MEMORANDUM

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Water Resources Group

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project: TMDL Restoration Plans

subject: Technical Memorandum: Development of Prince George's County Local TMDL Restoration Plans Using WTM

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1 INTRODUCTION

This technical memorandum discusses the methodology used to develop the loading computations used in the subwatershed (SWS) analyses. On the basis of guidance posted on MDE's *TMDL Data Center* website,[1] Tetra Tech and Ecosite have developed a methodology that will build on previous work done for the County by both firms and will provide a breakdown of loads that will help in the restoration planning process, as discussed in this technical memorandum. The technical guidance for developing restoration plans for WLAs (MDE 2014a). Part of this guidance allows entities to calculate updated load estimates using specific land-use and other data for restoration planning. The guidance allows entities to use their own data to develop loads if they retain the percent reduction specified in the respective TMDL between baseline loads and the allocations for the applicable pollutants (MDE 2014a). Baseline conditions, as defined by MDE, represent the impaired conditions that the watershed was under during TMDL development. The percent reduction of pollutants is based on loads needed to achieve the applicable water quality standards in specific water bodies.

Using MDE's guidance, the County used a County-modified Watershed Treatment Model (WTM) to calculate new loads for the implementation model baseline. The purpose of the implementation model was not to recalculate the WLA as defined in the TMDL documents and the MDE *TMDL Data Center*, but to convert the TMDL load reduction from the original TMDL model to an implementation model (WTM) that can be effectively used in the planning of restoration activities. The level of effort (load reduction percentage) to meet water quality standards is kept the same between the two models. WTM was modified to include more specific land-use types as well as to differentiate between connected and disconnected impervious areas to calculate more precisely loads generated from different land-use types. Therefore, the modified WTM provides the County the ability to specifically identify the land uses and land covers that produce the larger loads and target BMPs and other restoration measure to those land uses. This approach will allow the County to make better decisions on where a specific type of restoration activity should be implemented and to improve implementation planning.

Because the TMDLs in the County have been established in different years, the County opted to use one set of common data to establish *implementation model* baseline loads for all pollutants addressed in this restoration plan. Therefore, *baseline loads* in this plan refers to the pollutant loads calculated using the modified WTM (implementation model) with the most recent land use and impervious cover data available. This method provides a more accurate depiction of loadings from County land and establishes a common set of baseline data, which aids in the restoration planning process. The WTM baseline loads have been compared to both Maryland Assessment and Scenario Tool (MAST)[2], and TMDL baseline loads and are discussed in this technical memorandum.

The SWS analyses were conducted at several different levels. The first level of analysis evaluated the SWS in its entirety. This established all the SWS loads from runoff, some of which comprise the baseline TMDL loads. The next level of analysis was the Urban MS4 area, which comprises the source areas regulated by the TMDLs. It excludes low-density development, rural

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[1] http://www.mde.state.md.us/programs/Water/TMDL/DataCenter/Pages/index.aspx

[2] http://www.mastonline.org/ (accessed September 2, 2014).

areas, and natural areas. The next level of analysis partitioned the MS4 areas into their respective county, municipal, state, and federal ownerships. In this manner, it was possible to highlight where the pollutant loads are coming from, as well as which entity is responsible for which loads. This approach allowed a fair allocation of the obligations needed to meet the implementation load reduction goals.

To accomplish this analysis, we analyzed County geospatial information to obtain the different impervious and pervious source areas. There are substantial differences between land use and land cover. Land use looks at the way that land is developed for specific purposes, such as for commercial, residential, or agricultural purposes. Land cover looks at what is visible from above the Earth's surface, such as tree canopy, parking lots, roads, buildings, and agricultural fields. Land use lumps many different types of land cover into a single use category. It can be an effective metric for watershed runoff responses only when the differences in land cover between land uses (such as commercial versus residential) are much greater than the differences in land cover within a particular land use category (such as industrial, where land cover ranges from roof-dominated warehouses to junkyards). However, this is often not the case, particularly with institutional or industrial uses. In contrast, land cover is particularly useful in describing the features that affect the watershed in terms of hydrologic and pollutant loading responses, in particular those associated with impervious areas. This is why accurate geospatial land cover information is so important and is a vital aspect of this analysis.

The effect of impervious cover is particularly important for watershed analysis because it is a fundamental data set used as an input to the development of hydrologic models. It is recognized that directly connected impervious cover (conveyed by storm sewer directly to streams) is substantially more detrimental than disconnected land cover (conveyed overland before interception by storm sewers) due to the highly efficient conveyance associated with directly connected impervious cover that increases both flow and pollutant transport. Disconnection applies only to impervious areas such as roofs, which flow over adjacent turf areas. From previous work for the County, Tetra Tech and Ecosite developed a detailed calibrated model for the Piscataway Creek watershed that partitioned runoff into directly connected impervious areas, disconnected impervious areas, and pervious receiving areas, with a separate allocation for rural and natural areas.

The results from the Piscataway Creek model were used to adjust the factors available in the WTM (Version 2013) (Caraco 2013) to more accurately evaluate the effect of hydrologic partitioning and of different land covers. The model was adapted to allow for the effects of hydrology and land cover to refine runoff loading rates. The resultant loading rates were then summarized by SWS in terms of total nitrogen (TN), total phosphorus (TP), total suspended sediments (TSS), biological oxygen demand (BOD), and fecal coliforms (FC). The first four parameter concentrations are computed in terms of milligrams per liter (mg/L); FC is measured by most probable number per 100 milliliters (MPN/100 mL). The corresponding mass loads are expressed in pounds per acre (lb/ac) and billion MPN per acre. The following pages describe the procedures involved in generating these analyses. Through a technical review of the TMDL modeling documentation, we found polychlorinated biphenyls (PCBs) to be related to TSS load, and thus calculated them using the TSS model results. PCBs are discussed in a separate section later in this document.

These overland runoff primary loads for TN, TP, and TSS were calibrated against the baseline loads in the TMDL reports as well as the Maryland Assessment Scenario Tool (MAST). In addition, FC load contributions from human, domestic pet, livestock, and wildlife sources were examined to quantify their subcategory sources in terms of proportion of total category loads, and the extent to which they come from MS4 areas. This procedure also allowed for the baseline loads observed in the TMDL reports be accurately transformed into their respective overland runoff loads. This not only provides a more accurate delineation of sources, it also highlights the load reduction opportunities from using programmatic initiatives—non-structural measures (NSMs)—such as pet waste programs to assist in meeting the FC load reductions required in the TMDL reports. An important part of total TSS and TP loads, stream bank erosion computations complemented this process.

Following assignment of NSMs, the potential load reductions from installing BMPs were calculated by assigning removal efficiencies reported by MDE (2014b) for environmental site design (ESD) approaches. FC removal efficiencies were determined from the literature and assigned to the ESD BMPs. A watershed prioritization procedure was used to preferentially assign BMPs to the most impacted SWSs. BMPs were first assigned to retrofit existing dry ponds, and then all county owned right of ways. The resultant load reductions were computed and compared to the required load reductions. If additional load reductions were needed, then institutional land uses were selected for BMPs. If more reductions needed, then commercial land uses selected, and finally residential. A uniform removal efficiency was applied to each land use, but with differing costs. In this manner, the WTM model was used to determine the amount of area treated by BMPs and their cost.

2 GIS ANALYSIS

2.1 Watershed Delineation

Tetra Tech researched several GIS-based programs that are able to perform autodelineation of subwatersheds (Table 1). None of the programs were able to consider sewer lines in subwatershed delineation. The County's GEO-STORM program was not chosen because it is housed at County facilities and linked to HEC. The WIS BMP Module required an older version of ArcMap and Windows, so it could not be used. The remaining three programs are very similar, but BASINs is more difficult to set up. Tetra Tech decided to use ArcGIS 10.1 to delineate the subwatersheds in the County because it has all the necessary features and is available to both Tetra Tech and County staff.

Table 1. Review of available methods for subwatershed delineations

Program	Accessibility	Auto-delineation?	Ease-of-use	Manual selection of pour point?	Required shapefiles	Notes
GEO-STORM	Program at County offices.	Unknown	Need County support	Unknown	Unknown	Linked to HEC. 20-yr old system. Unix-based.
WIS BMP Module	Tetra Tech has program.	Yes	Tetra Tech has experts on use.	Yes	DEM, streams	Requires ArcGis 9.3.1 and Windows XP.
SUSTAIN	Tetra Tech has program.	Yes	Tetra Tech has experts on use.	Yes	DEM, major watershed, streams	
BASINs	Tetra Tech has program.	Yes	Due to required file setup, a project can be difficult to initiate. Tetra Tech has experts on use.	Yes	DEM, major watershed, streams	
ArcGIS	Tetra Tech and County have program.	Yes	Tetra Tech has experts on use.	Yes	DEM, major watersheds	

Tetra Tech used a shapefile of water quality stations to determine pour points in the watershed. The autodelineation process produced a range of subwatershed sizes. It created several hundred subwatersheds under 100 acres, which were manually combined with neighboring larger watersheds. Large subwatersheds (more than 2,000 acres) were manually split into smaller subwatersheds. This was done visually using elevations from the DEM layer from the GIS, while considering land use, land cover, and ownership information. The resulting subwatersheds were compared to larger-scale existing watershed layers (e.g., DNR geospatial data) for a quality check. Deviations in subwatershed boundaries were checked against the DEM layer. We found that the existing main watershed boundaries did not match each other in certain circumstances. The existing watershed layers were coarser and tended to generalize boundaries, so the autodelineation was seen to be more accurate on a finer scale. The new subwatershed delineation did not consider sewersheds because of limited resources.

2.2 Land Use and Land Cover

Because water resources are a central focus of the overall study, proper assignment of impervious cover is a key aspect of this task. Accurate mapping is essential for accurate impervious allocation (Endreny and Thomas 2009), especially compared to the generalized land use/land cover mapping typically used as the basis for impervious cover. In turn, impervious cover, particularly that which is connected, is essential in predicting runoff responses (Glick 2009). Furthermore, comprehensive evaluation of pervious cover is also essential to determining hydrological responses (Law et al. 2009).

For these reasons, it is essential that the land cover aspects of this analysis be as accurate as possible. Fortunately, the County has a remarkably detailed GIS inventory, which was analyzed to obtain a state-of-the-art analysis of land cover and land use mapping. Figure 1 schematically displays the steps involved in how the land cover analysis was conducted and how its results are used.

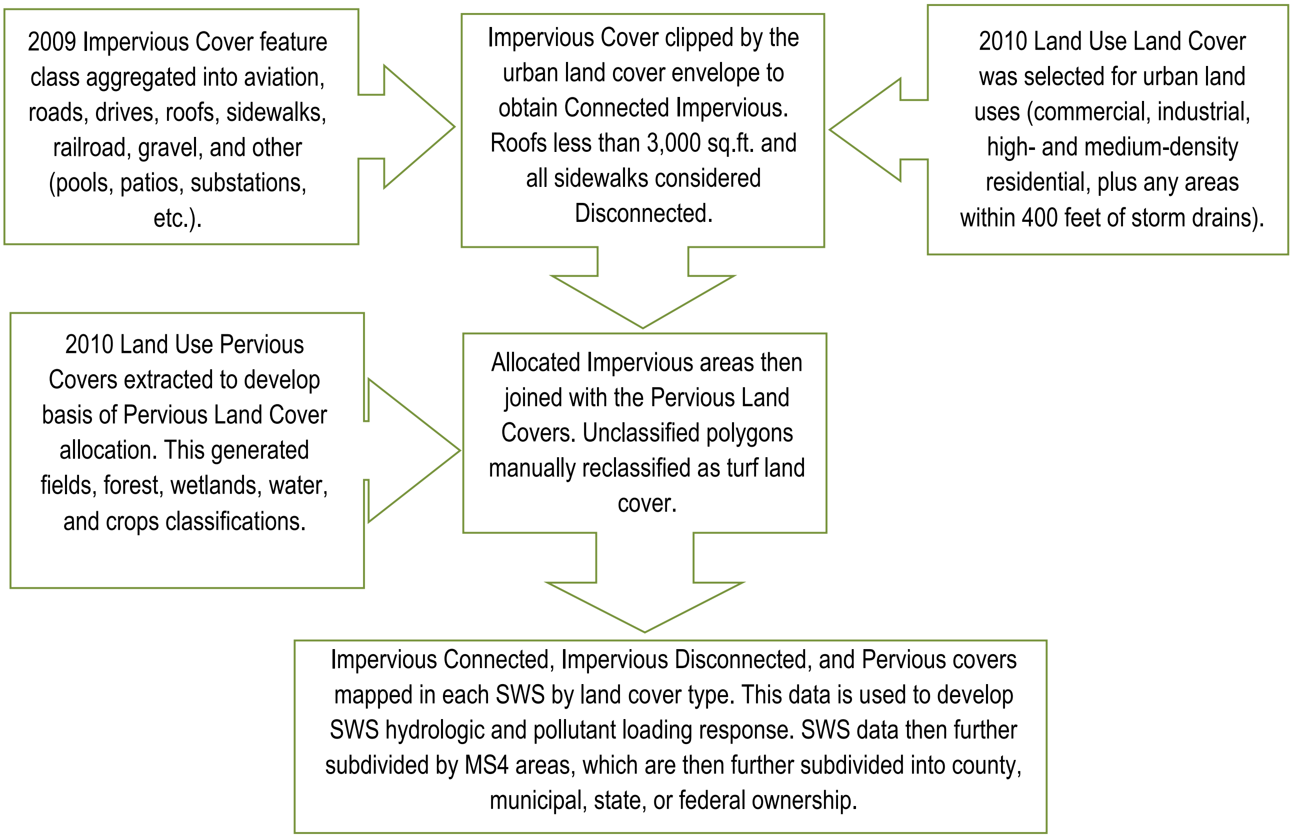

Figure 1. Land cover allocation and implications for additional tasks

(*Source*: PGAtlas GIS data.)

In processing the GIS, it was found that the impervious cover mapping (ARCDBA. Transportation_2009_Poly from *PGAtlas*) double-counted polygons where sidewalks crossed drives. By classifying the walks as disconnected and the drives as connected, subsequent GIS processing eliminated the redundant polygons. The resultant summary thus differs slightly from the GIS 2009 impervious cover data set but is more accurate as a result. Table 2 presents the raw impervious covers from the GIS data set. The *Other* category was aggregated to include several smaller land cover groups, which are identified in Table 2; bridges were aggregated with roads in terms of hydrologic and pollutant loading responses. Although there are data simplifications inherent in considering all sidewalks as disconnected and all drives as connected, the similar area for these classifications suggest that underestimates of connected sidewalks would be offset by overestimates of connected drives. Appendix A provides additional information on the differences in connected and disconnected impervious areas.

Table 2. Impervious covers from GIS data set

Type	Area (sq ft)	Area (acres)
Aviation	24,542,009	563.4
Bridge[1]	5,457,675	125.3
Roofs	583,944,997	13,405.5
Concrete[2]	37,624,978	863.7
Drives	176,701,057	4,056.5
Gravel	110,810,856	2,543.9
Other[2]	16,493,139	378.6
Parking	426,536,861	9,791.9
Patio[2]	30,487,148	699.9
Pool[2]	5,050,236	115.9
Railroad	795,844	18.3
Road	611,506,338	14,038.2
Track[2]	18,843,789	432.6
Walkways (Sidewalks)	128,092,215	2,940.6

[1] Aggregated with Road.

[2] Aggregated with Other.

As to the pervious land covers, all forest types (mixed, evergreen, and deciduous) were combined into one forest type (woods). Brush, pastures, and open urban areas were classified as field. Row crops, agricultural building areas, feeding operations, and orchards were classified as crops. These aggregations were based on the similar hydrologic and pollutant loading responses that these agricultural covers would generate. Any disparities are minimized by the small areas involved. (Less than 1 percent of the watershed is feedlot and orchard.) Because they are largely outside the boundaries of the MS4s, minor differences in loading rates between these covers had a minimal effect on the analysis.

This process resulted in extensive areas within the residential, commercial, industrial, and institutional land uses that were not classified as either impervious, or as one of the specific pervious covers listed in the previous paragraph. Any land cover that was not considered impervious, field, crops, woods, wetlands, or water was considered turf. Beaches, barren, and extractive land uses were not considered in the WTM as these land uses either do not contribute to stream runoff, or they constantly change over time. As a simplification, they were considered turf. Since these categories are under 1 percent of the area, this simplification has negligible effect upon the overall WTM loading. Table 3 presents the summary of the pervious land covers.

Table 3. Pervious covers from GIS data set

Type	Area (sq ft)	Area (acres)
Turf- the residual of unclassified land covers-see text.	3,903,267,216	89,607
Field (open urban area, pastures, brush)	872,513,349	20,030
Crops (cropland, orchards, row and garden crops, agriculture building, feeding operations)	1,174,276,077	26,958
Woods (including mixed, deciduous, and evergreen)	4,809,118,135	110,402
Wetlands	130,309,583	2,991
Open Water	412,223,712	9,463

3 PISCATAWAY RUNOFF ANALYSIS

The hydrologic analysis is based upon a detailed surface/surface model for the Piscataway Creek watershed. This model was calibrated to flows observed at USGS 1653650 for the 2009 water year. The model partitioned runoff into that from directly connected impervious areas (*Connected*), from disconnected impervious and pervious receiving areas (*Disconnected*), and from rural and natural areas (*Pervious*). Appendix A provides additional information on the differences in connected and disconnected impervious areas.

Table 4 displays how the hydrologic cycle in the Piscataway Creek watershed model was partitioned into these three different classifications. Surface evaporation was at least twice as high in the connected areas because of the absence of infiltration, which means that all depression storage evaporates. The balance of precipitation was then partitioned into infiltration or surface runoff (SRO). The results show how infiltration dominates the response from both disconnected and natural areas.

Of the fraction of runoff that infiltrated, approximately one-third was returned as groundwater (GW) flow; the remainder was lost to evapotranspiration (ET). Event GW flow comprises the GW discharged during the recession limb of a rainfall-runoff event. Baseflow GW is allocated separately from event GW and is added to event GW flow to obtain total GW flow. Event GW flow is a high proportion of total streamflow. A substantial portion (approximately one-third) of event GW flow would be considered part of the baseflow GW partition according to typical hydrograph separation procedures. There was a considerable amount of GW ET loss in the pervious areas. Most of this ET was actually lost from the soil profile after the event, with the rest lost as GW passed through the riparian zone before entering the streams.

As shown in Table 4, the partitioning resulted in roughly two-thirds of the total "runoff" hydrograph being conveyed by subsurface pathways in the recession limb of the hydrograph. Thus most of the watershed "runoff" was actually conveyed by subsurface flows. This partitioning has major implications for intercepting and treating disconnected runoff because it is already disconnected and its loads are already transformed by plant and soil processes, which tends to eliminate TSS, FC, and most of the TP and BOD. However, these processes do not attenuate TN nearly as much, as will be addressed in the WTM section. The WTM analysis considers this runoff in the recession limb (most of which is actually conveyed by subsurface flows) as part of the overall runoff response. Of the disconnected runoff watershed, the 0.66 inches classified as surface runoff comprises less than 7 percent of the entire disconnected event runoff of 9.62 inches. As a result, the proportion of disconnected runoff that is conveyed by subsurface flows in the recession limb is over 90 percent. This has important implications for the partitioning of nutrient transformations in disconnected flows.

Table 4. Hydrologic partitioning, Piscataway Creek watershed SWMM model analysis

Watershed	Surface type	Surface evap. (in.)	Surface infiltration (in.)	Surface runoff (in.)	Event GW flow (in.)	Total GW flow (in.)	GW evap. (in.)	Hydrologic pathway	Percent annual rainfall
Tinkers Creek	Pervious	3.04	40.07	0.00	7.72	13.61	26.46	Evapotrans.[1]	57.8%
	Disconnected	3.53	39.28	0.24	8.57	15.90	23.38	Groundwater[2]	28.2%
	Connected	7.89	0.00	35.23	0.00	0.00	0.00	Surface runoff[3]	14.0%
	Weighted total	4.04	33.01	6.04	6.73	12.16	20.85	Total runoff[4]	24.5%
Main Stem Piscataway	Pervious	3.04	40.07	0.00	7.72	11.86	28.21	Evapotrans.	63.7%
	Disconnected	3.89	38.31	0.85	9.11	17.03	21.28	Groundwater	29.2%
	Connected	7.77	0.00	35.34	0.00	0.00	0.00	Surface runoff	7.2%
	Weighted total	3.69	36.32	3.09	7.55	12.57	23.75	Total runoff	18.8%
Tidal Piscataway	Pervious	3.04	40.07	0.00	7.73	12.69	27.38	Evapotrans.	62.7%
	Disconnected	3.85	38.50	0.70	9.12	19.57	18.93	Groundwater	32.6%
	Connected	8.04	0.00	35.08	0.00	0.00	0.00	Surface runoff	4.7%
	Weighted total	3.53	37.55	2.01	7.74	14.06	23.49	Total runoff	16.7%
Entire Piscataway Watershed	Pervious	3.04	40.07	0.00	7.72	12.37	27.70	Evapotrans.	62.0%
	Disconnected	3.78	38.61	0.66	8.96	17.08	21.54	Groundwater	29.5%
	Connected	7.85	0.00	35.27	0.00	0.00	0.00	Surface runoff	8.5%
	Weighted total	3.75	35.68	**3.66**	**7.38**	12.71	22.98	Total runoff	19.9%

[1] Evapotranspiration is the sum of evaporation and event groundwater evapotranspiration.

