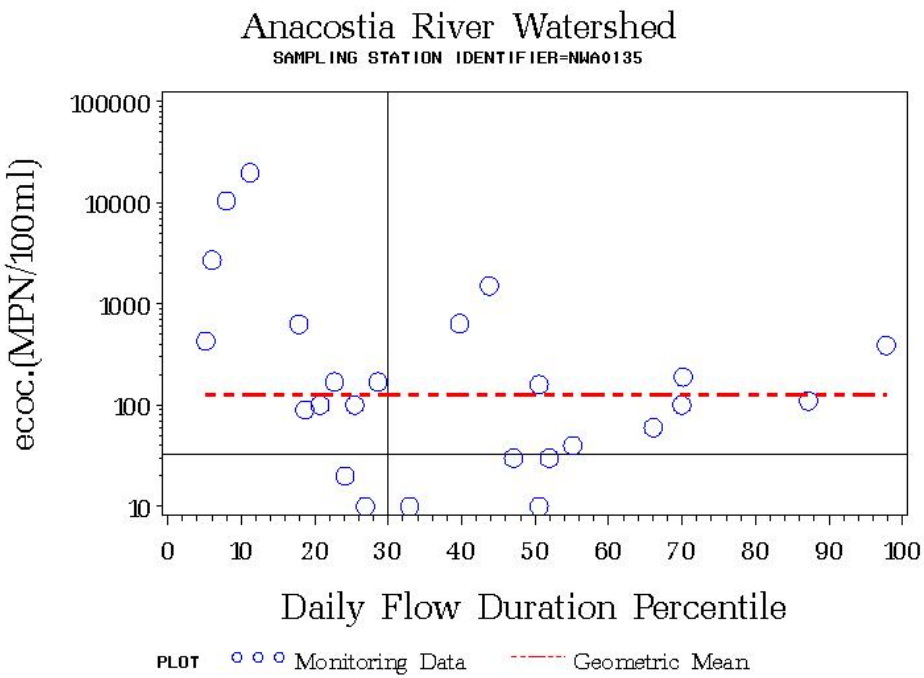


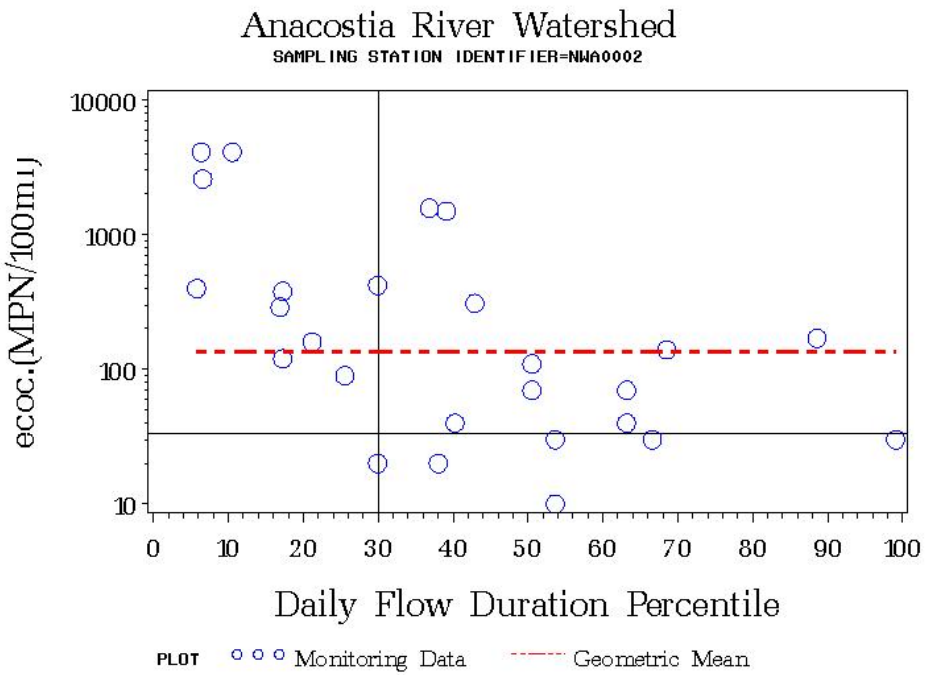






Water Quality Data – NW Branch





What does this mean?

