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showing City of Elmhurst employees recovering a dissolved oxygen probe from Salt Creek in Illinois as part of a stream dissolved oxygen feasibility study.

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A Method for Disaggregating Existing Model Pollutant Loads for Subwatersheds

Gene Yagow,[a]* Brian Benham,[b] Karen Kline,[c] Becky Zeckoski,[d] and Carlington Wallace[e]

Abstract

Sediment is the primary pollutant that results in nonattainment of Virginia's aquatic life use (general) water quality standard. Because the US Environmental Protection Agency's Total Maximum Daily Load (TMDL) Program requires pollutant load reductions that are protective of aquatic life use, and because Virginia has no sediment water quality standard, modeling procedures were needed to quantify existing and endpoint sediment loads and the corresponding required pollutant reductions. Previous sediment TMDLs in Virginia used a paired reference watershed approach (Yagow 2004). However, the recent model-based quantification of the Chesapeake Bay TMDL offers a simpler and potentially more consistent method for calculating target sediment loads for impaired watersheds within the Chesapeake Bay watershed. This paper illustrates the application of an alternative procedure, the *disaggregate* method, for developing target pollutant loads; this method should be applicable to many watersheds nationwide. The disaggregate method uses land use inputs to, and pollutant load outputs from, an existing model together with a locally derived land use inventory. Using this method, one can determine the pollutant load reductions needed to achieve target pollutant loads for upstream, low-order subwatersheds whose areas are smaller than the smallest modeling segments generally used in basin-scale modeling.

Introduction

Water quality modeling is often performed at the basin scale for planning purposes. However, modeling at this scale often yields insufficient detail for establishing specific loads or for determining specific, needed management changes at the subwatershed scale. This paper describes the *disaggregate* method, which determines target pollutant loads from land-based pollutant sources at the subwatershed scale, allowing for the development of more fine-tuned pollutant control measures. The method uses land use–specific unit-area loads (UALs)—calculated from the output of existing models of land-based pollutant sources (as opposed to point or population-based sources) coupled with fine-scale local land use data—to determine target pollutant loads. This method further increases the utility of existing model output by providing information for management decisions at a finer geographic level. Furthermore, the disaggregate method should promote greater consistency between larger-scale (basin-level) and smaller-scale (subwatershed-level) planning efforts.

Modeling studies typically include a scenario that represents existing conditions and one or more management scenarios that explore different ways to achieve some targeted load reduction. One widespread application of modeling is for load quantification in the US Environmental Protection Agency's (USEPA) Total Maximum Daily Load (TMDL) Program. The TMDL Program is based on Section 303(d) of the 1985 federal Clean Water Act and USEPA's current water quality planning and management regulations, 40 CFR Part 130 (2012), which require states to identify causative pollutants and develop TMDLs for "impaired" water bodies that violate state water quality standards (USEPA 1999). A TMDL study determines (1) the amount of each identified causative pollutant a water body can receive and still meet water quality standards and (2) the level of load reductions required from each source category. Essentially, a TMDL provides an outline of actions needed to restore water quality.

USEPA's Chesapeake Bay Program developed the Chesapeake Bay Watershed Model (CBWM) to simulate the fate and transport of nutrients and sediment in the 64,000-square-mile (mi^2; 165,760-km^2)[1] watershed that drains to the Chesapeake Bay. This model has evolved over time in complexity and accuracy. The first version was developed in 1983; the latest version (phase 5.3.2) was released in June 2011. Significant efforts have gone into developing the CBWM, and its characterization of nutrient and sediment sources contributing to the Bay, and designing the pollution control measures to reduce the adverse impact of

[1] English units have been used throughout this paper based on the CBWM model.

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those sources. USEPA (2010a) has overseen the calibration of the CBWM over a 21-year period at 287 flow gauging stations and at 164 water quality stations with varying periods of sediment data. Although simulated as 1,194 river segments, most of the CBWM inputs are based on county-averaged data and distributed on an area-weighted basis to portions of river segments that intersect each county.