[2] The total groundwater component represents baseflow, plus event groundwater flow.

[3] Surface runoff represents connected runoff plus disconnected overland runoff

[4] Total runoff is the surface runoff plus the recession limb due to disconnected runoff. (Sum of surface runoff plus two-thirds of event groundwater flow).

Total GW flow comprises both the recession limb return flow during events, as well as the baseflow between events. Most of the GW return flow from disconnected areas, which occurs during a storm event as subsurface flow, is not considered baseflow. The SWMM flow duration curves were calibrated to the Piscataway USGS gauge as shown in Table 4. By segregating connected, disconnected, and natural surfaces, it was possible to determine the relative contributions of these sources to GW. From that calibration, GW flow from disconnected areas for the entire watershed was 29.5 percent, compared to surface runoff contributions of only 8.5 percent. Using one-third disconnected runoff allocated to baseflow, total runoff increased to 19.9 percent, leaving 18.1 percent as baseflow, which are within the range of literature values.

The analysis of the Piscataway Creek watershed was helpful in that it represented a wide variety of development intensities. Tinkers Creek is fairly heavily developed; the tidal Piscataway Creek is minimally developed; and the main stem is between those two extremes, with moderate development. This is reflected in the partitioning of ET, GW, and SRO. Because of impervious cover, both ET and GW in Tinkers Creek are slightly less than the average of the less-developed watersheds, while SRO is nearly three times that of the least developed watershed. When event GW flow is added to SRO, the volume of runoff is much higher than SRO alone. As noted above, if one-third of this is considered baseflow, the annual runoff depth for the Piscataway Creek watershed would be about 8.6 inches (3.66 + 2/3 × 7.38), representing 19.9 percent of annual precipitation. This result is consistent with watershed studies on hydrograph separation in the Chesapeake Bay that show approximately 15 to 25 percent of precipitation is returned as baseflow, and 10 to 20 percent is stormflow, much of which is shallow subsurface flow (Jordan et al. 1997).

4 POLLUTANT LOADING METHODOLOGY

Pollutant loads comprise both surface washoff during wet weather and GW flow during and after rain events as baseflow. The hydrologic modeling was designed to partition these flows as realistically as possible as they would occur passing through the landscape. The analysis determined the volume of runoff from the individual source areas and how much rainfall is infiltrated in the process. From this information, it provided computations of GW flow contributions. The study also documented how runoff from impervious areas that flows over pervious surfaces is substantially reduced. This is a critical aspect of pollutant loading analysis.

The annual median concentrations (AMCs) of subsurface leaching and surface washoff concentrations are multiplied by their respective subarea source volumes to obtain the annual subarea mass loads. AMCs are the annual analogue of event mean concentrations obtained from individual events. For disconnected runoff where flows originate from impervious surfaces, it is assumed that the receiving pervious surface is a turf area twice the size of the source impervious area. While the actual area of runon may be more or less, this area of disconnection is also subject to the most fertilization, compaction, and dog waste, so its surface runoff loads will be higher than the same amount of isolated turf. On the other hand, since most of its total runoff comprises subsurface flow, nutrient and TSS transformations will reduce most runoff loads.

AMCs in the model are determined by the source AMCs, as modulated by the receiving pervious cover. When considered in this manner, the effects of impervious area disconnection are obtained. These subarea loads are then summed within their respective subwatersheds to obtain annual connected, disconnected, and natural runoff pollutant loads. The resulting loads are then divided by their subwatershed runoff volumes to obtain subwatershed AMCs. Figure 2 shows how the WTM model allocates flows and AMCs in terms of their pollutant loading implications.

Although there are different forms of N and P, these forms are aggregated in this analysis as TN and TP. TSS, TP, and FC are not considered to be found in GW because they do not infiltrate into soil to any appreciable extent. Because of the importance of N loads, this analysis does address dissolved N (DN) in GW flow by partitioning. DN initially comprises various forms such as nitrate, as well as ammonia and organic N, which are mostly converted into nitrate within the upper soil profile. Nitrate not taken up by plants then leaches into the GW, where it persists until discharged into streams through the riparian zone, where DN can be substantially attenuated. However, appreciable N attenuation requires favorable hydrological and geochemical conditions in the riparian zone, which are unlikely to occur in many watersheds, especially those that are urbanized (Lowrance et al. 1995). Although onsite wastewater disposal systems also generate DN, this was not addressed in the surface runoff analysis because of its relatively low contribution to total N loads throughout the county.

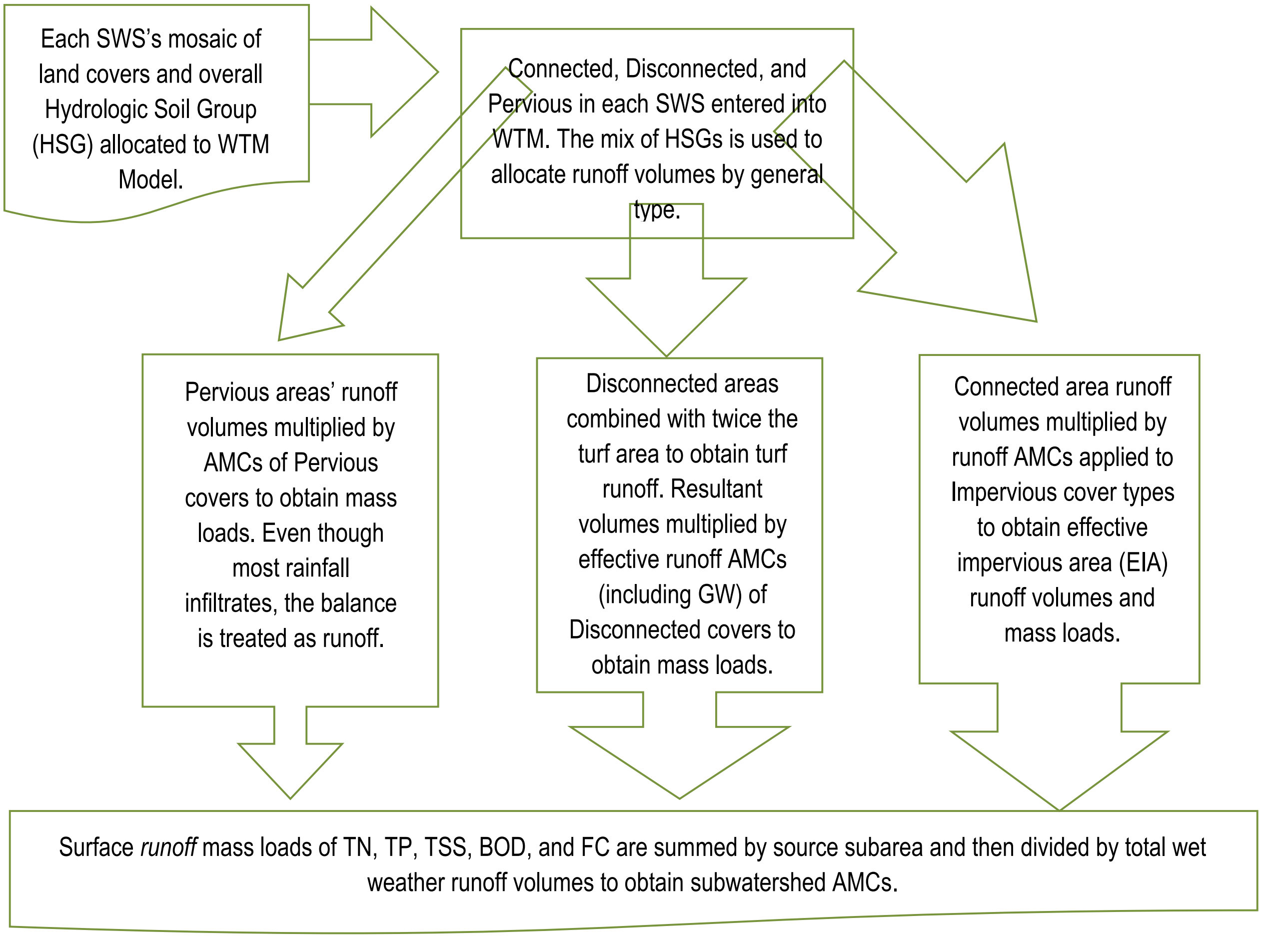

Figure 2. How land cover allocation used in WTM analysis

Unlike the SWMM model used in the Piscataway analysis, in which infiltration is based on Green-Ampt infiltration routines, WTM uses the SCS TR-55 method based upon the Hydrologic Soil Group (HSG). Each watershed mix of HSGs is used to calculate the relative amount of runoff volume from pervious surfaces. These volumes are multiplied by the AMC to obtain the mass loads. The various widths of the flow arrows in Figure 2 represent the approximate relative contribution to annual pollutant loads.

5 WTM INPUT DATA PARAMETERS

WTM 2013 has many features that are useful in allocating surface runoff loads. Although it has some capability for addressing the proportion that is subsurface flow, the Piscataway runoff analysis showed that this is a complex process. The calibrated Piscataway Creek SWMM model showed that most such runoff was interflow, not overland. Therefore, considerable efforts were taken to adapt WTM to provide results similar to the detailed Piscataway runoff analysis; it necessarily results in simplifications that are not entirely accurate. The critical factor is that impervious connected runoff not only dominates the annual runoff but is also the most accurately modeled. This higher degree of accuracy is important because impervious connected runoff is the source category that is both most impairing and most amenable to treatment. The pervious source area simplifications represent lower mass loads, and they are included to provide a basis for representing the entire watershed mass loads for calibration to TMDL mass loads. Table 5 presents the AMCs allocated to the various land cover types and surface conditions used in this analysis used in WTM. It follows the methods that were included in the Delaware Urban Runoff Management Model (Lucas 2004) and were used in the Piscataway SWMM model. Values were also chosen to correspond to the means found from the National Stormwater Quality Database (Maestre and Pitt 2005), as well as the values reported by Tetra Tech (2014).

5.1 Connected Land Covers

The Connected land covers are relatively straightforward. TN and TP values obtained from the literature were used to allocate their respective values in WTM. Aviation has relatively low TN and TP because none of the adjacent fields are fertilized. On the other hand, not only do drives collect direct fertilization overspill but adjacent pervious runon also has a considerable amount of dog feces and fertilizer. This also elevates its FC concentration relative to other land covers. BOD was allocated based on the National Stormwater Quality Database for sites in the Mid-Atlantic and then adjusted to follow trends in N and P loads. Because these land covers are directly connected, there was no turf cover allocated to them.

5.2 Disconnected Land Covers

Disconnected runoff AMCs are dominated by the pervious receiving surface AMCs, as that is what is measured in stormwater sampling. The disconnected land covers includes the turf areas adjacent to the disconnected impervious surfaces. In the WTM, twice as much turf area as the impervious area is allocated to account for proper disconnection of the impervious surface. The turf allocation is used to modulate the runoff volumes. The total runoff depth is the sum of the turf runoff volume and the impervious runoff volume, divided by the sum of the turf and impervious source areas. While this has no effect on total runoff volume, it substantially reduces surface runoff volume compared to direct runoff as noted above.

However, pervious areas are enriched in TN, TP, TSS, and FC, so an enrichment factor was also applied to reflect the increased AMCs from pervious areas. As shown in Table 5, this enrichment factor was allocated a value of 2.0 for TN, TP, and TSS; 1.0 for BOD; and 5.0 for FC. However, since the majority of disconnected runoff is conveyed by subsurface flow where AMCs are attenuated, this overstates the net enrichment factor for disconnected, which would be less than 1.0. As the WTM model is calibrated to the watershed, this factor has no effect upon loading or BMP removals. Future iterations of the model will use lower enrichment factors.

Table 5. Land cover AMC allocations by Connected, Disconnected, and Pervious areas used in WTM model

Primary sources		Turf partition		Concentrations				
Category	Land cover	Imperv. cover (%)	Turf cover (%)	TN (mg/L)	TP (mg/L)	TSS (mg/L)	BOD (mg/L)	FC (MPN/ 100 mL)
Connected	Aviation	100%	0%	1.90	0.15	30	5.5	200
	Drives	100%	0%	2.20	0.35	70	12.5	5000

Primary sources		Turf partition		Concentrations				
Category	Land cover	Imperv. cover (%)	Turf cover (%)	TN (mg/L)	TP (mg/L)	TSS (mg/L)	BOD (mg/L)	FC (MPN/ 100 mL)
	Gravel	100%	0%	1.80	0.20	110	7.5	1000
	Other	100%	0%	1.80	0.20	60	7.5	5000
	Parking	100%	0%	2.20	0.35	60	15.0	7500
	Railroad	100%	0%	1.80	0.15	100	7.5	1000
	Roads	100%	0%	2.20	0.30	60	12.5	5000
	Roofs	100%	0%	1.60	0.12	15	7.5	1500
	Walks	100%	0%	2.20	0.30	40	12.5	7500
Disconnected		**Enrichment Factor**		**2.00**	**2.00**	**2.00**	**1.00**	**5.00**
	Aviation	33%	67%	3.80	0.30	60	5.5	1000
	Drives	33%	67%	4.40	0.70	140	12.5	25000
	Gravel	33%	67%	3.60	0.40	220	7.5	5000
	Other	33%	67%	3.60	0.40	120	7.5	25000
	Parking	33%	**67%**	4.40	0.70	120	15.0	37500
	Railroad	33%	67%	3.60	0.30	200	7.5	5000
	Roads	33%	67%	4.40	0.60	120	12.5	25000
	Roofs	33%	67%	3.20	0.24	30	7.5	7500
	Walks	33%	67%	4.40	0.60	80	12.5	37500
Pervious	Turf	0%	100%	1.75	0.35	50	2.5	5000
	Field	0%	0%	1.50	0.15	25	1.5	5000
	Crops	0%	0%	10.00	0.50	250	12.0	15000
	Woods	0%	0%	1.25	0.05	15	0.8	500
	Wetlands	50%	0%	1.00	0.05	15	0.8	2500
	Open Water	100%	0%	1.50	0.05	15	0.8	200
	Barren	0%	0%	2.00	0.90	400	3.0	1000

As shown in Table 5, open water has 100% runoff retention with very low AMCs. Wetlands vary widely, so a mid-point value of 50% was chosen. As with open water, the AMCs for wetlands are low. These land covers have minimal bearing on overall watershed loads, which are dominated by impervious urban surfaces, and they have no bearing on MS4 loads by definition.

5.3 Pervious Land Covers

The pervious land covers include turf that is far enough away from adjacent impervious areas that it would be less likely to be heavily fertilized or to have high pet or goose waste concentrations. Consequently, its FC concentrations are similar to those of fields, which are essentially unmaintained, so its TN, TP, and TSS would be less. On the other hand, cropland includes heavily disturbed and fertilized areas. As a result, this land cover would have the highest loads of all stressors by a considerable margin. Values for TN and TP were obtained from the literature. In distinct contrast, woods have among the lowest concentrations of TN, TP, TSS, BOD, and FC. Wetlands have even lower TN due to their effective N removal, but higher FC due to waterfowl. Because wetlands are saturated, the percent impervious is allocated as if it were 50 percent to increase its runoff volumes. Similarly, water is considered 100 percent impervious in terms of runoff volumes. It has the lowest FC concentrations (roughly equal to baseline) because it is a sink for FC. Barren values were chosen to reflect the exposed nature of this land cover.

In addition to the AMCs, WTM allocates runoff volumes by land cover type and HSG. Table 6 presents how runoff coefficients are applied in WTM to each pervious land cover according to each HSG. As would be expected, impervious runoff has a constant runoff coefficient of 0.92. This gives the same annual runoff volume as that found in the Piscataway runoff analysis. Pervious runoff coefficients for each HSG were determined by evaluating the literature and by adjusting the trends in the coefficients so that the cumulative results were similar to those in the Piscataway runoff analysis. This resulted in slightly lower runoff coefficients than those allocated in WTM 2013. Coefficients for crops, fields, wetlands, and barren areas were chosen to bracket literature values, keeping in mind the effect of HSG on runoff for each of these land covers.

Table 6. Runoff coefficients by land cover and HSG used in the WTM model

Soils	Runoff coefficients						
HSG	**Imperv.**	**Turf**	**Forest**	**Crops**	**Field**	**Wetland**	**Barren**
A Soils	0.92	0.05	0.02	0.15	0.03	0.30	0.25
B Soils	0.92	0.10	0.03	0.25	0.08	0.35	0.35
C Soils	0.92	0.15	0.04	0.35	0.12	0.40	0.45
D Soils	0.92	0.20	0.05	0.45	0.18	0.45	0.55

The final attribute in WTM is the annual rainfall, as well as the proportion of pervious runoff in which the various stressors are conveyed. Table 7 displays the values used in this analysis. As noted above, much of the TN from pervious surfaces is actually conveyed in subsurface flows, so its coefficient was much lower than the coefficients of TP, TSS, BOD, and FC, all of which are substantially attenuated in the profile. The AMC values in Table 5 were selected to account for these partitioned flows so that the resultant loads would match those that would be expected if both surface and subsurface flow pathways were involved. Because of the way WTM was set up for this analysis, the parameter entries discussed in this section can be globally updated in the following results section.

Table 7. Annual rainfall and partitioning coefficients

Watershed data	Partitioning coefficients in runoff					
Annual Rainfall (in.)	**Pollutant**	**TN**	**TP**	**TSS**	**BOD**	**FC**
43.11	Fraction runoff	50%	90%	95%	95%	100%

6 WTM OPERATIONAL RESULTS

The preceding input parameters were globally applied to the 237 subwatersheds that are the subject of this study. As an example, the WTM entries for the entire SWS AR-10 are shown in Table 8 to illustrate how WTM applies these input assumptions (e.g., loading rates) to the results of the GIS analysis of each SWS. As expected, all impervious cover has the same runoff depth and volume over a year, so each land cover's loading rate is proportional to its AMC. Given a constant percentage of turf, disconnected area runoff is also identical. So, even though disconnected runoff is typically enriched relative to direct runoff, its loads are lower.

Table 8. WTM runoff and annual loading rate computations, entire Anacostia SWS AR-10

Primary sources			Annual loading rates					
Watershed category	AR-10 Land cover	Area (acres)	TN (lb/ac)	TP (lb/ac)	TSS (lb/ac)	BOD (lb/ac)	FC (# bn/ ac)	Runoff (in/yr)
Connected Impervious 30.5%	Aviation	0.0	15.33	1.21	242	44.37	7.4	35.7
	Drives	16.6	17.75	2.82	565	100.84	183.8	35.7
	Gravel	21.3	14.52	1.61	887	60.50	36.8	35.7
	Other	21.4	14.52	1.61	484	60.50	183.8	35.7
	Parking	140.5	17.75	2.82	484	121.01	275.7	35.7
	Railroad	0.0	14.52	1.21	807	60.50	36.8	35.7
	Roads	129.2	17.75	2.42	484	100.84	183.8	35.7
	Roofs	87.8	12.91	0.97	121	60.50	55.1	35.7
	Walks	0.0	17.75	2.42	323	100.84	275.7	35.7
Disconnected Impervious 5.6%	Aviation	0.0	13.86	0.82	219	20.06	16.6	16.1
	Drives	0.2	16.05	1.91	511	45.59	415.6	16.1
	Gravel	8.0	13.13	1.09	802	27.36	83.1	16.1
	Other	20.0	13.13	1.09	438	27.36	415.6	16.1
Disconnected Pervious 11.2%	Parking	0.4	16.05	1.91	438	54.71	623.4	16.1
	Railroad	0.0	13.13	0.82	729	27.36	83.1	16.1
	Roads	4.4	16.05	1.64	438	45.59	415.6	16.1
	Roofs	129.1	11.67	0.66	109	27.36	124.7	16.1
	Walks	67.4	16.05	1.64	292	45.59	623.4	16.1
Pervious 52.7%	Turf	233.6	2.52	0.50	72	3.60	32.8	6.4
	Field	126.4	1.84	0.18	31	1.84	28.0	5.4
	Crops	59.0	33.20	1.66	830	39.84	227.0	14.7
	Woods	248.4	0.47	0.02	6	0.30	0.9	1.7
	Wetlands	0.0	5.85	0.29	88	4.68	66.7	25.9
	Open Water	53.0	12.10	0.40	121	6.45	7.4	35.7
	Barren	0.0	0.75	0.34	150	1.13	1.7	16.1
100.0%	Total Acres	1,367	9.81	1.03	226	37.35	124.1	17.51

In the case of pervious runoff, there are large differences in runoff coefficient, ranging from very low in woods to very high in wetlands and water. Fields were close to turf but three times higher than woods. Because of compaction and seasonal fallow cover, crops had among the highest runoff of the pervious land covers. Due to their poor drainage, wetlands had the highest runoff coefficients, and given saturated conditions, these were magnified by allocating half their area as effectively impervious. Water is treated as being entirely impervious. Given the differing AMCs and runoff depths, the unit area loads vary widely. The pervious runoff depths and volumes for each SWS reflect the unique mixture of HSGs in the subwatershed.