- Identifies differences in bacteria loadings during high flow or low flow regimes
- Reduces flow bias from monitoring
- Management approaches can acknowledge differences in loading
- Relative source contributions can be estimated for both flow regimes

Load Estimation

- **Baseline Loads**
  - The baseline load is estimated using the geometric mean concentration and average daily flow for each flow stratum.

$$L_i = Q_i * C_i * F$$

  - Then the loads from the strata are weighted based on the proportion of each stratum, to estimate the total long term loading rate:

$$L_t = \sum_{i=1}^{2} L_i * W_i$$

Assimilative Capacity

- TMDL Loads and Reduction
  - The TMDL loading cap is an estimate of the assimilative capacity of the monitored watershed and is provided in MPN/day.
  - The "overall" percent reduction is estimated from the current concentration to the water quality criterion. It is assumed that a reduction in concentration is proportional to a reduction in load and thus the TMDL is equal to:

$$TMDL = L_b * (1 - R)$$

Margin of Safety

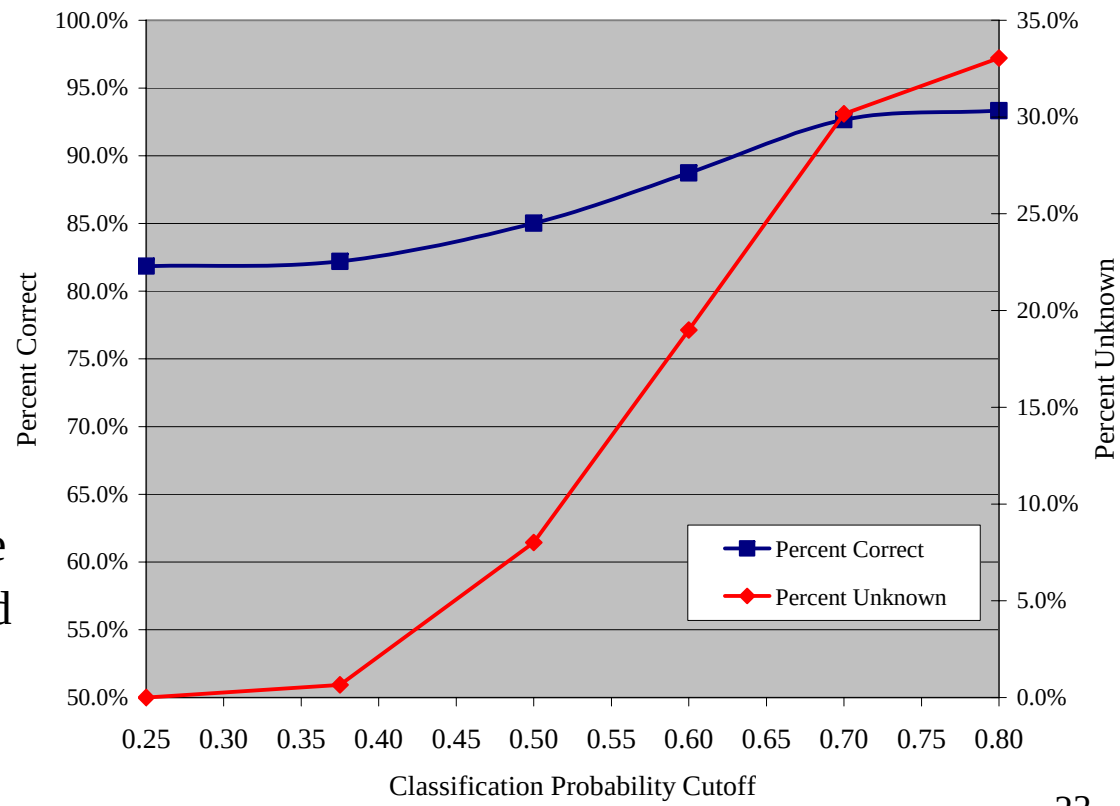
- TMDL Loads based on geomean concentrations calculated from log transformation of the data.
- Statistical theory has shown that when **back transformed values** are used to calculate average daily loads or total annual loads, the **loads will be biased low (**Richards, 1998)
- Several methods of determining this bias correction factor (Ferguson, 1986, Cohn et al., 1989, Duan, 1983).
- **The known low bias of the back-transformed concentrations would be used as a MOS in estimating the assimilate capacity of the stream systems.**
- This bias provides an environmentally conservative estimate of the load required to attain water quality standards.