Table 9 illustrates how the unit area loading rates are multiplied by the acres to obtain the final loads from each subwatershed, highlighting where the loads originate. This information can help in future restoration planning.

Table 9. WTM runoff and annual load computations, entire Anacostia SWS AR-10

Primary sources		Annual loads						
Watershed category	AR-10	TN (lb/yr)	TP (lb/yr)	TSS (lb/yr)	BOD (lb/yr)	FC (# bn/yr)	Annual runoff	
	Land cover						(ac-in.)	(ac-ft)
Connected Impervious 30.5%	Aviation	0.0	0.0	0	0.0	0	0	0.0
	Drives	294.8	46.9	9,379	1,674.8	3,053	593	49.4
	Gravel	309.5	34.4	18,915	1,289.7	784	761	63.4
	Other	311.3	34.6	10,377	1,297.2	3,941	765	63.8
	Parking	2,493.9	396.8	68,016	17,003.9	38,748	5,016	418.0
	Railroad	0.0	0.0	0	0.0	0	0	0.0
	Roads	2,292.8	312.7	62,530	13,027.2	23,749	4,611	384.3
	Roofs	1,132.9	85.0	10,621	5,310.5	4,841	3,133	261.1
	Walks	0.0	0.0	0	0.0	0	0	0.0
Disconnected Impervious 5.6%	Aviation	0.0	0.0	0	0.0	0	0	0.0
	Drives	3.8	0.5	121	10.8	98	4	0.3
	Gravel	105.5	8.8	6,447	219.8	668	130	10.8
	Other	262.6	21.9	8,752	547.0	8,310	323	26.9
Disconnected Pervious 11.2%	Parking	7.1	0.9	195	24.3	277	7	0.6
	Railroad	0.0	0.0	0	0.0	0	0	0.0
	Roads	70.9	7.3	1,934	201.4	1,836	71	5.9
	Roofs	1,507.1	84.8	14,129	3,532.3	16,098	2,084	173.7
	Walks	1,081.8	110.6	19,668	3,073.2	42,019	1,088	90.7
Pervious 52.7%	Turf	589.1	117.8	16,830	841.5	7,670	1,489	124.1
	Field	232.6	23.3	3,877	232.6	3,533	686	57.2
	Crops	1,960.4	98.0	49,011	2,352.5	13,402	867	72.3
	Woods	116.7	4.7	1,401	74.7	213	413	34.4
	Wetlands	0.0	0.0	0	0.0	0	0	0.0
	Open Water	641.2	21.4	6,412	342.0	390	1,891	157.6
	Barren	0.0	0.0	0.0	0.0	0	0	0.0
100.0%	Total acres	**13,414**	**1,410**	**308,614**	**51,055**	**169,629**	**23,933**	**1,994**

7 CALCULATING LOADS SPECIFIC TO MS4 URBAN AREAS

The preceding tables display the input parameters and results for a typical high-intensity urban subwatershed, which also included pervious land covers such as field, crops, woods, and wetlands. Although crops in this pervious source category can contribute substantial loads, these areas are not subject to the TMDL. Therefore, it is necessary to partition their loading from the urban areas of the County to obtain urban area loads.

Tetra Tech calculated the loads associated with the different municipalities in the County as well as state and federal lands at the urban area level. The first task was to identify these lands. MDE has developed a geospatial layer for "NPDES-Regulated Stormwater Systems" and posted the layer on its *TMDL Data Center* website. This layer contains information on the State Highway Administration (SHA) roadways, other state land, municipality boundaries, federal land (which mirrors what is used in the Chesapeake Bay Model), and industrial properties.

This geospatial data have several problems that would affect the loading calculations. The main problem is that smaller state, federal, and industrial properties have only a circular buffer drawn around each site. Reviewing the data against aerial photography shows that the buffers split neighboring buildings, drives, roads, parking lots, and the like and do not give a true sense of land use/land cover. Therefore, Tetra Tech used the parcel information obtained from the County to determine the placement of state and federal facilities. In addition, Tetra Tech obtained the municipal and transportation geospatial data from *PGAtlas*. The transportation layer had additional roadways, so it was compared to the SHA information.

On review, the County's transportation data were found to be of higher quality, so the data were modified to remove roadways that were not part of the SHA system and to align the data layer with roads in the rural portions of the County based on aerial photographs. Once complete, the municipal, parcel, and transportation data were combined and cleaned. State and federal lands within municipal boundaries were categorized as state or federal and not part of the municipality's area. Land not falling within municipal, state, or federal boundaries was considered County land. Although municipal land was tracked separately, all municipal land, excluding the city of Bowie, is considered under the County's MS4 and thus included in County MS4 totals. This provided the base map defining the MS4 boundaries and the respective ownership entities.

MDE, as part of its guidance on developing stormwater restoration plans (MDE 2014a), recommended using land use to determine the urban areas to which implementation load reduction goals would apply. The 2010 Maryland Department of Planning land use data were used to determine the urban land use areas. These urban areas were then combined with the entity geospatial data along with the impervious cover and soils information to develop the input parameters for WTM. Therefore, the final MS4 areas in the County are considered all County land that falls within the 2010 MDP land use data's urban footprint minus any federal, state, and city of Bowie areas within this urban footprint.

8 WTM MS4 WATERSHED RESPONSE

Table 10 displays the resultant allocation for the entire Anacostia MS4 watershed. It shows how the loads from each individual SWS are summed to obtain the entire loads from the major watershed. In this manner, a rigorous, hydrology-based land cover approach is able to provide a very detailed accounting of watershed loads. Because the analysis was limited to the MS4 boundaries, only turf and fields are found in the pervious categories. The percent impervious connected, disconnected impervious, and pervious are shown, along with summaries of the relative loading contributions from these source categories.

In terms of both unit area loading rates and the annual load, it can be seen that the connected impervious cover category is higher in all categories except FC. Even though the disconnected impervious and pervious area is almost as large as the connected area, because the runoff from the disconnected area is less than half that of the connected impervious area, the loads are lower, even with the connected area's enriched concentrations. Only the high enrichment applied to FC (reflecting the contributions of pets and wildlife such as geese) has a higher total load from the disconnected areas.

Based on the flow partitioning presented in Table 10, the amount of the surface runoff loads (which represent the loads that can be intercepted) is displayed for all urban area in the Anacostia River watershed in the County. This comprises all the connected runoff, as well as the proportion of disconnected runoff that can be intercepted. Because a substantial amount of TN is dissolved, there is a lower percentage of TN than of the other stressors. The total length of stream miles is also displayed. As is discussed in the calibration discussion, stream miles represent a potential source of TSS.

Table 10. WTM runoff and annual load computations, Entire Anacostia urban area

Primary sources			Annual loading rates						Annual load					Annual runoff	
Watershed category	Anacostia Land cover	Area (Acres)	TN (lb/ac)	TP (lb/ac)	TSS (lb/ac)	BOD (lb/ac)	FC (# bn/ac)	Runoff (in/yr)	TN (lb/yr)	TP (lb/yr)	TSS (lb/yr)	BOD (lb/yr)	FC (# bn./yr)	(ac-in.)	(ac-ft)
Connected	Aviation	10.0	15.33	1.21	242	44.4	7	35.7	154	12.2	2,432	446	74	359	29.9
Impervious	Drives	832.2	17.75	2.82	565	100.8	184	35.7	14,770	2,349.8	469,962	83,922	152,990	29,707	2,475.6
31.0%	Gravel	488.7	14.52	1.61	887	60.5	37	35.7	7,096	788.5	433,654	29,567	17,967	17,444	1,453.7
	Other	485.4	14.52	1.61	484	60.5	184	35.7	7,048	783.2	234,946	29,368	89,231	17,326	1,443.9
	Parking	3342.0	17.75	2.82	484	121.0	276	35.7	59,312	9,436.0	1,617,605	404,401	921,534	119,292	9,941.0
	Railroad	6.5	14.52	1.21	807	60.5	37	35.7	95	7.9	5,278	396	241	234	19.5
	Roads	3594.4	17.75	2.42	484	100.8	184	35.7	63,792	8,698.9	1,739,773	362,453	660,755	128,302	10,691.8
	Roofs	2137.6	12.91	0.97	121	60.5	55	35.7	27,591	2,069.3	258,667	129,334	117,888	76,303	6,358.6
	Walks	0.0	0.00	0.00	0	0.0	0	0.0	0	0.0	0	0	0	0	0.0
	Connected summary	**10896.9**	**16.51**	**2.22**	**437**	**95.4**	**180**	**35.70**	**179,859**	**24,146**	**24,146**	**1,039,887**	**1,960,679**	**388,967**	**32,414**
Disconnecte	Aviation	0.0	0.00	0.00	0	0.0	0	0.0	0	0.0	0	0	0	0	0.0
Impervious	Drives	30.6	15.21	2.42	484	43.2	394	15.3	466	74.1	14,827	1,324	12,067	469	39.1
9.3%	Gravel	92.1	12.50	1.39	764	26.0	79	15.4	1,151	127.9	70,320	2,397	7,284	1,414	117.9
	Other	664.5	12.54	1.39	418	26.1	397	15.4	8,332	925.8	277,747	17,359	263,716	10,241	853.4
Disconnecte	Parking	141.9	15.26	2.43	416	52.0	593	15.3	2,166	344.5	59,061	7,383	84,117	2,178	181.5
Pervious	Railroad	0.0	0.00	0.00	0	0.0	0	0.0	0	0.0	0	0	0	0	0.0
18.6%	Roads	110.2	15.23	2.08	415	43.3	394	15.3	1,679	229.0	45,795	4,770	43,482	1,689	140.7
	Roofs	5896.1	11.14	0.84	104	26.1	119	15.4	65,682	4,926.1	615,766	153,942	701,592	90,821	7,568.4
	Walks	2866.0	15.35	2.09	279	43.6	596	15.4	43,982	5,997.5	799,664	124,948	1,708,354	44,229	3,685.8
	Disconnected summary	**9801.4**	**12.60**	**0.97**	**192**	**31.8**	**288**	**15.41**	**123,457**	**12,625**	**1,883,181**	**312,122**	**2,820,611**	**151,041**	**12,587**
Pervious	Turf	12140.7	2.08	0.42	59	3.0	27	5.3	25,219	5,043.8	720,549	36,027	328,392	63,765	5,313.8
41.1%	Field	2299.2	1.51	0.15	25	1.5	23	4.5	3,482	348.2	58,028	3,482	52,893	10,270	855.9
	Crops	0.0	0.00	0.00	0	0.0	0	0.0	0.0	0.0	0	0	0	0	0.0
	Woods	0.0	0.00	0.00	0	0.0	0	0.0	0.0	0.0	0	0	0	0	0.0
	Wetlands	0.0	0.00	0.00	0	0.0	0	0.0	0.0	0.0	0	0	0	0	0.0
	Open Water	0.0	0.00	0.00	0	0.0	0	0.0	0.0	0.0	0	0	0	0	0.0
	Barren	0.0	0.00	0.00	0	0.0	0	0.0	0.0	0.0	0	0	0	0	0.0
	Pervious summary	**14439.9**	**1.99**	**0.37**	**54**	**2.7**	**26**	**5.13**	**28,701**	**5,392**	**778,577**	**39,509**	**381,285**	**74,036**	**6,170**
	TOTAL	**35138.2**	**9.45**	**1.20**	**211**	**39.6**	**147**	**17.48**	**332,017**	**42,163**	**7,424,076**	**1,391,518**	**5,162,575**	**614,043**	**51,170**
	Surface runoff		**7.28**	**1.15**	**207.5**	**39.10**	**146.92**		**255,938**	**40,361**	**7,290,988**	**1,373,937**	**5,162,575**	**Stream length (mi)**	
	Subsurface runoff		**2.17**	**0.05**	**3.8**	**0.50**	**0.00**		**76,079**	**1,802**	**133,088**	**17,582**	**-**	**194.9**	

9 WTM CALIBRATION

The calibration process involved several steps. Overall, AMCs were calibrated to total watershed loads for TN, TP, and TSS using MAST loads for the entire watersheds. The Anacostia MS4 watershed was then adjusted to meet the MS4-specific BOD and bacteria loads per local TMDLs.

First, the runoff coefficients were adjusted among the various pervious covers to obtain a runoff volume similar to what was modeled in the Piscataway runoff analysis. From Table 4, the direct runoff was 3.66 inches and the recession limb was 7.38 inches. If two-thirds of that event GW flow is considered event "runoff," that amounts to 4.92 inches. (The remaining event GW flow is considered baseflow, and thus not part of the stormflow responses monitored.) Adding the two amounts together results in a total "runoff" of 8.58 inches. Using the various runoff coefficients in Table 6, the entire watershed runoff for the WTM model for Piscataway was 8.53 inches, thus meeting the pervious runoff computations test.

After calibrating the pervious runoff parameters, the next step was to compare the predicted loads to the load projected by the Anacostia TMDL, as well as the MAST results. MAST presents loads for the edge-of-stream (EOS) and for the loads delivered to the Chesapeake Bay. For this analysis, the EOS stream loads were used. The Anacostia River watershed is the only watershed in the County for which recent TMDLs have been conducted for all five of the stressors listed in Tables 8, 9, and 10. (PCBs are addressed separately and discussed later in this memorandum.) Therefore, the baseline loads from these TMDLs were used to calibrate the assumptions in Table 5 and Table 6.

Table 11 presents the result of the TMDL comparison. The baseline loadings were derived from the values found in MDE's *TMDL Data Center* (MDE 2014a). While MDE reported WLAs for the County's MS4 permit for some parameters, other parameters were reported for a combination of MS4 permits in the watershed, making it difficult to identify the County's portion. The *TMDL Data Center* also presented the required percent reduction. This was used in conjunction with the WLA to back-calculate the initial urban area baseline load from the TMDL modeling, which is presented in Table 11. The values chosen in Table 5 and Table 6 resulted in computed results that were very close to the TMDL in the case of TN, TP, BOD, and FC. The order of magnitude difference in TSS represents the contributions of bank erosion, which were not addressed in this land cover runoff model. The TSS WTM results are consistent with those from MAST.

Table 11. WTM annual load computations, entire Anacostia urban area, WTM compared to TMDL

Anacostia MS4 Area	TN (lb/yr)	TP (lb/yr)	TSS (lb/yr)	BOD (lb/yr)	FC (# bn/yr)
WTM results	332,017	42,163	7,424,076	1,391,518	5,162,575
Baseline Loadings derived from MDE's TMDL Data Center (MDE 2014a)	346,526	44,144	66,118,667	1,456,388	5,211,950
Difference	**-4.4%**	**-4.7%**	**-790.6%**	**-4.7%**	**-1.0%**

Table 12 presents the results of the various MAST urban area computations for the Anacostia, Upper and Lower Patuxent, Piscataway, Potomac, and Western Branch watersheds. No comparisons were made for the Mattawoman or Middle Patuxent because the areas in MAST differed from the areas calculated for this study by an order of magnitude; so it is not possible to be certain that MAST is a representative comparison. Table 12 shows that the areas in MAST were close in the six watersheds used for comparison, so their projections are valid. The differences lie in the more accurate methodology used to delineate the MS4 in this analysis.

Several important points stand out in this analysis. TSS computations in MAST for the edge of stream (without bank erosion) are very close to those projected by WTM given the parameters chosen. When all watersheds are summed, with the total loads normalized to the same total area, the difference is only 2 percent for TSS. In the case of TN, given the more watershed-specific method used in the TMDL, the WTM computation parameters were selected to be within 5 percent on the low side of the TMDL. The result was 22 percent higher than the MAST results.

Table 12. WTM annual load computations, entire Anacostia urban area, WTM compared to MAST

Watershed	Results	TN (lb/yr)	TP (lb/yr)	TSS (lb/yr)	Area (acres)
Anacostia River	WTM	332,017	42,163	7,424,076	35,138
	MAST	342,392	29,201	8,088,226	40,538
	Difference	**-3.1%**	**30.7%**	**-8.9%**	**-15.4%**
Lower Patuxent	WTM	19,716	2,939	595,711	4,357
	MAST	20,247	1,850	746,688	2,529
	Difference	**-2.7%**	**37.1%**	**-25.3%**	**42.0%**
Upper Patuxent	WTM	118,543	15,168	2,671,880	14,415
	MAST	146,545	9,917	3,141,022	17,022
	Difference	**-23.6%**	**34.6%**	**-17.6%**	**-18.1%**
Piscataway Creek	WTM	149,083	18,681	3,313,767	19,338
	MAST	118,027	10,674	3,172,961	20,488
	Difference	**20.8%**	**42.9%**	**4.2%**	**-5.9%**
Potomac River	WTM	186,518	24,090	4,183,775	21,329
	MAST	141,144	13,545	5,540,238	23,804
	Difference	**24.3%**	**43.8%**	**-32.4%**	**-11.6%**
Western Branch	WTM	304,348	39,452	6,846,603	36,721
	MAST	227,778	20,889	6,262,328	39,538
	Difference	**25.2%**	**47.1%**	**8.5%**	**-7.7%**
All subwatersheds	WTM Total	1,110,226	142,492	25,035,811	131,299
	Area adjusted	1,216,938	156,189	27,442,205	143,919
	MAST Total	996,134	86,076	26,951,462	143,919
Adjusted Difference		**21.8%**	**49.2%**	**2.0%**	**-9.6%**

In the case of TP, the divergence between MAST and the TMDL is quite pronounced. The TMDL projected TP loads were 51 percent higher than those from MAST. Again, given the more detailed method used in the Anacostia TMDL, the WTM computation parameters were selected to be 4.7 percent lower than the TMDL in this case, which is still almost 50 percent higher than the MAST projections. The resultant flow-weighted concentration of 0.30 mg/L is still below the mean of values for the Chesapeake Bay watershed of 0.41 mg/L (Tetra Tech 2014). On the other hand, the MAST value of 0.21 mg/L (MAST loads were divided by runoff volume from the WTM model) is barely half of this mean, so it would seem that the MAST loading is not entirely accurate.

A final aspect to note is that the WTM values for Mattawoman Creek were 44 percent higher for TN and 50 percent higher for TP. Given the long period of development since the TMDL, these results were expected due to increased urban area. Given its small area and likely errors, this TMDL was not used for calibration.

In conclusion, the WTM model was able to replicate the Anacostia TMDL quite closely. Disaggregating by land cover permits a far more accurate projection of future loads and the potential benefits of BMPs than would be obtained by a generalized land use approach or the simple area-weighting approach originally contemplated.

10 ESTIMATING PCB CONCENTRATIONS

PCBs were not modeled in WTM. Their sources are usually hotspots from legacy contamination and are highly associated with soils and sediment. Tetra Tech reviewed the tidal Potomac TMDL and found that the model developers had determined that after multiple types of multiple linear regressions, the data showed that TSS predicted PCB3+ concentrations better than did other variables (Haywood and Buchanan 2007). Regressions were developed for three zones: DC Urban, Near DC, and Elsewhere (Table 13). PCB3+ loads were converted to total PCBs by dividing by 0.92 (Haywood and Buchanan 2007).

Table 13. TSS/PCB regression equations

Zone	Area	Equation	Correlation coefficient (R^2)
DC Urban	Watts Branch, Beaverdam Creek	[PCB3+] = 0.855 × [TSS]0.9702	0.61 (n = 30)
Near DC	Remainder of Anacostia River watershed, Oxon Run, Potomac drainages north of Piscataway Creek mouth	[PCB3+] = 0.3290 × [TSS]0.5059	0.63 (n = 94)
Elsewhere	Piscataway Creek, Mattawoman Creek, Potomac drainages south of Piscataway Creek mouth	[PCB3+] = 0.0458 × [TSS]0.5008	0.52 (n = 25)

Source: Haywood and Buchanan 2007.

11 STREAM BANK EROSION

Streambank erosion can add significant amounts of sediment and phosphorus (which sorbs to sediment) to a stream network. Nitrogen, BOD, and bacteria are not increased nearly as much due to streambank erosion. A primary source of streambank erosion is the increase in runoff volume and peak flows due to increased impervious cover, and other land cover changes (Klein 1979, Booth 1990).

During the calibration of the Anacostia River watershed WTM model, TN and TP were calibrated to instream observed concentrations and to loadings reported in MAST. MAST loadings did not consider streambank erosion[3], so TSS baseline loads in the TMDL document were much higher than the TSS from watershed runoff projected by WTM. Therefore, a method to determine bank erosion loads is needed. Modeling streambank erosion requires a continuous simulation of flows for comparison of existing conditions to pre-development flows. It also requires monitoring to determine allowable shear stress, and the increase in shear stress from development, which is beyond the scope of this document.

WTM is not a bank erosion model. To account for streambank erosion and its contribution to phosphorus and TSS loadings, the County used an MDE-recommended procedure to determine an adjustment factor to translate the EOS loadings from the WTM to loading totals that contained streambank erosion. The first step was to determine the unit loading rate for urban land in the TMDL. The next step was to find the combined urban land plus stream bank erosion unit loading rate. The ratio of urban + erosion unit loading rate to the urban land-only unit loading rate is the adjustment factor. These calculations are summarized in Table 14.

After determining the adjustment factors for TP and TSS, we multiplied the MS4 loads by the adjustment factor to obtain the loads including streambank erosion from the MS4 area. The TP and TSS loads reported in the restoration plans include loads from streambank erosion according to this method. Stream restoration measures will reduce stream bank erosion, thus reducing this source of TP and TSS loads. Reductions from these measures according to this method have been accounted for in WTM for the Anacostia River watershed.

Table 14. Calculation for phosphorus and TSS loadings from streambank erosion using information from TMDL reports

<table>
<tr><th colspan="6">Calculation of Unit Loading Rate for Urban Areas Using Information from TMDL Reports</th></tr>
<tr><th>Pollutant</th><th>Urban Load</th><th>Acres</th><th>Urban Loading Rate</th><th colspan="2">Notes</th></tr>
<tr><td>Phosphorus</td><td>54,030 lb/yr</td><td>65,005</td><td>0.83 lb/acre/yr</td><td colspan="2">From Table 6 of nutrient TMDL. Totals include portions of watershed in Montgomery County. (MDE and DDOE 2008)</td></tr>
<tr><td>TSS</td><td>9,331 ton/yr</td><td>77,017</td><td>0.12 ton/acre/yr</td><td colspan="2">From Table 2 of sediment TMDL. Totals include entire Anacostia. (MDE and DDOE 2007)</td></tr>
<tr><th colspan="6">Calculation of Unit Loading Rate for Urban Areas + Streambank Erosion</th></tr>
<tr><td>Pollutant</td><td>Urban Load</td><td>Streambank Erosion Load</td><td>Urban + Streambank Load</td><td>Acres</td><td>Urban + Streambank Loading Rate</td></tr>
<tr><td>Phosphorus</td><td>54,030 lb/yr</td><td>14,990 lb/yr</td><td>69,020 lb/yr</td><td>65,005</td><td>1.06 lb/acre/yr</td></tr>
<tr><td>TSS</td><td>9,331 ton/yr</td><td>34,250 ton/yr</td><td>43,581 ton/yr</td><td>77,017</td><td>0.57 ton/acre/yr</td></tr>
<tr><th colspan="6">Calculation of Loading Rate Adjustment Factor</th></tr>
</table>

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[3] As defined in the Chesapeake Bay model documentation, the "edge-of-stream (EoS) load" is the "load delivered to the represented river or stream from the land segments. … Another portion of the sediment load delivered to the Bay is the sediment load mobilized in river reaches and is defined as the difference between the EoS erosion load and the sediment load scoured and mobilized in the simulation during high flows" (USEPA 2010).

Calculation of Unit Loading Rate for Urban Areas Using Information from TMDL Reports					
Pollutant	Urban + Streambank Loading Rate	Urban Loading Rate	Adjustment Factor	WTM County MS4 Load	WTM County S4 Load + Estimated Streambank Erosion
Phosphorus	1.06 lb/acre/yr	0.83 lb/acre/yr	1.28	34,952 lb/yr	44,738 lb/yr
TSS	0.57 ton/acre/yr	0.12 ton/acre/yr	4.75	3,042 ton/yr	14,450 ton/yr

12 FECAL COLIFORM SOURCE LOAD COMPUTATIONS

The first element in developing a strategy to reduce fecal pathogen loads is to characterize their many sources. The source tracking methods in the TMDLs in the County distinguish sources into the general categories of human, domestic pet, livestock, and wildlife. Each of these source categories then has their own characteristic composition of subcategory types, predominant locations, transport pathways, and fecal compositions.

As discussed in the preceding sections, the loads conveyed in overland flow washed off from different land covers are classified as *primary loads*. Primary loads comprise most watershed loads. However, there are additional loads that are not conveyed in runoff. These are called *secondary loads* and include subsurface TN loads from onsite sanitary disposal systems (OSDSs), as well as human fecal pathogen loads from leaky sewer pipes that flow directly into streams. Bank erosion is another major secondary source of TSS and TP. These secondary loads must also be addressed as part of the WTM modeling process.

Since pathogen loads comprise both primary and secondary loads, this section addresses both processes. This discussion also includes the basis for how to convert instream bacteria loads (from the TMDL reports) to their equivalent runoff loads that are calculated with WTM. This is necessary to determine the reductions in pathogen loads from adoption of programmatic initiatives—non-structural measures (NSMs)—in the same manner as primary loads are reduced through the use of BMPs.

These different source characteristics and their conveyance pathways are relevant to the TMDL for defining whether they are MS4 sources. For example, a substantial portion of human pathogen bacteria (in addition to TN, TP, and BOD) loads originate from leaky pipe systems. Additional loads originate from OSDSs. As these secondary source loads are generally conveyed either by subsurface flow or discharged directly into streams, they are not considered MS4 loads. However, it is important to identify the relative contribution of such loads to the overall baseline loadings.

There are also substantial human primary sources that discharge into MS4s from cross connections, dumpsters and washing facilities. Likewise, domestic pets mostly defecate in turf areas near impervious surfaces that are part of the MS4. On the other hand, livestock defecate in pastures, barnyards and riparian areas that are generally not in MS4 boundaries. Wildlife are ubiquitous in both urban MS4 as well as rural and natural areas. Together, these comprise primary pathogen sources.

Pollutant removal efficiencies are the key element needed to determine the load reduction from BMPs and NSMs, such as public outreach. Ecosite and Tetra Tech performed a literature search to determine the pathogen reduction potential from BMPs and other pollution reduction practices, few of which have established pathogen removal efficiencies. This literature review documents how the resultant BMP efficiencies were determined.

After comparing the necessary load reductions and the load reductions from existing BMPs and programs, Ecosite and Tetra Tech have identified the gaps that still need to be addressed to meet the implementation load reduction goals. These gaps will be the focus of both programmatic implementation initiatives and the placement of BMPs in the subwatersheds.

12.1 Fecal Pathogens and Indicator Bacteria

Fecal pathogens comprise the most common cause of impairment to streams and water bodies in the U.S. (UWRRC 2014). Pathogens are a very broad category that includes viruses such as Norwalk virus and Rotavirus, bacteria such as *Escherichia coli*, enterococci, and *bacteriodes* spp., as well as protozoans such as *Giardia lamblia* and *Cryptosporidium parvum*. Excessive pathogen levels are responsible for shellfish bed and beach closures. Detailed discussion of gastrointestinal pathogens is not included in this report.

Given the myriad pathogen species and types, federal and state regulatory agencies have converged on using the metric of fecal indicator bacteria (FIB). These organisms are always associated with pathogenic species, even though FIB themselves might have few pathogenic characteristics. Prior to 1986, fecal coliform bacteria were the predominant FIB. The principal FIB currently used today comprise *E. coli* and enterococci spp. These FIB, in particular enterococci, have been better correlated with gastrointestinal sickness (USEPA 1986). This correlation is greatest for human FIB, less so for domestic pets, even less for livestock, and the least for wildlife (MDE 2006a).

The correlation between FIB and *E. coli* used in the TMDLs in the County is a linear relationship where *E. coli* = 0.9 × FIB (MDE 2006a). Hathaway et al (2010) noted the following relationship: *E. coli* = $0.988 \times \mathrm{FIB}^{0.919}$ (VADEQ 2003), which is close to the MDE relationship at low FIB concentrations. The Anacostia River watershed TMDL used enterococci as the FIB, which has the linear relationship of enterococci = FIB/2.94 (MDE 2006a). These relationships are used to convert the observed FIB to their equivalent FC FIB loads. Given its presence in the literature and close correspondence to *E. coli*, the equivalent FC values are used in WTM.

If there is one characteristic common to FIB and pathogens in general, it is that the concentrations found in runoff are extremely variable, ranging from less than 10 colony forming units (CFU) per 100 mL into the millions. Typical edge-of-field (EOF) concentrations range from 100 to 100,000 CFU/100 mL. This extreme variability and the processes that underlie FIB dynamics must be recognized before effective strategies can be developed to reduce FIB loads. This starts with understanding where FIB are generated, the various source types, the pathways by which they are conveyed, and finally, the processes involved in their attenuation and removal.

12.2 Fecal Indicator Bacteria Dynamics

FIB are ubiquitous, being found at substantial quantities in even pristine alpine soils (Vierheilig et al. 2012, cited in Kronlein et al. 2013). They originate from deposited feces, colonize the underlying soils, and persist in lake and stream sediments. This section briefly addresses growth, transport, and attenuation responses to provide a framework for understanding implications of FIB for the TMDLs.

12.2.1 Environmental Responses

Pathogen attenuation processes have significant effects on primary and secondary sources. FIB generated in upland source areas are attenuated prior to rainfall events, during runoff conveyance overland, and through the MS4 pipes to County water bodies. Additional attenuation processes occur in the stream itself. As a result, instream baseline loads reported in the TMDL reports are often at least an order of magnitude lower than those projected as primary source loads. The dynamics involved in FIB transport and attenuation also play an important part in determining the extent of pathogen removal by BMPs.

Parameters such as moisture, temperature, antecedent rainfall, and UV light exposure play an important, but often opposing, part in modulating FIB dynamics. FIB numbers increase substantially during the warmer seasons as well as under moister conditions, both conditions favoring the growth of FIB as would be expected for biological systems (Hathaway et al. 2010; McCarthy et al. 2012). FIB numbers are often more correlated with antecedent 5-day runoff than event runoff (Hathaway et al. 2010), suggesting antecedent moisture is mostly responsible for favorable growth conditions.

On the other hand, FIB die-off escalates with increasing UV light exposure (Hathaway et al. 2011a) while higher temperatures are also associated with increasing microbial predation (Pedley et al. 2006). However, even though bacterial predation and die-off increase, the net contribution of FIB to receiving water bodies increases during the summer. As a result, virtually every study shows that storm runoff concentrations increase during warmer temperatures (Pedley et al. 2006; UWRRC 2014). So even though summer flow regimes are generally reduced, FIB concentrations increase.

12.2.2 Event Surface Flow Responses

It is widely noted that the concentration of FIB increases during storm events, often by several orders of magnitude (Hyer and Moyer 2003; Moyer and Hyer 2003; Hathaway et al. 2010; Gonzalez et al. 2012; Sidhu et al. 2012; Kronlein et al. 2013; UWRRC 2014) . This is largely from the washoff of pathogens accumulated during the antecedent dry periods (McCarthy et al. 2007). However, there is no apparent first flush effect (Hathaway and Hunt 2010). Instead, it is common to see the highest concentrations toward the end of an event (McCarthy et al. 2012, UWRRC 2014). It is thought that this occurs due to saturated soils contributing more runoff at the end of an event than at the beginning (UWRRC 2014).

FIB in feces deposited on pervious areas are eventually mobilized in surface runoff. As a result, FIB concentrations increase dramatically when rainfall events transport surface FIB into receiving waters. This response would be applicable to domestic pets, livestock, and wildlife such as pigeons and geese that defecate on pervious areas subject to washoff (Whitlock et al.

2002; Burnes 2003; UWRRC 2014). FIB from wildlife defecating on roofs and directly inside storm sewers also would demonstrate this response (UWRRC 2014). It would also apply to livestock sources such as feedlots and pastures, which are outside the County's MS4 area.

There is also an event response when sediment in streams is disturbed by the increased event flows. During high flows, sediment disturbance can also introduce a substantial load of FIB from resident FIB previously washed off by overland flow from the sources into streams and other water bodies (Hathaway et al. 2011, Kronlein et al. 2013, UWRRC 2014). As a result, resuspension of sediment FIB is a substantial component of the event flow response (Moyer and Hyer 2003).

In areas where waterfowl and livestock congregate, FIB are deposited in the water body and on surfaces immediately adjacent to water bodies from which FIB are washed into the adjacent water bodies during rain events. As a result, not only are the sediments highly elevated in FIB, but the overlying water column FIB concentrations also are elevated (Swallow et al. 2012). Displaced during high-flow events, the water column concentrations are similar to those in baseflow, resulting in much less of a stormflow response than seen for loads from runoff. So, even though these FIB loads might originate in upland water bodies, their overland/instream flow-dependent responses represent primary FIB loads. As a result, they are included as part of the source area loading in WTM.

12.2.3 Subsurface Flow Responses

In addition to overland flow, there are subsurface processes involved in FIB mobilization. In coastal plain watersheds, roughly half of event stormflow is conveyed by subsurface pathways. Under unsaturated conditions, most FIB are immobilized within several feet (Keswick et al. 1982), so any deposited on the surface are removed. However, this does not occur with soils that have developed preferential flows by means of macropores (Gargiulo et al. 2008; Pang et al. 2008; Fox et al. 2012). Once FIB are in groundwater, longer distances, sometimes up to several hundred feet, can be required to eliminate them (Keswick et al. 1982).

An ubiquitous symptom of older sewer systems is leaking pipes and manholes— infiltration and inflow (I&I). During large events, runoff infiltrates into sanitary sewers through these leaks, creating overloaded pipes that cause sanitary sewer overflows (SSOs). Between storm events, infiltration into pipes reverts back to exfiltration from pipes. Where exfiltrated flows encounter macropores, the leaks become a constant source of FIB, creating the consistent baseflow of human FIB often observed in many urban settings (Burnes 2003; Sidhu et al. 2012).

OSDSs are another potentially significant source of subsurface FIB. OSDSs most often fail in areas where groundwater is elevated (Whitlock et al. 2002) or where soils have poor drainage (Day 2004). These conditions favor FIB movement in groundwater. In well-drained upland areas, surface overflows due to OSDS failure typically infiltrate after a fairly short distance, so failing upland OSDSs would not have much of a surface runoff response except for the flush from rinsing off the initial surface accumulation.

I&I and OSDSs represent secondary loads that are not conveyed in runoff and, therefore, are not part of the MS4. Nonetheless, it is important to acknowledge their importance and relevance to the TMDLs, as their reduction will reduce overall bacteria loads to the County's water bodies.

As a result of these sources and pathways, elevated human FIB loads have been invariably correlated with increasing urban density and the presence of sewers in virtually every study published (e.g., Young and Thackston 1999; Line et al. 2008; UWRRC 2014).

12.2.4 Instream Transport Responses

Instream FIB transport processes play an important role in the further attenuation and resuspension of FIB originating from both primary and secondary sources. The literature on runoff from urban settings generally presents observations by land use or land cover, which would be characterized as EOF. In WTM, literature EOF observations are adjusted to account for pathogen attenuation during conveyance through the MS4 pipes to EOS values. It is presumed that relatively little attenuation occurs inside MS4 conveyance pipes from EOF to EOS. The resultant EOS values are multiplied by land area and runoff volumes to provide the EOS loading used in WTM.

However, EOS FIB runoff concentrations are typically orders of magnitude higher than those found in the observed values further downstream in the receiving water bodies, as reported in the TMDL document. This is due to dilution, natural attenuation, and transport losses in the stream itself. As a result, receiving instream baseline loads are often an order of magnitude lower than projected as EOS loads. Therefore, further adjustment factors are necessary to relate WTM EOS source area load computations to the baseline loadings in the TMDL reports. Those factors are discussed for each loading source in the next section.

12.3 Fecal Indicator Bacteria Responses in the Piscataway Creek Watershed

12.3.1 Flow Regime Responses

Because of the different flow regime responses, the bacteria TMDLs in the County segregate low flows from high-flow regimes to provide for a more accurate representation of the status of the water body. In the Piscataway Creek watershed, water quality monitoring was performed more on the 25 percent of the flow regime that represents high flow than on the remaining 75 percent low-flow regime. Table 15 presents FIB counts in the Piscataway Creek watershed. Even though the weighted average annual *E. coli* geometric means were below water quality criterion, seasonal means were substantially higher, hence the need for the TMDL. The number of FIB increase substantially during high flow.

Table 15. Annual and Seasonal (May 1–September 30) *E. coli* counts

Tributary	Flow Stratum	Steady State Geometric Mean (MPN/100 mL)	Weighted Geometric Mean (MPN/100 mL)
Annual Mean Period			
Piscataway Creek	High	180	123
	Low	109	
Tinkers Creek	High	203	108
	Low	87	
Seasonal Mean Period			
Piscataway Creek	High	358	232
	Low	200	

Tributary	Flow Stratum	Steady State Geometric Mean (MPN/100 mL)	Weighted Geometric Mean (MPN/100 mL)
Tinkers Creek	High	395	183
	Low	141	

Source: MDE(2006b)

12.3.2 Source Tracking Methods

The first task in determining how to reduce the FIB to acceptable levels is to define the source. Various methods have been used to differentiate sources into human (e.g., sewage and OSDS), livestock (e.g., cattle, horses, and sheep), domestic animals (e.g., dogs and cats), and wildlife (e.g., gulls, geese, pigeons, and raccoons). Watershed managers focus on the pathogen sources of greatest interest in their watershed.

Several microbial source tracking (MST) techniques are used to accomplish this task. They are divided into genetic, biological and chemical methods.

- Genetic methods are often based on polymerase chain reaction (PCR) techniques to rapidly amplify DNA or RNA segments of FIB from certain strains specific to the various hosts.
- The most common biological method is antibiotic resistant analysis (ARA), in which resistance is highest in humans, less so in livestock (which have a palette of antibiotics specific for each type), less so for domestic pets, and very little in the case of wildlife (Kronlein et al. 2013).
- Chemical methods differentiate on the basis of the presence of indicators such as caffeine, triclosan, and other chemical signatures associated with human waste. It is primarily used for human source tracking (MDE 2006b).

The implications of the different sources are discussed below for the example of the Piscataway Creek watershed TMDL. The analysis and findings from this analysis are generally transferable to the loading analyses performed for the other watersheds with TMDLs in the County. Using ARA microbial source tracking techniques, Table 16 displays the source partitioning, as partitioned into high-flow regimes and low-flow regimes, reported in the Piscataway Creek watershed TMDL (MDE 2006b). The low unknown percentage indicates that the ARA technique used was very discriminating. In the TMDL, this percentage was proportionately reallocated to the four dominant sources.

Table 16. Annual and Seasonal (May 1–September 30) MST results

Tributary	Flow Stratum	% Domestic Animals	% Human	% Livestock	% Wildlife	% Unknown
Annual Mean Period						
Piscataway Creek	High	23	37	8	27	5
	Low	5	29	20	42	5
	Weighted	9	31	17	38	5
	High	38	23	2	29	7

Tributary	Flow Stratum	% Domestic Animals	% Human	% Livestock	% Wildlife	% Unknown
Tinkers Creek	Low	5	29	11	45	10
	Weighted	14	28	9	41	9
Seasonal Mean Period						
Piscataway Creek	High	26	25	7	40	3
	Low	2	31	12	51	3
	Weighted	8	29	11	48	3
Tinkers Creek	High	38	21	2	37	2
	Low	5	31	7	55	2
	Weighted	13	29	6	51	2

Source: MDE(2006b)

The low livestock percentage means that agriculture is a minor component of total loads. The relatively low proportion during high flow suggests a water body sediment displacement process as opposed to a surface runoff response.

In a similar manner, human loads have a much lower flow-dependent response and so are relatively higher in baseflow, which resulted in stormflow loads that are only 44 percent and 90 percent higher than baseflow in the Main Stem of Piscataway Creek and Tinkers Creek, respectively. This response suggests a predominantly subsurface origin for such loads, the most likely of which appears to be leakage from sewer lines as discussed above, along with a potential contribution from failing OSDSs.

In contrast, domestic pet loads have much more of a flow-dependent response and so are much higher in storm flow. The much higher stormflow percentages, the result of which is that the *E. coli* summer mass load increased by over 2,000 percent in both watersheds, demonstrates how pet loads are dominated by runoff, as would be expected from feces deposited over pervious surfaces. While the relatively low domestic pet proportion indicates that pets are a minor contributor of total loads, the amount involved is still considerable and would be amenable to surface interception BMPs and programmatic NSMs.