Identifying Sources

- Bacteria Source Tracking (ARA)
- sampling design reduces uncertainty in methodology
  - Temporal variation
  - Spatial variation
- Refined statistical analysis CART®, to identify unknown source category

Anacostia BST Analysis

- Library of approximately 1200 known source isolates
- four categories:
  - domestic (pets, specifically dogs)
  - Human
  - Livestock
  - wildlife
- Unknown sources
  - 80% cutoff probability
  - 93% ARCC
  - 30% unknown removed from source library
- Water Samples
  - 24 isolates per water sample
  - 80 % cutoff probability used for unknown classification



Estimating Source Contribution

- Average source at each station is estimated by using a stratified weighted mean of the identified isolates.
  - Weighted mean proportion of isolates for each source in each stratum

$$MS_{i,k} = \frac{\sum_{j=1}^{n_i} \log_{10}(C_{i,j}) * S_{i,j,k}}{n_i}$$

  - Weighted mean proportion of isolates of each source

$$MS_k = \sum_{i=1}^{2} M_{i,k} * W_i$$

Change in Source Contribution
Low Flow to High Flow

Station	domestic	human	livestock	wildlife
BED0001	12.6	-15.1	-4.2	6.7
INC0030	7.8	-27.5	10.4	9.4
NEB0002	29.8	-7.5	-28.2	5.9
NWA0135	21.8	-21.0	0.5	-1.2
PNT0001	-14.4	-6.6	6.8	14.1

- General trends
  - Increase in domestic
  - Decrease in human
  - Livestock inconsistent
  - Increase in Wildlife

Source Contribution

BST Results

Station	% Domestic	% Human	% Livestock	% Wildlife	% Total
BED0001	45%	15%	9%	32%	100.0%
INC0030	30%	23%	13%	33%	100.0%
PNT0001	29%	23%	7%	41%	100.0%
NEB0002sub	24%	9%	28%	38%	100.0%
NWA0135	28%	55%	6%	12%	100.0%
NWA0002sub	31%	17%	8%	44%	100.0%

Comparative Analysis

Min	24%	9%	6%	12%
Max	45%	55%	28%	44%

DC All Samples	20%	24%	3%	56%

Source: MWCOG, 2003. Identification of Fecal Bacteria Sources in District of Columbia Waterways Using Bacteria Source Tracking

Source Estimates - Uncertainty

- Representativeness of the samples
  - Do they represent possible/probable sources in the Anacostia Watershed?
- Analytical (laboratory) results
  - Precision in the laboratory
- Statistical analysis results using CART
- Summary
  - …Results adequately classifies the probable sources of bacterial contamination in the Anacostia Watershed

- Standard error of mean

Scenario Development and Maximum Practicable Reduction Targets

	Human	Domestic	Livestock	Wildlife
Max Practical Reduction per Source	95%	75%	75%	0%
Rationale	(1) Direct source inputs (2) Human pathogens more prevalent in humans than animals. (3) Enteric viral diseases spread from human to human	(1) Target goal reflects uncertainty in effectiveness of urban BMP's[1] and is also based on best professional judgment	Target goal based on sediment reductions from BMP's[2] and best professional judgment	No programmatic approaches for wildlife reduction to meet water quality standards

1. USEPA. 1999. Preliminary Data Summary of Urban Storm Water Best Management Practices. EPA-821-R-99-012. U.S. Environmental Protection Agency, Washington, DC.