The most dominant category of loads is the wildlife component. Similar to human loads, its proportion increases during low flow. As a result, mass loads during high flow increased by only 40 percent and 88 percent for the Main Stem of Piscataway Creek and Tinkers Creek, respectively. This suggests that much of wildlife FIB is already present in water bodies and is in both baseflow and stormflow in relatively similar concentrations. The main source of wildlife FIB could be droppings from waterfowl that congregate in and adjacent to water bodies. The transient input from runoff is diluted by the much larger background volume discharged from the FIB already present in the water column.

12.3.3 TMDL Management Implications

The Piscataway Creek TMDL identifies a 61.2 percent annual reduction in FIB in the Main Stem and a 51.8 percent reduction in Tinkers Creek. These reduction percentages mean that, even if all of the domestic animal and human loads were to be entirely eliminated, the Main Stem would not ever attain FIB compliance. In Tinkers Creek, elimination of these sources would meet the reductions only in the summer high flows. While there are many methods, practices, and BMPs that can be used to reduce source area loads and intercept runoff loads, such high removal efficiencies for FIB are virtually impossible to attain watershed-wide. Other sources will need to be addressed to meet the TMDL. Similar conclusions are applicable to the Anacostia River watershed and Upper Patuxent River watershed.

This analysis is restricted to the MS4 portions of the watersheds. In the Piscataway Creek TMDL, MDE has allocated a uniform MS4 reduction of 42.6 percent reduction for both Tinkers Creek and the Main Stem (MDE 2014a), a value more attainable than those allocated to the watershed as a whole. In the Upper Patuxent River watershed TMDL, the required watershed reductions are 49.9 percent, with a reduction of 53.4 percent allocated to the MS4 portion. In contrast, the required reduction is 79 percent in the upstream Anacostia River and 78 percent for the lower segment. MDE has allocated a reduction of 80.3 percent for the Northwest and Northeast branches and 99.3 percent of the areas below their confluence (MDE 2014a). These values are much more difficult to attain, as they demand not only elimination of human and pet loads, but also elimination of livestock and wildlife loads.

12.4 Source Area Controls

There are many management options that can be used to reduce source area TN, TP, TSS, BOD, and FIB loads. As background for a discussion of these options in terms of removal efficiency, this section first presents the extent of source loads, particularly FIB loads. By segregating by source, it is possible to better evaluate the potential of NSMs to remove FIB loads. NSMs are defined as programmatic and/or dispersed measures, as opposed to localized structural BMPs. Certain NSMs are effective for a broad range of sources. The reductions from individual NSMs are incorporated into the modified WTM model to project FIB reductions when deployed. Due to their higher virulence, FIB loads from human sources are differentiated from other nonhuman sources.

12.4.1 WTM Model Setup

Just as WTM uses a common master spreadsheet for allocating loads by source area types across all watersheds, a common master tab is used to apportion geographical and source loading attributes that are to be applied equally to all watersheds. The various attributes are discussed in the following sections for each source category and subcategory. By estimating attributes of fecal sources (and the likely effect of dilution, attenuation, and other losses), a more refined estimate of the relative proportions of various sources was determined. These estimates allow for a more realistic projection of the potential removal efficiencies from programmatic initiatives and structural BMPs. By addressing FIB sources, the estimates serve to highlight the relative importance of the various sources and provide the basis for comprehensive approaches to address FIB loads.

The general approach for all sources was to first characterize human or animal waste in terms of fecal material dry weight per unit of population and percentage of TN, TP, TSS, FC, and FIB per pound of waste—either human or animal. The relevant population was determined by explicit GIS analysis (e.g., by number of dwelling units [DU]) or by animal source-density based on the land cover where the animal would be found (e.g., geese in turf areas). This provided the estimated total waste-material mass.

After fecal material is deposited by animals or otherwise enters the environment (e.g., SSOs), TN, TP, TSS, BOD, and FIB encounter transfer and attenuation losses from the site of deposition to the EOF. There are then subsequent additional losses in conveyance from EOF to EOS, and then further instream attenuation and conveyance losses. Together, the losses are represented in WTM as transfer factors. While the composition of waste is less variable, population density and transfer factors are adjusted so that the final projected FIB values correspond to baseline observations.

12.4.2 Human Sources

On the basis of MDE analyses, as presented in its bacteria TMDLs, human FIB are the primary non-wildlife source of FIB loads in the MS4 areas in the Piscataway Creek and Patuxent River watersheds. Therefore, aggressive NSMs must be deployed by the County to reduce the loads to the extent that they are applicable to the MS4. Much of the human FIB are not considered a source to the County's MS4 unless they enter the County's stormwater sewer system. Since the TMDLs address all potential sources, the following discussion includes human sources, such as infiltration and inflow (I&I) and OSDSs.

The results of the overall FIB modeling in Tinkers Creek is presented as an example of how the WTM model works. A common thread to all FIB sources is the composition of the various wastewaters, their likely transfer factors, and their extent throughout the developed watershed. Based on geographical characteristics, Table 17 presents the watershed-wide secondary loading assumptions (i.e., default values) for water use, I&I exfiltration, and OSDS performance, along with assumptions as to primary loads originating from illicit connections, washing facilities, and dumpsters. The default values are shown in the yellow cells. Because of limited literature information, most of these parameter values are estimated using our best professional judgment, and are similar to other sources (Caraco 2013; Moyer and Hyer 2003). The estimated values were chosen so that calculated loads were as close as possible to the baseline values in the TMDL reports when populations and geospatial attributes were assigned to the relevant parameter.

Table 17. Loading assumptions for human FIB secondary sources

Source Type	Parameter	Default Value	Reference
Sewage Use	Water Use (gpcd)	60	WTM Model documentation
	Individuals/DU	2.19	Piscataway population divided by DU
I&I Losses	Exfiltration gal./LF/yr	1.50	Estimate based on Tetra Tech 2011
OSDS	Fraction Failing OSDS	5%	See text
	Transmission Factor	5%	See text
Illicit Connections	% Dwelling Units	0.02%	Estimated
	Business as %DU	0.01%	Estimated
	EDU/Business	1.0	Estimated
Washing	Business as %DU	0.02%	Estimated
	Wash Water Flow (gpd)	300	Estimated

Source Type	Parameter	Default Value	Reference
Dumpsters	DU/ Dumpster	30	Estimated
	Leakage depth (in)	2	Estimated
	Dumpster sq.ft.	24	Estimated
FIB Conversions	FC/Enterococci ratio	2.94	MDE 2006a
	FC/*E. coli* ratio	1.1	MDE 2006a

Table 18 presents the composition of wastewater for the different sources, along with the per-dwelling unit (DU) annual load found in literature. Each category loading rate is multiplied by the number of sources in each category to obtain the effective depositional loads for each category. While sewage composition is well characterized (Caraco 2013; Asano et al. 2006), washing and dumpster concentrations were estimated based on best professional judgment as there is very little literature on these sources. However, load contributions from these sources can be substantial. For instance, FIB from washing and dumpster sources comprised approximately 27 percent of dry weather FIB loads in San Diego (Weston 2009, cited in UWRRC 2014).

It was necessary to adjust the EOF loads to account for dilution and transformations to obtain each category's final instream loadings. Table 19 presents the concentration adjustment factors applied to human waste sources of TN, TP, BOD, TSS, and FIB. This results in the specific "characteristics of effluent" presented for the various human sources such as illicit connections, OSDS, and SSOs, which are discussed in more detail for the individual source categories.

Table 18. Estimated composition of various human FIB sources

Wastewater Characteristic Concentrations				Per DU Annual Load	
Pollutant	Sewage	Washing	Dumpsters		
TN (mg/L)	50	10	25	20.3	lb
TP (mg/L)	7.5	1.5	5	3.1	lb
TSS (mg/L)	250	75	75	102	lb
BOD(mg/L)	200	50	150	81	lb
FIB (MPN/100 mL)	1,000,000	10,000	100,000	1,816	bn MPN

Source: Sewage per Caraco (2013) and Asano et al (2006). Loads from washing and dumpsters are estimated using best professional judgment and Weston (2009).

Table 19. Concentration adjustment factors applied to various human sources

Parameter	SSO	I&I	OSDS	Failing OSDS	Illicit Discharges
TN	75%	75%	70%	70%	100%
TP	75%	25%	3%	100%	100%
TSS	75%	10%	5%	65%	100%
BOD	75%	75%	50%	70%	100%
FIB	75%	25%	0.01%	50%	30%

Sanitary Sewer System Overflows

I&I into aging sewer lines and manholes is a ubiquitous phenomenon, with I&I being worse in the older systems. Annual inflows into even relatively new sewer lines have been measured at 320 gallons per linear foot (Tetra Tech 2014b). In heavy rains, this results in SSOs, as evidenced by the largest recent SSOs being attributed to Superstorm Sandy. The resultant average annual SSO volume is multiplied by the sewage characteristics in Table 18 and modified by the dilution factors in Table 19. Also presented is the extent to which each source category is included in the County's MS4.

For SSOs, it is assumed that loads are diluted by 25 percent, although a higher reduction might be more appropriate. Table 20 illustrates this for the Tinkers Creek, with data obtained from County GIS information entered in the yellow cells. The annual FIB load from SSOs is less than wastewater from only one DU (Table 18), leading to the conclusion that SSOs are a minor component of annual human FIB loads.

Table 20. Estimated annual FIB loads from SSOs in Tinkers Creek

Time Span (yr.)	Characteristics of Effluent		Annual Load	
8	TN (mg/L)	37.5	13.8	lb
No. Overflows	TP (mg/L)	5.6	2.1	lb
40	TSS (mg/L)	188	69.1	lb
Gal./Overflows	BOD (mg/L)	150	55.3	lb
347,482	FC (MPN/100 mL)	750,000	1,233	bn MPN

Note: Source not included in MS4 allocation/responsibility (unless discharge enters into stormwater sewer).

Sanitary Sewer System Leakage

Representing the inverse of sewer leakage associated with I&I, Table 17 projects a global annual value of 1.5 gallons of effective sewer leakage per linear foot of sewer line. This represents the estimated flow that is discharged into storm sewers or the streams by means of macropores. The value chosen was less than half a percent of the annual inflow. The resultant volumes were then multiplied by the sewage characteristics, and adjusted according to the factors in Table 19. TN and BOD were assumed to have little dilution as they are the most soluble. Having more of a particulate fraction, TP is reduced by 75 percent, while TSS is reduced even more, by 90 percent. FIB are reduced by 75 percent to account for attenuation in subsurface flow.

Table 21 presents the resulting loads for the Tinkers Creek watershed, with GIS data on linear feet (LF) of sewer entered in the yellow cell. The resultant loading rate and characteristics of effluent are computed to obtain annual FIB loads. The annual FIB load from leakage is projected to be nine times higher than SSOs (Table 20), leading to the conclusion that leakage is a substantial component of annual human FIB loads. Being a relatively continual load, the predominance of this baseflow source is supported by the TMDL finding that there was little increase in human FIB loads in high flow events.

Table 21. Estimated annual FIB loads from sewer leakage (I&I) for Tinkers Creek

LF Sewer	Characteristics of Effluent		Annual Load	
756,373	TN (mg/L)	37.5	361	lb
Annual Exfiltration (cu.ft.)	TP (mg/L)	1.9	18	lb
151,679	TSS (mg/L)	25	241	lb
	BOD (mg/L)	150	1,443	lb
	FC (MPN/100 mL)	250,000	10,738	bn MPN

Note: Source not included in MS4 allocation/responsibility (unless discharge enters into stormwater sewer).

The single most effective measure to reduce SSOs and I&I is to repair and rehabilitate existing sewer lines. Washington Suburban Sanitary Commission (WSSC) is under a consent decree with EPA to overhaul its sewer lines to reduce SSOs. Comprehensive improvements to leaking sewer lines could substantially reduce human FIB loads. However, loads from sewer overflows and leakage are not part of the MS4 load reduction responsibility. Their correction will help the overall achievability of the bacteria TMDLs.

On-site Disposal Systems: Functioning

There are 109 OSDSs in the Tinkers Creek watershed. When they are operating properly, few FIB manage to survive in the unsaturated vadose zone. Given an estimated four order of magnitude reduction (Keswick et al. 1982), FIB concentrations in groundwater plumes from OSDS could approach the criterion. However, the very low volumes involved result in very low FIB loads from functioning OSDS. In contrast, TN loads from OSDS can be relatively high, as there is very little attenuation of N in OSDS or in groundwater. While TP and TSS are largely eliminated, BOD is expected to be similar to TN loads. Table 22 presents how the interaction between the number of OSDS and the concentration adjustments result in generating negligible FIB loads from functioning OSDS.

Table 22. Estimated annual FIB loads from functional OSDSs in Tinkers Creek

Unsewered DU(#)	Characteristics of Effluent		Annual Load	
109	TN (mg/L)	35.0	1,552	lb
Annual Effluent (cu ft)	TP (mg/L)	0.2	10	lb
698,897	TSS (mg/L)	13	554	lb
	BOD (mg/L)	100	4,433	lb
	FC (MPN/100 mL)	100	20	bn MPN

Note: Source not included in MS4 allocation/responsibility.

On-Site Disposal Systems: Failing

The extent of OSDS failure was not available from the County. Some studies show high proportions of OSDS failure (>30 percent), with concomitant elevated FIB loads (Ahmed et al. 2005; Whitlock et al. 2002). Other studies show that elevated FIB concentrations are correlated with OSDS density (Line et al 2008). These findings seem to occur where groundwater is elevated (Whitlock et al. 2002) or where soils have poor drainage (Day 2004). Other studies suggest failing OSDS are not a major source of FIB (Baffaut 2006), that the impact of OSDS on FIB is localized (Pang et al. 2006), that the presence of OSDS are not correlated with elevated FIB (Mallin et al. 2000), and that many older systems still perform well, especially if loaded at no more than an inch per day (Siegrist et al. 2000).

The well-drained coastal plain setting of the County suggests that failure rates of OSDS are likely to be relatively low. As sewer lines have been extended to new development in Tinkers Creek watershed, the number of OSDS declined from 1810 in 2006 (MDE 2006b) to 476 in the most recent data. This process would also tend to remedy existing failures, so the failure rate for OSDS was estimated at 5 percent. In well-drained upland areas, surface overflows due to OSDS failure typically infiltrate after a short distance (Siegrist et al. 2000), so failing upland OSDSs would not have much of a surface runoff response except for the flush from rinsing off the initial surface accumulation. This results in the transfer rate of 5 percent shown in Table 17. Table 23 presents the resultant loads.

Table 23. Estimated annual FIB loads from failing OSDSs in Tinkers Creek

Annual Effluent (cu ft)	Characteristics of Effluent		Annual Load	
1,747	TN (mg/L)	35.0	4	lb
	TP (mg/L)	7.5	1	lb
	TSS (mg/L)	163	18	lb
	BOD (mg/L)	140	16	lb
	FC (MPN/100 mL)	500,000	247	bn MPN

Note: Source not included in MS4 allocation/responsibility.

In this case, loads from OSDS failures are but a fraction of that from SSOs. Even though loads from failing septic tanks are not part of the MS4 load reduction responsibility, their correction will help the overall achievability of the bacteria TMDLs.

Illicit Cross-Connections

Another potential human direct FIB sources is cross-connections where sanitary sewers for properties are directly connected to the storm sewer instead of to the sanitary sewer. This introduces raw sewage into the County's stormwater system and results in no additional attenuation of nutrients or TSS, but an estimated conveyance loss of 70 percent to account for transfer losses from either overland flows and losses in the storm sewer before FIB enter the County's water bodies. Using these assumptions and the information in Table 5, each illicit connection in the County is estimated to annually contribute over 500 billion FIB. For Tinkers Creek (which is mostly rural), the number of residences and businesses with illicit connections are estimated to be 5 DU, using the assumptions in Table 17 (0.02 percent of DUs and 0.01 percent of business have illicit connections). These estimates are best used to provide an estimate of the potential magnitude of these sources, which might enter into the County's MS4. Detailed field investigations are needed to locate and identify illicit connections.

Given these assumptions, the magnitude of illicit loads (Table 24) considerably exceeds that of OSDS failures. Unlike the other diffuse secondary loads, these loads are generally discharged into and conveyed by stormwater sewers, so they are considered an MS4 contribution. The County has a program to discover and eliminate cross-connections that could noticeably reduce human FIB loads.

Table 24. Estimated annual FIB loads from illicit connections in Tinkers Creek

Number of DU	Characteristics of Effluent		Annual Load	
2.3	TN (mg/L)	50.0	69	lb
Number of Businesses	TP (mg/L)	7.5	10	lb
1.1	TSS (mg/L)	250	344	lb
Illicit Connection Volume (cu.ft.)	BOD (mg/L)	200	275	lb
21,665	FC (MPN/100 mL)	300,000	1,841	bn MPN

Note: Source is included in MS4 allocation/responsibility.

Vehicle Washing and Dumpster FIB loads

There are other potential human FIB sources as well. Wash water from industrial and commercial activities often contain considerable amounts of FIB. A study in San Diego (Weston 2009, cited in UWRRC 2014) showed that washdown water contained a median of 2,000 MPN/100 mL enterococci, while median concentrations from dumpster and grease trap leaks were an order of magnitude greater. In San Diego, these sources comprised nearly 27 percent of dry weather flow from commercial land uses.

Since FIB numbers are several times higher than enterococci (Table 17), the FIB concentrations shown in Table 18 are the results. Even though the estimated discharge volumes are less, washing and leakage from trash cans, dumpsters, and garbage trucks can discharge high FIB loads. Table 25 presents projected washing loads, and dumpster, garbage truck, and trash loads, which are similar to those in WTM (Caraco 2013). A business census would provide a more accurate estimate, but was beyond the scope of this analysis.

Table 25. Estimated annual FIB loads from vehicle washing, dumpsters, and garbage trucks in Tinkers Creek

Wash Water				
Number of Businesses	**Characteristics of Effluent**		**Annual Load**	
2.3	TN (mg/L)	10.0	21	lb
Total Flow/business (cu ft/yr)	TP (mg/L)	1.5	3	lb
32,976	TSS (mg/L)	75	157	lb
	BOD (mg/L)	50	105	lb
	FC (MPN/100 mL)	10,000	934	bn MPN
Dumpsters and Garbage Trucks				
Number of Dumpsters /Trucks	**Characteristics of Effluent**		**Annual Load**	
376	TN (mg/L)	25.0	2.4	lb
Runoff per Dumpster/Truck (cu ft)	TP (mg/L)	5.0	0.5	lb
4.0	TSS (mg/L)	75	7.2	lb
Annual Runoff cu.ft)	BOD (mg/L)	150	14.3	lb
1,504	FC (MPN/100 mL)	100,000	426	bn MPN

Note: Sources are included in MS4 allocation/responsibility.

12.4.3 Human Source Summary

The preceding discussion illustrates how basic global assumptions were applied to geographic data to partition human sources between flow regimes and between conveyance methods. The relative contribution of primary human FIB MS4 sources amenable to both NSMs and BMPs have been identified and estimated. The contribution from non-MS4 secondary sources is also enumerated to provide a basis for coordination and prioritizing efforts with other agencies that are part of the TMDL. Table 26 displays the relative contribution of the various human secondary sources. By partitioning the source loads as accurately as possible, this determines the relative contributions to the total load that the various human FIB sources contribute.

Table 26. Projected human FIB loads in Tinkers Creek

Total Human Loads	TN (lb/year)	TP (lb/year)	TSS (lb/year)	BOD (lb/year)	FIB (bn/year)	FIB as % TMDL
Sanitary Sewer Overflows (SSOs)	14	2	69	55	1,233	7.3%
Exfiltration from Sewer System (I &I)	361	18	241	1,443	10,738	63.6%
Operating Septic Systems	1,552	10	554	4,433	20	0.1%
Failing Septic Systems	4	1	18	16	247	1.5%
Illicit Connections	69	10	344	275	1,841	10.9%
Wash Water Loads	21	3	157	105	934	5.5%
Dumpsters and Garbage Trucks	2	0	7	14	426	2.5%
Total Human Load	**2,022**	**45**	**1,389**	**6,341**	**15,439**	**91.4%**
Overland Human Load (MS4 or primary)	92	14	508	394	3,200	18.9%

Translated for FC, the annual FIB load in the Tinkers Creek TMDL was 55,744 bn MPN, of which human FIB would be 16,891 bn MPN. The sum of the Tinkers Creek allocations as presented in Table 17 through Table 25 projected a total of 15,439 bn MPN, or 91.4 percent of this value. Over two-thirds of the total human FIB is attributed to exfiltration from existing sewer lines. This seems to be an appropriate partitioning of human FIB loads, given the predominance of FIB in baseflow. The first four categories comprise estimated secondary loads that are not part of the MS4. The last row of Table 26 sums the estimated MS4 overland human FIB loads originating from the last three source categories in the table. The MS4 loads are thus but a relatively small fraction of the estimated total human FIB loads, so the effect of the particular allocations in Table 17 and Table 18 for these primary sources are relatively less important in terms of the entire watershed loads.

12.4.4 Non-human Sources

As in the case of human FIB, the waste composition of non-human FIB sources must also be characterized. Using their populations, the source deposition loads are then calculated. Finally, transfer factors are assigned that represent the total losses from deposition in the field to observed concentration in the stream (i.e., attenuation within field, losses in transfer to EOF, losses in transfer to EOS, and attenuation within the stream itself). As a result, the transfer factors can be very low. These transfer factors are adjusted to the actual baseline loads in the TMDL reports. In this manner, the assumptions are effectively calibrated to the actual watershed FIB loads.

As in the case with human FIB, it is necessary to characterize the waste composition of nonhuman FIB sources. Given their populations, the source deposition loads are then calculated. Finally, transfer factors are assigned. These factors represent the total losses from deposition in the field to observed concentration in the stream (i.e., attenuation within field, losses in transfer to EOF, losses in transfer to EOS, and attenuation within the stream itself). As a result the transfer factors can be very low. These transfer factors are adjusted to the actual baseline loads in the TMDL reports. In this manner, the assumptions are effectively calibrated to the actual watershed FIB loads.

There is not much literature on dog, cat, or wildlife waste composition in terms of nutrient content. Karr-Lilienthal et al. (2004) reported nitrogen content of dog feces, but not for other nutrients or FIB. The WTM 2103 documentation (CWP 2013) also has FIB and nutrient data for dogs. Kiefer et al. (2012) present useful nutrient data on deer and geese. The BSLC Model (Zeckoski et al. 2005) has additional information on different livestock and wildlife waste characteristics, as does Moyer and Hyer (2003). There is also a significant amount of literature on livestock waste composition summarized by the USEPA (2002), which includes pigs. Because dogs are carnivorous, the nutrient composition of their feces is assumed to be high in TN, similar to that of omnivores like pigs. Because of the variation among these sources, best professional judgment was used to arrive at values intermediate between the extremes in the literature. Table 27 presents the assumptions involved in computing non-human nutrient, TSS, and FIB loads.

As noted with human sources, many attenuation factors exist that reduce the amount of waste constituents prior to entering the stream, as well as attenuation in the stream itself (UWRRC 2014). In the case of nutrients, these losses are estimated using recognized overland/subsurface flow transport processes and transformation characteristic to each constituent from each source type. Similarly, both WTM 2013 and BSLC models also apply transfer factors to account for attenuation of FIB loads from deposition to instream observations. As a representation of very complex processes, the transfer rates chosen in Table 27 are oversimplifications.

However, the nutrient and TSS content of these source categories is accounted for as part of the primary area-based EOS loads in WTM. As a result, the precise allocation of nutrients and TSS by source category is less relevant than their FIB loads that are the main focus of this section. Using these assumptions, approximately one-fourth to one-third of total watershed nutrient loads originate from animal waste. The balance of watershed nutrient loads come from atmospheric deposition and fertilization.

As pet waste is a very important aspect of the MS4 loads, and since the TMDL provides explicit computation of pet wastes, the FIB transfer rate was chosen to match the amount of pet waste reported in the TMDL document. A more accurate load reduction estimation is obtained though using these assumptions and calculations. The following sections describe how the various waste sources were determined.

Table 27. Projected non-human populations, waste composition, and transfer factors

Animal Sources	Dogs	Cats	Livestock	Geese	Deer	Wildlife
Populations	Number	# /Household	acre/AU	# /acre	acre/AU	#/acre.
	Per GIS	0.25	12.0	1.5	8	5.0
Waste (lb/day)	0.08	0.02	10.0	0.20	0.50	0.02
TN %	8.5%	8.5%	3.8%	2.4%	9.2%	8.0%
TP %	0.6%	0.6%	1.4%	0.4%	3.0%	0.6%
TSS %	20.0%	20.0%	20.0%	20.0%	30.0%	30.0%
BOD %	40.0%	40.0%	15.0%	15.0%	20.0%	20.0%
FC (bn/lb)	10.0	10.0	6.0	1.6	0.7	3.5
TN Transfer	50%	25%	50%	75%	25%	25%
TP/TSS Transfer	25%	10%	25%	50%	5%	5%
BOD Transfer	50%	25%	50%	75%	25%	25%
FIB Transfer	**1.15%**	**0.20%**	**0.50%**	**2.50%**	**0.20%**	**0.50%**

Sources: See text

Dog Waste

The values shown in Table 27 fall within the values reported in the various sources listed in the Section 12.4.4. The weight of waste per dog was adjusted to one-fourth of the WTM value to account for dry vs. wet weight, and to better correspond to the observations in the TMDL report. TN content was obtained from Karr-Lilienthal et al. (2004), while the TN/TP ratio was estimated at 14:1, a value between the 23:1 ratio used for dogs in WTM (Caraco 2013) and 2.5:1 average ratio found for swine (USEPA 2002). Since half the TN is bacterial (Karr-Lilienthal et al. 2004), this suggests that TSS (comprising largely protein) would be 20 percent of the dry weight. BOD was assigned at 5 times TN, roughly twice that assigned for cattle (USEPA 2002), which was the only literature value available for this conversion. FIB values were derived from WTM values and those presented in Moyer and Hyer (2003). Given the weight per animal, this amounts to 0.4 bn MPN per dog, which is about 80 times that of raccoons as reported by Zeckoski et al. (2005).

Given these source loads per animal, the transfer factors were determined according to best estimates of runoff loads (including infiltration losses). Dogs being walked typically defecate in areas close to impervious surfaces such as sidewalks and driveways, so overland flow losses are likely to be lower than those for animals not as likely to defecate so close to impervious areas. Due to the high concentration of TN, 50 percent of it is projected to infiltrate at high rates, as soil interception processes are unable to totally transform TN loads. TP and TSS have been assigned a transfer rate of 20 percent, which might overstate TSS transfer rate, as most of the TSS is broken down. BOD losses also were estimated at 50 percent. The low transfer factor of 1.15 percent for FIB for immobilization and attenuation, conveyance losses, and instream attenuation was selected to meet the TMDL FIB baseline loads as closely as possible.

Using the loading rate per individual dog, we multiplied the number of dogs by their waste characteristics and their transfer factor to obtain the watershed dog nutrient, BOD, TSS, and FIB loading. The number of dogs (licensed and stray) was obtained from data provided by the Animal Management Division of DoE. Table 28 displays the dog FIB and nutrient and TSS loads in Tinkers Creek. A watershed-specific enrichment factor was used to calibrate the results to the FIB loads reported in the TMDL document. Dogs are by far the dominant source of domestic pet FIB loads. By calibrating the projected loads to the TMDL observations, the resultant reductions by application of NSMs are rigorously quantified. The most effective program for reducing FIB loads from dogs is an aggressive waste pickup program.

Table 28. Projected dog populations and annual loads in Tinkers Creek

Number of Licenses	Annual Load	
2,041	TN (lb)	2,797
Number of Strays	TP (lb)	100
213	TSS (lb)	3,291
Enrichment	BOD (lb)	13,163
1.00	FC (bn MPNl)	7,569

Cat Waste

Unlike dogs, cats often defecate into litter pans, with the contents disposed of in the garbage. However, some owners let their cats roam outdoors, where feces are deposited randomly in pervious areas. Another important feline source is feral cat colonies. The composition of cat waste was estimated to be the same as dogs, but the FIB amount was one quarter, or 0.1 bn/MPN per cat per day. This is similar to the 6:1 ratio used by Moyer and Hyer (2003). The density of outside cats was estimated at 1 per 4 households, which also accounts for feral cat sources.

Since cat droppings are more likely to be more remote than dogs, they are more attenuated by overland flow transport processes. As a result, the nutrient, TSS, and BOD transfer factors are half that of dogs. The FIB transfer of only 0.2 percent is even less due to much greater attenuation losses given the more remote locations. Table 29 presents the resulting cat waste loads in Tinkers Creek.

Table 29. Projected cat populations and annual loads in Tinkers Creek

Number of Cats	Annual Load	
2,816	TN (lb)	437
	TP (lb)	31
	TSS (lb)	1,028
	BOD (lb)	2,055
	FC (bn MPNl)	411

Waterfowl Waste

Except for three segments of the Anacostia River watershed, wildlife comprises the category with the highest FIB baseline loads in the TMDL documents. While it would seem that wildlife would not be an MS4 load, there are many wildlife species that thrive in urban and suburban areas. In particular, whitetail deer and non-migratory Canada geese are very widespread in suburban areas, while raccoons and other wildlife such as rats, squirrels, and pigeons are also found in MS4 locations. Canada geese are plentiful, their waste has very high FIB loads, and most of it is deposited adjacent to streams at a very high density (Swallow et al. 2012). As a result, not only are goose runoff FIB concentrations high, they are also very high in the adjacent pond sediments. The daily loads of TN and TP percentages for goose waste were described by Ayers (2009). TSS is at 20 percent (Kiefer et al. 2012) with BOD estimated as a percentage of TN and TSS similar to livestock. FIB estimates range from only 0.005 bn MPN/lb (calculated from Kiefer et al. 2012) to 3.6 bn MPN/lb (Zeckoski et al. 2005). An intermediate value of 1.8

bn MPN/lb was used in Table 27. Duck waste FIB concentrations are several times higher, as 10 ducks have the same FIB load as a cow (Zeckoski et al. 2005). Goose density in turf areas was assigned at 1.5 per acre, or twice the 0.70 per acre used in Zeckoski et al. (2005).

Because geese congregate in water impoundments and immediately adjacent turf areas, they have very high transfer factors compared to other sources, as shown in Table 27. Given the densities applied to turf areas, the FIB transfer factor of 2.5 was chosen to represent goose loads so as to meet the observed loads presented in the TMDL reports. Table 30 presents the results of these loadings for Tinkers Creek.

Table 30. Projected Canada Goose populations and annual loads in Tinkers Creek

Number of Geese	Annual Load	
6,830	TN (lb)	8,975
	TP (lb)	997
	TSS (lb)	49,859
	BOD (lb)	56,092
	FC (bn MPNl)	19,944

Deer Waste

Whitetail deer are another prominent category of wildlife in the County, with a density that can exceed 1 deer per 3 acres (USNPS 2009). The TN content of deer feces can be as high as it is for cows, and its TP percentage is several times higher (Kiefer et al. 2012). Given deer's cellulosic food source, their waste's TSS content is high, while BOD is relatively low. Deer waste FIB content is relatively low (Zeckoski et al. 2005). While deer populations are high as they are found in forests (outside the MS4 area) as well, they are well dispersed away from water bodies, so their transfer factors are selected to be relatively low compared to other sources that are either closer to impervious areas or water bodies. Table 31 presents the baseline deer FIB loads in Tinkers Creek.

Table 31. Projected Whitetail Deer populations and annual loads in Tinkers Creek

Number of Deer	Annual Load	
1,084	TN (lb)	4,548
	TP (lb)	297
	TSS (lb)	2,966
	BOD (lb)	9,888
	FC (bn MPNl)	277

Other Wildlife Waste

Other wildlife comprises raccoons, rats, ducks, and pigeons as well as other smaller mammals and birds. This category is the residual wildlife waste contributions beyond those of geese and deer. As such, its nutrient components are intermediate between the extremes of deer and dogs. FIB loads vary widely from as high as 2.4 bn MPN for each duck down to 0.05 bn MPN for each raccoon. An intermediate value of 3.5 bn MPN/lb was selected as an average for all of these species. While their numbers are high, they are generally well dispersed away from water bodies, so their transfer factors are relatively low. However, raccoons have been noted nesting in storm sewers, so their FIB contribution can be quite high.

Livestock Waste

While not relevant to MS4 loads, livestock nonetheless comprises a substantial amount of the baseline loads in the TMDL reports for the rural portions of the County. Livestock loads are substantial, comprising 9.4 percent (4,764 bn FIB) in Tinkers Creek, but are not that pronounced in other watersheds with bacteria TMDLs in the County. By definition, livestock is not considered a typical MS4 source, even though there may be a few hobby farms within the Tinkers Creek MS4 boundaries. Livestock waste composition was derived from USEPA (2002) as applied to dairy cattle, and modified slightly to better match TMDL observations. While livestock as a general class includes horses, sheep, and other bovines, representative values were selected that when applied to the watersheds as a whole approximate the observations of the TMDL. This results in the waste characteristics and loading factors shown in Table 27.

Given these factors, an animal density of 12 acres per animal unit (AU) is applied to the overall pasture category. This value was chosen to calibrate to the observed loads reported in the TMDL document. While this is less accurate than an estimate based on pasture/feedlot areas, or an agricultural census, it is suitable for partitioning livestock FIB loads from other sources. Table 32 presents the results of this analysis for Tinkers Creek.

Table 32. Projected livestock populations and annual loads in Tinkers Creek

Number of Livestock AU	Annual Load	
53	TN (lb)	3,697
	TP (lb)	681
	TSS (lb)	24,323
	BOD (lb)	14,594
	FC (bn MPNl)	5,838

12.4.5 Non-human Source Summary

Taken together, the sum of the preceding non-human loads is considerable. Table 33 displays the relative contribution of the non-human sources in Tinkers Creek. By estimating these source loads as realistically as possible, we have allowed for more accurate determination of the relative contributions to the total load contributions from non-human FIB sources. By knowing the FIB loads that each source contributes, it is possible to more accurately estimate load reductions from proposed NSMs. The various FIB transfer factors were assigned to the estimated populations and their waste characteristics to obtain the resultant FIB load partitioning in Tinkers Creek. The sum of each TMDL category (i.e., livestock, pets, and wildlife) is within 22.5 percent of the TMDL source allocation estimates, with the total exceeding the TMDL partitioning by 12 percent. This demonstrates how the selected global assumptions predict loads that are reasonably close to that observed.

Table 33. Projected Non-Human Baseline Loads from Sources in Tinkers Creek

Total Non-human Loads	TN	TP	TSS	BOD	FIB	FIB as %
	(lb/year)	(lb/year)	(lb/year)	(lb/year)	(bn/year)	Total Type
Dog Waste Loads	2,797	100	3,291	13,163	7,569	99.6%
Cat Waste Loads	437	31	1,028	2,055	411	5.4%
Livestock Waste Loads	3,697	681	24,323	14,594	5,838	122.5%
Goose Waste Loads	8,975	997	49,859	56,092	19,944	86.9%
Deer Waste Loads	4,548	297	2,966	9,888	277	1.2%
Other Wildlife Waste Loads	6,328	90	4,746	15,821	5,537	24.1%
Total Non-human Load	26,782	2,196	86,213	111,613	39,575	112.0%
Total Overland Loads (including human sources)	28,407	2,217	86,575	111,903	41,663	76.7%

Even when restricted to only the MS4 non-human loads, these loads can still be substantial as demonstrated in Table 34. While the current paradigm is to address only the dog and cat waste FIB loads in the MS4, Table 34 demonstrates that there are other substantial FIB sources in the MS4 that can be addressed.

Table 34. Projected Non-Human MS4 Loads from Sources in Tinkers Creek

Total Non-human Loads	TN	TP	TSS	BOD	FIB	FIB as %
	(lb/year)	(lb/year)	(lb/year)	(lb/year)	(bn/year)	Total Type
Dog Waste Loads	2,797	100	3,291	13,163	7,569	99.6%
Cat Waste Loads	437	31	1,028	2,055	411	5.4%
Livestock Waste Loads	0	0	0	0	0	0.0%
Goose Waste Loads	6,765	752	37,585	42,283	15,034	65.5%
Deer Waste Loads	1,843	120	1,202	4,007	112	0.5%
Other Wildlife Waste Loads	2,564	37	1,923	6,411	2,244	9.8%
Total Non-human Load	11,173	909	40,710	52,700	25,370	71.8%

12.4.6 Source NSM Overall Effectiveness

The preceding analysis has been used to partition primary and secondary loads as realistically as possible. It was been conducted to allow for more informed judgment on what the potential impact of reducing primary and secondary FIB and other loads by NSMs. By default, the approach to be taken in determining NSM removal is to allocate a percentage of the loads that would be reduced by NSMs. Then it is a simple matter of reducing the loads shown in Table 20 through Table 25 and Table 28 through Table 32 by the percent of the reduction.

However, a final step is necessary to convert these loads to their equivalent EOS loads used by the WTM model. The loads discussed in this document are the actual counts of FIB in the streams, not the much higher primary loads conveyed in overland runoff from land surfaces, and which are intercepted by BMPs. Therefore, it is necessary to normalize these instream estimates back to their equivalent EOS loads. In this way, NSMs that remove FIB loads are treated in the same manner as the BMPs used to treat primary EOS loads.

This is done in WTM by determining the FIB overland factor, which is the percentage of watershed FIB projected in primary overland flow at EOS that are considered part of the baseline load in the TMDL reports. These non-human baseline loads are summarized in the last row of Table 33. Given the different watershed land cover characteristics, the overland factor varies from as low as several percent up to nearly 10 percent. The equivalent EOS primary FIB loads are normalized by dividing the projected instream FIB by this factor. In this way, any reductions in instream FIB loads applied as a percentage reduction of the source load are converted to their equivalent reductions in EOS loads.

This is accomplished using the MS4 toggle in the WTM spreadsheet. By setting the MS4 toggle to a null value (so as to include the entire watershed), the WTM spreadsheet calculates the percentage of the primary land cover loads that are represented by the baseline primary overland loads. In Tinkers Creek, this value was 5.4 percent, as shown in the “FC Overland Factor” cell in WTM. This represents the overall baseline factor that is used to convert the various overland secondary loads to their equivalent EOS loads.

To ensure that the normalized MS4 loads should be determined by this value, this cell is then copied and pasted as a value into the adjacent static “FC Overland Factor Used” cell. This cell is used for converting instream MS4 FIB loads to their EOS loads. The MS4 toggle cell is set to “yes”, which sets the spreadsheet to compute only the MS4 loads (which generates a higher, but now uncalibrated overland factor). This procedure ensures that the proper ratio of instream to overland EOS loads is applied. Table 35 displays how these factors are displayed in Tinkers Creek.

Table 35. FC Overland Factor entries

FC Overland Factor-Current	
9.65%	Ratio of overland entire watershed FIB to watershed EOS FIB-dynamic
FC Overland Factor- Used	
5.36%	Value pasted from entire watershed FIB.- static

In this way, the WTM model obtains a more precise estimate of the percentage of primary overland FIB loads that are actually human and animal derived secondary loads. By determining the relative contributions of different secondary loads and their proportion of the land cover based primary loads, estimates of different source control NSM reductions can be obtained with a greater degree of reliability. This becomes particularly useful when accurate subwatershed determinations are needed during the implementation stages.

12.5 Bacteria BMP Efficiencies

As discussed in previous sections, many processes affect FIB dynamics. Their resultant effect reflects the balance between growth and attenuation. Growth is supported by the presence of nutrients, moisture, and temperature. Attenuation processes include UV inactivation, settlement, predation, straining, and adsorption (Pedley et al. 2006). While temperature and moisture increase both predation and growth, these environmental factors tend to result in net growth (Hathaway and Hunt 2012).

BMPs are designed to maximize attenuation processes, while discouraging growth. The following section briefly outlines the literature on FIB removal using BMPs.

BMPs can be classified into the following categories in increasing order of effectiveness:

- ***Overland Filters:*** Filter strips and swales
- ***Permanent Ponds:*** Wetlands and extended detention wet basins
- ***Media Filtering:*** Sand filters and infiltration trenches
- ***Biological Filtration:*** Bioretention and gain gardens

The various processes that affect FIB dynamics in wet pond and wetland BMPs can be broadly categorized as follows:

- ***Settlement:*** In wetlands and detention ponds, free FIB in the water column do not settle, compared to the fraction of FIB attached to sediments (Characklis et al. 2005). This results in about 30 to 40 percent of FIB settling out in wetlands and wet detention ponds (Hathaway et al. 2009; 2011).
- ***UV inactivation***: In the water column, UV light will inactivate FIB (Pedley et al. 2006). This seems to result in better FIB removal for shallow ponds (Hathaway et al. 2011a). However, UV inactivation does not occur at depth, so reductions may be less in deeper ponds than in shallow ponds (Hathaway and Hunt 2012).
- ***Resuspension:*** Interstitial sediment pore water is highly concentrated with FIB. Disturbance of sediments releases this pool of FIB into the water column. This can occur because of flow increases mobilizing sediment (UWRRC 2014) or by means of waterfowl disturbing sediments as they feed (Hathaway et al. 2011a).
- ***Predation:*** Protozoa feed on FIB in the water column and in the bottom sediments.