2. USEPA. 2004. Agricultural BMP Descriptions as Defined for The Chesapeake Bay Program Watershed Model. Nutrient Subcommittee Agricultural Nutrient Reduction Workshop.

Scenario Development

- **Scenario 1 – Practicable Reduction Scenario**
  - Objective function is to minimize risk
  - Min (P_h*5 + P_d*3 + P_l*3 + P_w*1)
    - Where P=proportion of sources in final allocation
  - Subject to constraints set at maximum practicable reduction targets

    R_h <= 95%

    R_l <= 75%

    R_d <= 75%

    R_w = 0

    and C = C_{cr}
  - Initial conditions set at maximum practicable reduction

Scenario Development

- **Scenario 2**
  - For watersheds that do not meet water quality standards based on maximum practicable reductions.
  - Relax constraints
    - maximum allowable reduction up to 98% for all sources, including wildlife.
  - Min $(P_h*5 + P_d*3 + P_l*3 + P_w*1)$

    $R_h <= 98\%$

    $R_l <= 98\%$

    $R_d <= 98\%$

    $R_w <= 98\%$

    and $C = C_{cr}$

Reduction Results

Maximum Practicable Reduction

Station	Applied Reductions				Maximum Practicable Reduction[1]	Target Reduction[2]	Baseline Concentration[3] (MPN/100ml)	MPR Final Concentration[4] (MPN/100ml)	Achievable
	Domestic %	Human %	Livestock %	Wildlife %					
BED0001	75%	95%	75%	0%	54%	90%	346	159	No
INC0030	75%	95%	75%	0%	55%	74%	126	57	No
PNT0001	75%	95%	75%	0%	49%	35%	51	26	Yes
NEB0002sub	75%	95%	75%	0%	49%	80%	169	87	No
NWA0135	75%	95%	75%	0%	77%	74%	127	29	Yes
NWA0002sub	75%	95%	75%	0%	45%	83%	191	105	No

Final Reduction

Station	Domestic %	Human %	Livestock %	Wildlife %	Target Reduction
BED0001	98%	97%	98%	74%	90%
INC0030	98%	98%	98%	24%	74%
PNT0001	29%	95%	68%	0%	35%
NEB0002sub	98%	98%	98%	52%	80%
NWA0135	75%	95%	18%	0%	74%
NWA0002sub	98%	98%	98%	64%	83%

TMDL Allocations
(the right hand side of the equation)

TMDL Allocation Rules

Allocation Category	Human	Domestic	Livestock	Wildlife
WWTP	x		x[1]	
MS4		x		x
LA	x	x	x	x

1. Special condition for treatment plant

- Specific to watershed
- Domestic based proportioned from households
- Wildlife proportioned on habitat (pervious area)

Bacteria TMDL Challenges

- Wildlife contributions
  - Risk
  - Reductions
- Maximum practicable reductions
  - BMP effectiveness (range of values)
    - Pet waste programs
  - MS4 permits

Interstate Issues

- Challenges
  - Differing Water Quality Standards
  - Different indicator
  - Different datasets (i.e. time period, location, etc)
- Solutions
  - Use paired sampling for various indicators (EMPACT)
  - Establish general ratio
  - Compare TMDL (assimilative capacity)

	TMDL Load (Bil MPN/Ac/yr)
DC Estimate	3.755
MD Estimate	4.943
MD/DC	1.32

Conclusion

- TMDL based on logical approach that…
  - Accounts for hydrologic variation
  - Identifies bacteria levels and sources from varied delivery mechanisms (e.g. high flow/low flow)
  - Addresses spatial variability of bacteria reductions
  - Integrates with NPDES permit structure for clean up initiatives
  - Provides cost effective solution to complex modeling

Thanks !

Questions and Comments