The various processes that affect FIB dynamics in bioretention BMPs can be broadly categorized as follows:

- ***Predation:*** Protozoa feed on FIB in the water column and in the soil pore water. Longer retention times in the BMP lead to greater extent of predation. (Pedley et al. 2006; Zhang et al. 2011; 2012).
- ***Straining:*** While most FIB are much smaller than the pore space in media filters, their attachment to soil particles results in that fraction of FIB being effectively strained (Pedley et al. 2006). If flows are unsaturated, this results in much smaller effective pore space, substantially increasing interception of FIB that are not attached to soil particles (Auset and Keller 2005). This improved removal is associated with increased hydraulic retention time (Auset and Keller 2005; Giargulo et al. 2008).
- ***Adsorption:*** In addition to straining, an even more important process is adsorption to soil particles (Pedley et al 2006). Since FIB are negatively charged, adding positively charged cations such as iron oxide particles to soil media results in very high levels of

FIB retention (Zhang et al. 2010, Bradley et al. 2011; Grebel et al. 2013; Mohanty et al. 2013). The addition of organic matter can reduce adsorption as it also is negatively charged and competes with sorption sites (Pedley et al. 2006).

Most of these processes reduce FIB counts. There is no one source of load reduction removal efficiencies for bacteria. There are relatively few studies on fecal coliform bacteria removal by BMPs. The following text discusses the rationale for assigning load reduction efficiencies.

Overland filtering systems. The literature shows that filter strips, grass swales, biofiltration swales and other overland filtering systems provide some fecal overland filtering systems coliform bacteria load reduction, but they can also be sources if heavily visited by dogs, deer, geese, or other wildlife. Assuming that these sources are controlled by programmatic measures, the resulting removal efficiencies are allocated at 35 percent, on the basis of the literature review.

Permanent ponds. While **wet ponds** would be expected to have high removal efficiencies, the literature indicates that reductions are low. This is due to waterfowl visitation as well as the water depths shielding fecal coliform bacteria from reductions by UV light from the sun. Extended detention wet ponds slightly improve performance, but shallow marshes are considered more effective because of the absence of these factors.

Media and biological filtering systems. Stormwater flow through filtering systems (primarily bioretention systems with underdrains) can provide very high fecal coliform bacteria retention, often reported as high as 99 percent. However, fecal coliform bacteria loads can still be considerable in high flows that bypass BMPs designed to treat only the first inch of runoff, as per current design guidelines.

Similarly, infiltration systems capable of 100 percent elimination of treated loads also are subject to bypass during high flows. Therefore, the fecal coliform bacteria removal efficiency is estimated to be 90 percent for infiltration practices (including porous pavement) and bioretention systems. The removal efficiency from sand filters is estimated to be 80 percent, but was adjusted to 70 percent to account for bypass during high flows.

No reductions are allocated to ultra-urban hydrodynamic devices (e.g., oil and grit separators) due to their minimal retention time.

Table 36 presents the resultant removal efficiencies for the preceding structural BMPs. Removal efficiencies for generic BMPs of each era are included. These removal efficiencies applied to the source areas treated are used to determine the amount of loads removed by the installation of BMPs.

Table 36. Determination of bacteria BMP efficiencies

Overall BMP type	Specific BMP type(s)	FIB removal efficiency	Source(s)	Comment
Overland Filtering Systems	Dry Swales	35%	UWRRC 2014	Settlement of attached FIB only. Can resuspend, and FIB can multiply between events.

Overall BMP type	Specific BMP type(s)	FIB removal efficiency	Source(s)	Comment
Permanent Ponds	Extended detention Ponds	35%	Hathaway and Hunt 2012 Krometis et al. 2009	Wetlands settle the particle-bound fraction, and UV exposure reduces FIB. However, waterfowl resuspend FIB in the sediments.
	Emergent wetlands	50%	Hathaway et al. 2011a Hathaway and Hunt 2012	Wetlands settle the particle-bound fraction, and UV exposure reduces FIB. Emergent vegetation reduces waterfowl resuspension.
	Wet Swales	70%	Estimated	Flow regime retains FIB, and discourages growth due to UV exposure.
	Submerged Gravel Wetlands	75%	Estimated	Lack of resuspension and very high hydraulic retention time increases FIB removal
Media Filtering Systems	Filtering Practices, Sand Filters	70%	Rusciano and Obropta 2007 Hunt et al. 2008	Unvegetated sand filtering systems provide some adsorption and straining, but not total FIB removal. Estimated to be 80 percent, but was adjusted to 70 percent to account for bypass during high flows
Biological Filtering Systems	Rain Gardens	75%	Estimated	Infiltrated flows considered entirely removed, but bypass flows reduce overall capture
	Bioretention, Micro-bioretention	90%	Sources cited in text above, Li et al. 2012	Vegetated media filtering systems provide almost total FIB removal. Estimated to be 99 percent, but adjusted to 90 percent to account for bypass during high flows. Bypass lower than rain gardens due to underdrain.
	Green Roofs	90%	Estimated	Green roof media assumed to treat 100 percent of rainfall, but removal reduced to 90 percent to account for low retention time.
Infiltration Practices	Porous pavement, Dry Wells, Infiltration Berms, Landscape Infiltration Infiltration Trench	90%	Based on capture volume	Infiltrated runoff considered 100 percent eliminated. But subject to bypass during high flows. Therefore reduced to 90 percent.
Ultra-Urban	Hydrodynamic Devices Oil and Grit Separators	0%	Estimated	The minimal retention time and potential for sediment resuspension suggest very low reliable FIB removal

13 WTM BMP CALCULATIONS

The preceding sections have identified and quantified watershed primary loads by their land cover source runoff characteristics. The volume of runoff is multiplied by the AMC for each land cover category for each subwatershed and totaled for each watershed. In addition, FIB loads have been identified and quantified in terms of their contribution to baseline FIB loads reported in the bacteria TMDL reports. A procedure was developed to methodically convert these FIB loads calibrated to the baseline loads into their proportion of primary surface runoff loads. This process is essential to properly allocate the reductions of FIB primary loads by means of NSMs (i.e., programmatic initiatives).

This section presents how WTM was modified and updated to use NSMs and BMPs to obtain the projected load reductions to meet the County's MS4 wasteload allocations and to develop their projected costs. Figure 3 displays how these steps are conducted, as discussed in the restoration plans. Further explanation of this procedure is found in each TMDL restoration plan.

The overall approach was to first identify programmatic and overall watershed BMPs such as stream restoration. These BMPs are not specifically located to any particular subwatershed. Instead, they are applied to the watershed as a whole. This results in global reductions in the WTM loads computed above.

After accounting for nonspecific BMPs (programmatic and management related, such as street sweeping), the next steps presented in Figure 3 were followed to identify specific retrofits and BMPs for treating impervious surfaces as described below.

- Existing BMP retrofits to enhance load reductions
- Load reductions from public ROW projects
- Load reductions from public institutional projects
- Load reductions from commercial/industrial land uses
- Load reductions from residential properties

The initial focus of BMP identification and selection targets retrofitting (i.e., improving) the first generation of stormwater practices—such as dry ponds, which are not very effective—and bringing them into conformance with current water quality standards. If the load reduction goals were not met, the focus shifts to treating the impervious surfaces throughout the MS4 areas of the watershed.

The impervious areas are split into four categories: public ROW, public institutional, commercial/industrial, and residential. There is a varying degree of difficulty in implementing BMPs on each type of surface. Similarly, there is a varying degree of difficulty in implementing BMPs within each type. To accommodate these variations, the County first considered which BMPs might be relatively easy to implement on each type of surface for the initial cycle compared to the BMPs that would be necessary for the required load reduction. The initial assumption is that 50 percent of each land use type will be retrofitted relatively easily. If gaps still exist in necessary load reductions after the first cycle, then in the next cycle, an additional 20 percent of each type will be retrofitted. In the third cycle, a further 20 percent will be retrofitted. If a gap still exists after the third cycle and a fourth cycle is needed, then the remaining 10 percent will be retrofitted. This process is being used solely for planning level purposes. During implementation, the County could use different percentages based on actual implementation opportunities.

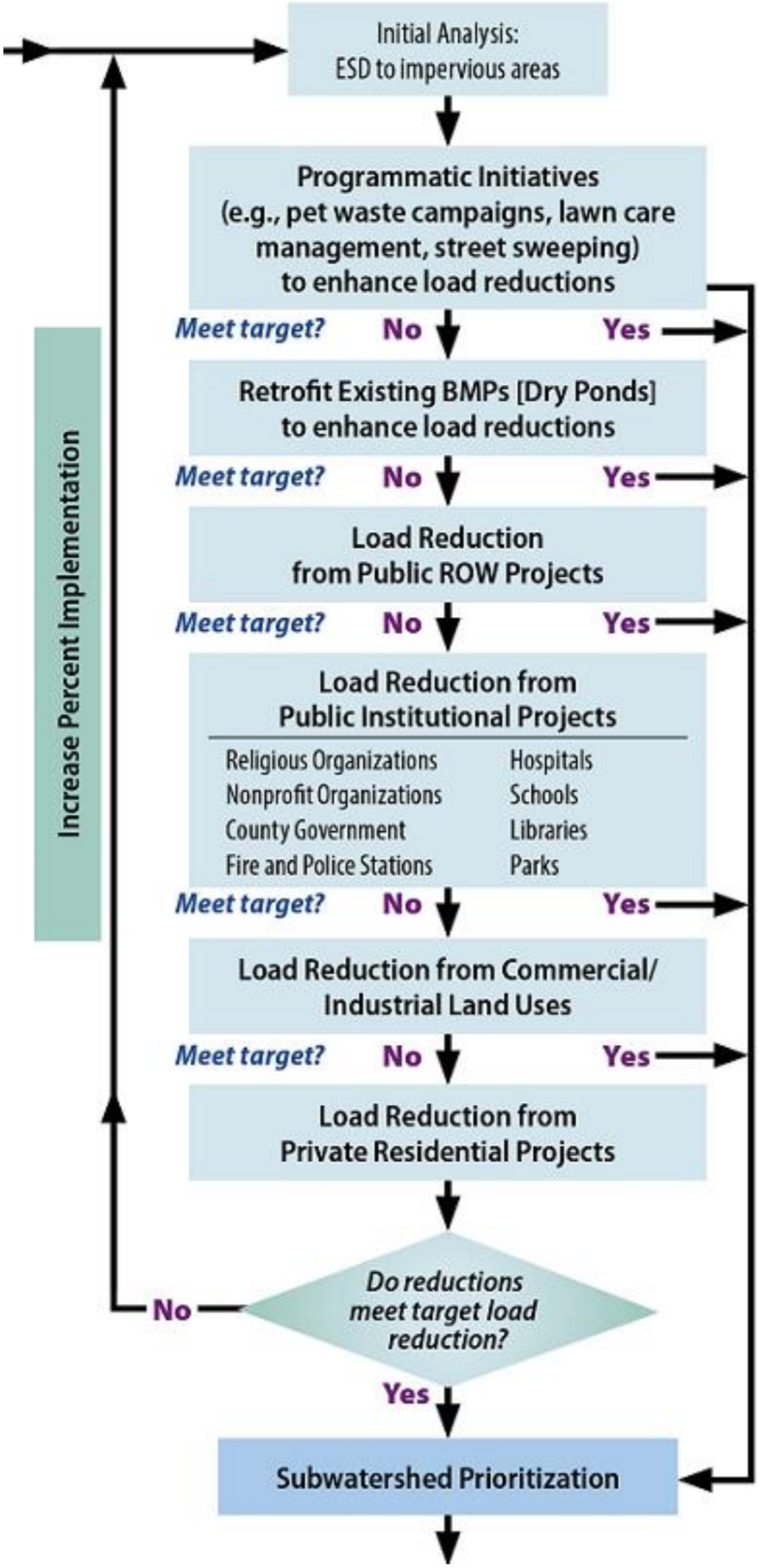

Figure 3. Flow chart for restoration evaluation procedure to meet required load reductions

The first type of impervious surface to be treated is public ROWs. If load reduction gaps still exist, then the next step is to determine if institutional properties (e.g., religious institutions, government offices, and facilities and municipally owned organizations [i.e., libraries, fire stations, and schools]) could help to fill the remaining gap. Next, the focus shifts to commercial and industrial land and finally to residential land. These land-use types were prioritized according to increasing complexity for planning and implementation of stormwater controls. For example, a ROW is least complex because it is public property and typically constitutes about 15–20 percent of total impervious area within a subwatershed. Stormwater controls within a ROW can be retrofitted with moderate effort. This process is repeated for each cycle.

The following sections set forth how the load reductions from the various programmatic, nonspecific, and specific structural BMPs are computed.

13.1 NSM (Programmatic Initiatives) Load Reduction Calculations

NSMs can be very effective in removing nutrients, in particular FIB loads. The modified version of WTM is arranged so that NSMs are first considered before determining the reductions from BMPs. Load reductions from these measures were applied to the watershed total reduction as necessary and not to the subwatershed level. These NSMs comprising the following measures are discussed below.

13.1.1 Lawn Care Management

The Chesapeake Bay Program recently convened a panel of experts to look at the removal efficiencies for urban nutrient (fertilizer) management (Schueler and Lane 2013). The expert panel found that a majority of residential lawns (50−83 percent) were fertilized. Of the homeowners that fertilized, less than 20 percent consulted professional services, while the remainder applied the fertilizers themselves. Low- and high-risk categories were assumed in the Chesapeake Bay model with the 20/80 percent split, irrespective of fertilization regime (i.e., including non-fertilized lawns). An estimated 60 percent of turf was considered fertilized, with 80 percent assumed to be low risk using the percent reductions described above. This resulted in 48 percent of turf that is fertilized by homeowners and 12 percent managed by lawn care companies. Maryland fertilizer legislation and subsequent regulations are expected to attain a statewide 25 percent total phosphorus reduction removal efficiency applied to all fertilized lawns. In addition, there is a 9 percent total nitrogen reduction removal efficiency for lawns managed by commercial applicators, and a 6.0 percent total nitrogen reduction removal efficiency for lawns managed by homeowners.

WTM entries allow for entering up to 48 percent for low lawn care and 12 percent for high lawn care for the fertilizer nitrogen and phosphorus bans. These percentages are applied to 80 percent of the disconnected plus all natural turf area for low care, and to 20 percent of the disconnected turf area for high care. These values are multiplied by the turf annual unit area loading rates and multiplied by these percentages to obtain the resultant reductions in TN and TP loads. Costs for the lawn care program were calculated outside of WTM.

13.1.2 Tree Canopy Installation

MDE (2014b) has allocated reductions in nutrient and TSS loads for conversion of pervious and impervious areas into forest cover. The load reductions from increasing the tree canopy is only applicable if there is a survival rate of 100 trees per acre or greater and at least 50 percent of the trees are 2 inches or greater in diameter at 4.5 feet above ground level (MD DNR 2009 and MDE 2014b). In WTM, the reductions are expressed in pounds per 100 trees planted on pervious areas based on TN, TP, and TSS reductions of 6.22, 0.44, and 800 pounds, respectively (MDE 2014b). The values for impervious forest conversion are 7.69, 1.81, and 860 pounds, respectively (MDE 2014b). Multiplied by number of trees planted, this provides the load reductions obtained. Trees in pervious areas are projected to each cost $500.

13.1.3 Street Sweeping

MDE (2014b) has allocated reductions in nutrient and TSS loads for street sweeping through the mass loading and street lane approaches (MDE 2014b, Appendix D). Because the County's frequency of street sweeping does not meet the credit requirements of the street lane approach, the mass loading approach is used to calculate the load reductions. For mass loading, the street dirt collected is measured in tons at the landfill or ultimate point of disposal. The pollutant load removed is then based on a relationship between the pollutant load present in a ton of street dirt dry mass. This relationship is 3.5 lb TN, 1.4 lb TP, and 420 lb TSS per ton. The assumed 12-foot wide lane miles were converted to acres using the total linear feet to be swept. Based on the number of tons removed per acre, the sweeping resulted in TN, TP, TSS, BOD, and FC reductions of 3%, 3%, 9%, 10%, and 1%, respectively. These are applied to the annual unit area street loading rate multiplied by acres swept. Using past County data, the projected cost of sweeping is $276 per treated acre.

13.1.4 Pet Waste Program

The source loads from pet waste originate primarily from dogs. The reductions from pet waste NSMs are applied only to dog loads. The number of dogs licensed from 2010 through 2013 and the number of stray dogs were obtained from the Animal Management divisions, and are considered a conservative estimate of the dogs in the County. The deposited nutrient and TSS loads computed as part of the FIB computations have already been reduced by their applicable transfer factor. These loads are then reduced by the target percentage effectiveness of a pet waste adoption program. The FIB overland factor used is then applied to the computed instream FIB loads to convert them to their equivalent primary overland runoff loads. This number is then multiplied by the percentage adoption of the pet waste NSM. Since this category comprises such a large part of watershed loads, this method is used to provide better accuracy in projecting potential NSM load reductions. Costs for the pet waste program were calculated outside of WTM.

13.1.5 Dumpster and Washing Program

A dumpster programs includes covering dumpsters and other trash collection areas, and preventing leakage from garbage trucks. A washing program comprises methods to identify washing facilities that discharge to storm sewers. While the precise determination of such loads from these two sources is beyond the scope of this report, such loads can be substantial and the method for such an estimate was given in Section 12.4.2. The same procedures as used for pet waste are involved in calculating the reductions. Costs for this program were calculated outside of WTM.

13.1.6 *NSM Summary*

Table 37 summarizes the load reductions discussed in the previous section. Reductions from removal of illicit discharges were not estimated due to their very random nature.

Table 37. Projected NSM costs and removal efficiencies / unit area load reductions

NSM Performance	TN (%, /lb)	TP (%, /lb)	TSS (%, /lb)	BOD (%, /lb)	FC (%, /lb)	Cost per Treated Unit
80% Low Intensity Lawn Mgmt.	6%	25%	0%	0%	0%	n/a
20% High Intensity Lawn Mgmt.	9%	25%	0%	0%	0%	n/a
Tree Canopy - Pervious (lb/100)	6.22	0.44	800	0.00	0.00	$500
Tree Canopy - Impervious (lb/100)	7.69	1.91	860	0.00	0.00	$1,500
Bank Stabilization ((lb/100LF)	7.50	6.80	24,754	0.00	0.00	$150
Street Sweeping	5%	6%	25%	10%	1%	$150
Inlet Cleaning (lbs/ton)	3.5	1.4	420	0.00	0.00	$150
Pet Waste Programs	Calculated using methods described in the Source Area Control section of this document.					n/a
Dumpster						n/a
Washing						n/a

Note: n/a = not applicable. Calculated outside WTM.

13.2 BMP Load Reduction Calculations

The preceding discussion on NSM effectiveness highlights how NSMs can be effective in reducing loads, particularly in terms of FIB from pet waste and certain human loads. For the restoration planning calculations, it is also necessary to address how WTM addresses runoff loads with structural BMPs, as further load reductions are required in every TMDL. This is done according to the series of steps outlined in Figure 3. These steps proceed from evaluating existing BMPs and their retrofits, to proposed BMPs according to source area land use loads. In order to project load source area loads by land use, the procedures involved in allocating these loads to individual land uses must be performed.

13.2.1 *Necessary Data for Proposed BMP Loading Calculations*

Table 38 presents the various model input from GIS analysis for each area. The *MinorShed* is used to subdivide the entire watershed into its TMDL subwatersheds, as needed. For example, the Piscataway Creek TMDL provided allocations for the Main Stem and Tinkers Creek. Entering "All" for *MinorShed* defaults to the entire watershed. This is used for baseline calibration. The *X* column is used to toggle whether the WTM model is looking up the entire watershed or just the MS4 area. The *Final_Ent* cells toggle to identify if the area is the County-, state-, federal- owned. These categories are used to screen the database to identify respective obligations of the various entities, their respective loads, and opportunities for treatment from a watershed perspective. The other columns identify the land use (*LandUse*), land cover (*WTMgroup_F*), subwatershed number (*SWS*), impervious type (*Surface_F*), and acres; all of which is determined through GIS analysis. Given this database, a WTM worksheet for each subwatershed first computes connected and disconnected loads by a variety of lookup functions.

Table 38. Example Piscataway Creek GIS database used in WTM analysis

MinorShed	LandUse	WTMgroup_F	Final_Ent	SWS	Surface_F	X	Acres
Main Stem Tinkers Creek Tidal	Right of Way Institutional Commer./Indust. Residential Natural	Aviation, Drives Gravel, Other Parking, Railroad Roads, Roofs Walkways, Turf Field, Crops Forest, Wetlands Water	County State Federal	PC-1 through PC-33	Connected Disconnected	(blank) Footprint	Each polygon's area

The WTM tab for each subwatershed then computes connected and disconnected loads using several lookup and logic functions. First, connected and disconnected areas are segregated into two sets of columns in the WTM. Separate rows correspond to the different impervious land covers that are treated by the BMPs and area classified by the land uses where BMPs are proposed. The resulting matrices partition the source GIS information by impervious area treated into the different land covers, land uses, and connection status, which are all used by WTM in factoring BMP reductions.

Next, several computations are run to determine the TN, TP, TSS, BOD, and FIB loads using the source area-weighted AMCs and runoff volumes for each land use and land cover combination. For each connection status, each individual combination of land cover/ land use area is multiplied by their area proportion of the total loads to obtain connected area loads. As an example, institutional loads are multiplied by their proportion of total connected loads to obtain the institutional connected loads. This process is repeated for each land cover and land use combination by connection status. By explicitly disaggregating land use loads in this manner, and then adding their cumulative results at the subwatershed level, the accuracy of the land cover data set can better inform the assignment of BMPs. This provides the basis for the subsequent series of steps involved in computing load reductions by BMPs as discussed below.

13.2.2 Existing BMPs

The first step in the restoration planning process was to conduct a systematic identification of current BMPs and their treated drainage areas to make sure that new BMPs were not applied to areas that were already treated. The information available for most BMPs included drainage area (i.e., total land area flowing to a specific BMP [e.g., a dry pond]). If a BMP was missing a geospatial drainage area, the average drainage area (and land cover) for the same type of BMP was used in the following computations.

The load reduction calculation only included BMPs that have been implemented since the TMDL water quality data were collected. For instance, the Anacostia River bacteria TMDL was developed by MDE in 2006; however, the water quality data for it were collected in 2003; therefore, any BMP or other practice implemented or established before 2003 was not included. Any BMP or practice implemented or established after 2003 was included in the load reduction calculation.

Load reductions for the existing BMPs were calculated with WTM using the BMP drainage area land cover, and land cover-specific pollutant loading rate. This provided the loading attributed to the BMP drainage area. This information was then imported into Microsoft Access. Queries in Access were used to determine which BMPs are applicable (i.e., after the date of the water quality used in the TMDL). The BMP drainage area loading was multiplied by the BMP pollutant removal efficiency for the individual BMP type to determine the amount of load reduction attributed to that specific BMP. This information was then transferred to Excel, where additional calculations for load reductions from existing tree plantings and stream restoration were completed. These loads were summed for each subwatershed. This Excel file also contains information on the drainage areas (including connected and disconnected impervious area) for each BMP.

These loads and drainage areas for each subwatershed were then imported into the WTM spreadsheet using a pivot table (in the "Data2" worksheet) to select the data and classify existing BMPs and their load reductions for each subwatershed. These individual subwatershed loads were then added together, and subtracted from the total loads. The total connected and disconnected source areas and resultant load reductions from these BMPs are shown as the "2002-TMDL" row in the "All" worksheet. Load reductions for each watershed were computed only for the relevant pollutant in the TMDL. In addition, the sum of the BMP drainage areas by land use and their percentage of connected and disconnected impervious areas are shown in the "Existing Areas" row in WTM and subtracted from the available impervious area available for implementation.

13.2.3 Dry Pond Conversions

While existing wet pond BMPs are generally effective in reducing loads, this is not the case with dry ponds, which have poor load reductions. Therefore, as the first step in selecting BMPs, all areas treated by dry ponds were selected to be converted from dry ponds to ESD-type BMPs (e.g., bioretention). The difference between dry pond and ESD load reductions were then allocated to these retrofit areas in Access and imported into WTM. Looking at the "All" worksheet in WTM, the percent of dry ponds allocated is shown in the "Dry Pond Retrofits" row as the yellow cell allocated a "100%". This triggers the pivot table to call up all relevant dry pond source areas and computed load reductions for each subwatershed and multiply them by 100 percent. The $19,500 cost per acre converted was multiplied by acres converted to obtain the line item cost for the retrofits. The load reductions are computed by the increase in removal efficiency from dry ponds to wet ponds. A dry pond reduces nitrogen only by 5 percent, phosphorus, and sediments by 10 percent, and BOD by 27 percent. Converting dry ponds to the wet pond efficiency practice provides increased reductions of 33 percent for nitrogen, 52 percent for phosphorus, 66 percent for sediments, and 63 percent for BOD.

The resultant total area of existing BMPs was then summarized to show how much of the source area of each watershed is treated, the cost of the retrofits, and the total load reductions from existing BMPs and the retrofitted dry ponds.

13.2.4 Stream Restoration

MDE (2014b) has allocated reductions in nutrient and TSS loads for stream bank restoration. For each 100 linear feet, the values from bank restoration for TN, TP, and TSS are reductions of 7.50, 6.80, and 24,754 pounds, respectively (MDE 2014b). Multiplying by the number of linear feet restored provides the load reductions obtained. Stream bank restoration is projected to cost $500 per linear foot. Unlike other BMPs, stream restoration is calculated by WTM at the watershed scale, not the subwatershed scale.

13.2.5 Watershed Ranking

The WTM modifications allows users to assign a greater ESD implementation percent to subwatersheds that are ranked higher (i.e., have larger required reductions) by categorizing each of the ranked subwatersheds into quartiles. In doing so, the user can account for greater ESD implementation in subwatersheds with a higher prioritization ranking. Developed from a GIS analysis, the subwatershed unit area loading rates were tabulated, with the composite scores being the sum of individual scores. This was done in a separate Access database. A lookup table in WTM referenced this database. The look up table imported (into WTM) the relative priority ranking accorded to each subwatershed. The relative priorities were then normalized along the range from highest to lowest. This range was then split into four equal interval quartiles, with each subwatershed ranking classified into its quartile according to the relative ranking along the range.

The user then entered the percent deployment of proposed BMPs into each category for each quartile. In watersheds where high load reductions are required, this resulted in high values (often 100 percent) being assigned to each quartile. In watersheds where low load reductions are required, this resulted in lower values being assigned to lower quartiles (i.e., lower load reductions were necessary). The quartile percent is applied to all BMPs applied to the different land uses. They are shown as the yellow input cells in the "Quartile Allocation" cells in the "All" worksheet in WTM. This process then assigned the weighted quartile deployment of BMPs into each subwatershed area. By this process, if the user identified 25 percent implementation for the lower quartile and 100 percent of right-of-ways (ROWs) to be treated, then the lowest quartile would have 25 percent implementation on ROWs for the subwatersheds in that quartile, while other quartiles might have higher percent implementation. This allocation was applied to the BMP selection process described below.

13.2.6 Proposed BMP Calculations

A key part of determining the potential load reductions and cost of proposed is summarizing the allocated BMP efficiencies used in WTM and their respective costs. Table 39 presents the removal efficiencies used in WTM to project load reductions from different land uses, in addition to the unit cost of the BMPs. Removal efficiencies for TN, TP, and TSS were assigned by MDE (2014b) for ESD practices (based on treating 1 inch of runoff), while BOD reductions were estimated from Harper (1995) and FIB reductions were assigned from Table 36. Because of their high required percent reduction requirements, BMP efficiencies for the Anacostia River and Mattawoman Creek Restoration Plans were based on treating 2.5 inches of runoff for institutional, commercial, and residential land uses. Costs were adopted from King and Hagan (2011) and a description of how the costs were determined is included in the restoration plans.

Table 39. Projected BMP costs and removal efficiencies (based on treating 1 inch of runoff)

BMP/Land Use Category	TN (%)	TP (%)	TSS (%)	BOD (%)	FC (%)	Cost per Treated Unit Impervious Acre
ESD Closed ROWs	57%	66%	70%	91%	75%	$55,929
ESD Open ROWs	57%	66%	70%	91%	75%	$52,758
Dry Pond Retrofit	33%	52%	66%	63%	75%	$11,700

BMP/Land Use Category	TN (%)	TP (%)	TSS (%)	BOD (%)	FC (%)	Cost per Treated Unit Impervious Acre
Institutional	57%	66%	70%	91%	75%	$51,368
Commercial/Industrial	57%	66%	70%	91%	75%	$51,368
Residential	57%	66%	70%	91%	75%	$17,477
Stream Restoration (lb/100 linear feet)	7.50	6.80	24,754	0.0	0.0	$500
Institutional, Commercial and Residential with 2.5 inches storage	72%	85%	90%	91%	95%	Same as above

The next step shown in Figure 3 (the restoration evaluation procedure) was to explore the effects of deploying ESD BMPs to the County owned ROW. At this point in the screening process, no particular BMP was chosen. Instead, a suite of BMPs appropriate to whether the roadway section was closed (with curb and gutter) or open (swales) was selected. As the GIS did not differentiate between these two categories, the default partitioning was selected with 60 percent of ROW areas being closed, and the balance of 40 percent being open. This had no effect on load reductions, as both open and closed sections were assumed to have load reductions (Table 39).

Since this step in the restoration evaluation procedure calls for maximizing ESDs in County ROW as much as possible, the 60 percent applied to the connected and 40 percent applied to disconnected means that the entire ROW is treated, subject to the global adjustments from the quartile allocations. These reductions were then applied to both open and closed sections of the ROWs in the same manner as above to obtain the load reductions for each ROW category. The costs of $55,929 and $52,758 per treated acre were then allocated to each of these source areas, and summarized for the ROW category along with the total ROW load reductions.

If load reduction gaps still exist after implementing BMPs on roads/ROWs, then the next step is to determine if institutional properties (e.g., religious institutions, government offices, and facilities and municipally owned organizations such as libraries and schools) could help to fill the remaining gap. Likewise, impervious areas from commercial/ industrial land uses and residential properties are included if a load reduction gap remained. To eliminate double counting of area treated, the area available for ESD practices was reduced by the amount of area that was treated by existing BMPs.

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APPENDIX A: ADDITIONAL INFORMATION ON *CONNECTED IMPERVIOUS* AND *DISCONNECTED IMPERVIOUS* AREAS

The County model accounts for impervious areas that are directly connected and impervious areas that are disconnected. Connected impervious areas are areas where runoff directly flows into the storm sewer system. Disconnected impervious areas are areas where runoff flows onto pervious areas prior to flow into the storm sewer system. To all for this distinction the County model made the following assumptions:

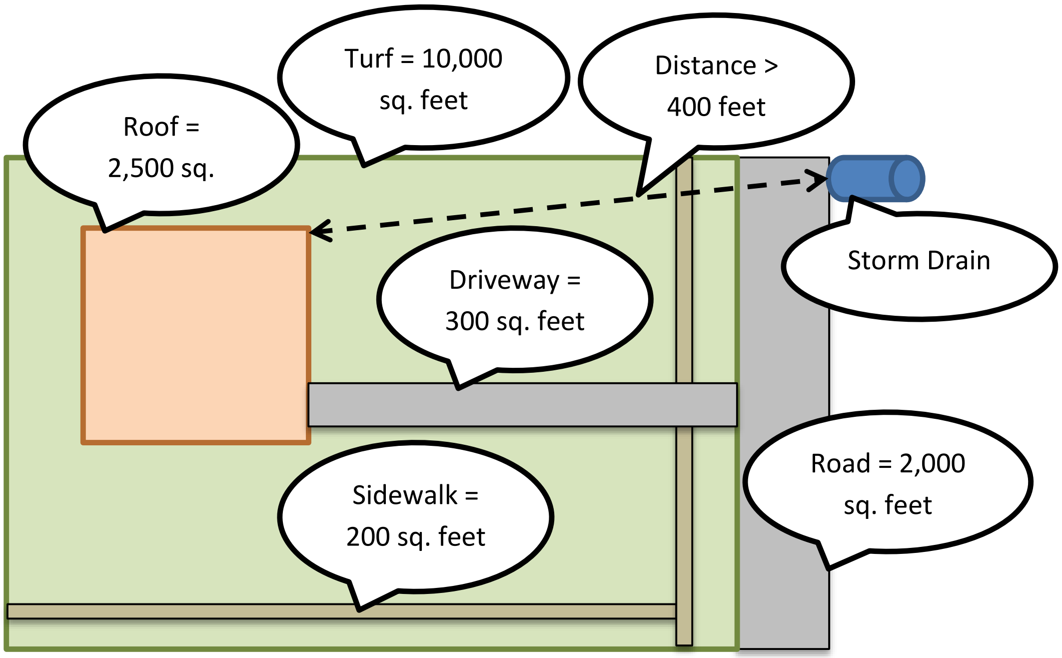
- All impervious areas within the "Urban" land use layer (MDP 2010) are considered connected impervious areas with the following exceptions.
  - If the impervious area is a building with a footprint less than 3,000 sq. feet and the building is greater than 400 feet from a storm drain line, it is considered disconnected impervious.
  - If the impervious area is a sidewalk, it is always considered disconnected impervious.
- All impervious areas within the "Rural" land use layer (MDP 2010) are considered disconnected impervious areas with the following exceptions.
  - If the impervious area is a driveway, it is always considered connected impervious.
  - If the impervious area is not a sidewalk and is within 400 feet from a storm drain line, it is considered connected impervious.

The "Urban" land uses consist of the following land use categories: commercial, industrial, institutional, and high and medium density residential areas. The remaining categories fall within the "Rural" land uses. Therefore, other than driveway and sidewalk impervious areas, which are always modeled as connected or disconnected, respectively, the other impervious areas are generally classified based on whether they fall within the "Urban" or "Rural" land use sectors. The exceptions are when the impervious area is a building that is less than 3,000 sq. feet and when the impervious area is within 400 feet of a storm drain. The example below illustrates some of these assumptions.

Implications of Impervious Area Designation Towards Load Generation

Whether an impervious area is a connected impervious area or a disconnected impervious area impacts that area's load output in the model for some pollutants. When an area is a disconnected impervious area, the model assumes that an area twice as much is required from adjacent turf area for runoff to flow over prior to entry into a storm sewer system. For example if the disconnected impervious area is 100 sq. feet, then 200 sq. feet is required from turf area for the runoff from the impervious area to flow over. While the model does not change the runoff volume, it increases the unit pollutant loading rate from the turf area by applying a pollutant *enrichment factor* for some pollutants. Table 5 contains the enrichment factor values for different pollutants. This result in some of the turf areas associated with disconnected impervious areas contributing higher levels of pollutants than when the turf area is not associated with a disconnected impervious area. The example below explains this modeling aspect as well.

Example 1 (Urban Setting)



Site Conditions

- In an urban area
- Total area = 15,000 sq. feet
- Building (roof area) = 2,500 sq. feet
- Road = 2,000 sq. feet
- Driveway = 300 sq. feet
- Sidewalk = 200 sq. feet
- Turf = 10,000 sq. feet

Connected Impervious areas

- Since the area is in an urban area, the road is modeled as connected impervious.
- Since driveways are always considered as connected impervious, the driveway is modeled as connected impervious.

Disconnected Impervious areas

- Since the roof area is less than 3,000 sq. feet, and is more than 400 feet away from the storm drain, it is modeled as a disconnected impervious area.
- Since sidewalks are always considered as disconnected impervious, the sidewalks are modeled as disconnected impervious.

Pollutant load computation

Since the roof (building) and the sidewalk are considered disconnected impervious area, these areas are "paired" with a turf area that is twice as much (for runoff flow requirements). The roof and sidewalk area amounts to 2,700 sq. feet. Therefore, 5,400 sq. feet of turf area is required to be assigned for the disconnected impervious area. This leaves a balance of 4,600 sq. feet of turf area that is modeled separately.

This results in the following 4 load calculation groups.

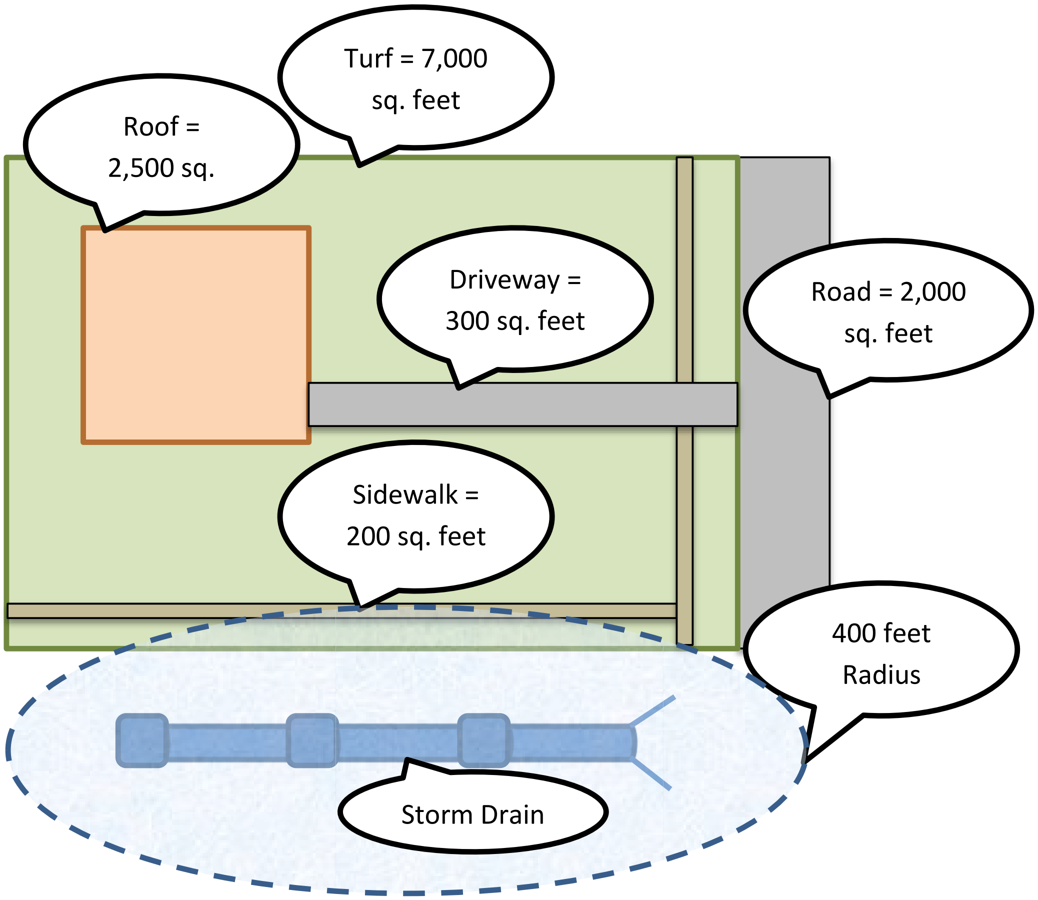
- Connected impervious area – Road (2,000 sq. feet) and Driveway (300 sq. feet)
- Disconnected impervious area – Roof (2,500 sq. feet) and Sidewalk (200 sq. feet)
- Pervious area for disconnected impervious – Turf (5,400 sq. feet)
- Pervious area (remaining) – Turf (4,600 sq. feet)

Runoff for the different land uses are all computed using the Simple Method. The pollutant load contribution for the different land uses in the example are then computed as the following.

- Road — Runoff × Unit pollutant load concentration
- Driveway — Runoff × Unit pollutant load concentration
- Roof — Runoff × Unit pollutant load concentration
- Sidewalk — Runoff × Unit pollutant load concentration
- Pervious (disconnected impervious) — Runoff × Unit pollutant load concentration × *Enrichment Factor*
- Pervious (remaining) — Runoff × Unit pollutant load concentration

As can be seen above, the key difference in the load calculations is the enrichment factor that is applied to pervious areas that are bring "paired" with disconnected impervious areas. When the enrichment factor is greater than one, the load generated from that pervious area will be increased.

Example 2 (Rural Setting)



Site Conditions

- In a rural area
- Total area = 12,000 sq. feet
- Building (roof area) = 2,500 sq. feet
- Road = 2,000 sq. feet
- Driveway = 300 sq. feet
- Sidewalk = 200 sq. feet
- Turf = 7,000 sq. feet

Connected Impervious areas

- Since driveways are always considered as connected impervious, the driveway is modeled as connected impervious.

Disconnected Impervious areas

- Since the area is in a rural area, and the road is more than 400 feet away from the storm drain, it is modeled as disconnected impervious.

- Since the roof is less than 3,000 sq. feet, and is more than 400 feet away from the storm drain, it is modeled as a disconnected impervious area.
- Since sidewalks are always considered as disconnected impervious, the sidewalks are modeled as disconnected impervious.

Pollutant load computation

Since the roof (building), the road, and the sidewalk are considered disconnected impervious area, these areas are paired with a turf area that is twice as much (for runoff flow requirements). The roof, road and sidewalk area amounts to 4,700 sq. feet. Therefore, 9,400 sq. feet of turf area is required to be assigned for the disconnected impervious area. This leaves a balance of 600 sq. feet of turf area that is modeled separately.

This results in the following 4 load calculation groups.

- Connected impervious area – Driveway (300 sq. feet)
- Disconnected impervious area – Roof (2,500 sq. feet), Road (2,000 sq. feet) and Sidewalk (200 sq. feet)
- Pervious area for disconnected impervious – Turf (9,400 sq. feet)
- Pervious area (remaining) – Turf (600 sq. feet)