The scale of CBWM output limits the development of targeted management actions at a finer spatial scale. As an example, the 31-mi² (80-km²) Moore's Creek was listed as "impaired" in the 2008 *Virginia Water Quality Assessment 305(b)/303(d) Integrated Report* because of water quality violations of the general aquatic life use water quality standard (Virginia Department of Environmental Quality [VADEQ] 2008). This listing required the state to oversee the development of a TMDL for Moore's Creek. The impaired segment of Moore's Creek is located within the Rivanna River basin in Virginia, with 91% of the contributing watershed area in Albemarle County and the remainder in the City of Charlottesville (Figure 1). The Rivanna River drains into the James River, which empties into the Chesapeake Bay.

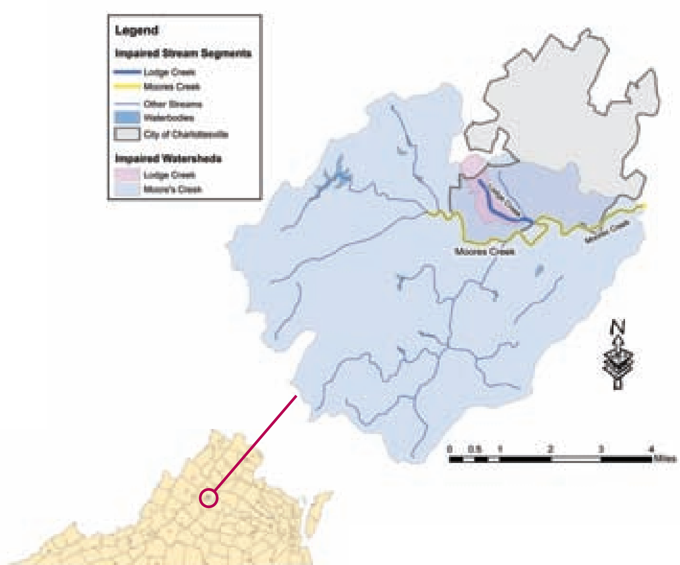

Figure 1. Location of the Moore's Creek subwatersheds.

A violation of the aquatic life use standard in Virginia is based on measurements of the instream benthic macroinvertebrate community compared against an accepted value of Virginia's multimetric stream condition index (VADEQ 2008). A follow-up stressor analysis on the violation in Moore's Creek found that sediment was the most probable stressor, based on repeated poor habitat metric scores and observations of insufficient riparian buffer, erosion, and bank instability at many locations in the watershed.

The development of a TMDL requires the calculation of pollutant loads for an existing, or baseline, condition and for a target condition. The target condition reflects load reductions that are expected to allow the benthic macroinvertebrate community to recover and, in time, to meet the aquatic life use water quality standard. Whereas the identification of impairments is based on monitoring data that are periodic, short-term, and related to ambient conditions, modeling allows the TMDL developer to calculate both existing and target pollutant loads under long-term, variable hydrologic conditions. Because target TMDL loads are typically based on an instream pollutant concentration standard, and because Virginia has no numeric water quality standard for sediment (State Water Control Board 2011), TMDL developers under contract to the state needed a different method for establishing a sediment reference endpoint (the TMDL target load) representing the restoration condition.

In many watersheds with an aquatic life use impairment where sediment has been identified as the primary pollutant, TMDL developers have used a *reference watershed* approach to quantify the TMDL target load for the impaired watershed. This approach pairs two watersheds—one whose streams are supportive of their designated uses (the reference watershed) and one whose streams are impaired. TMDL developers select a reference watershed based on its similarity with the impaired watershed in terms of land use and topographical, ecological, and soils characteristics. They then simulate sediment loads for both watersheds and use the area-adjusted load from the reference watershed as the reference load that quantifies the TMDL target load for the impaired watershed (Yagow 2004).

Prior to the development of the Chesapeake Bay TMDL (USEPA 2010a), the state coordinated development of many local TMDLs for sediment throughout the Chesapeake Bay watershed in Virginia; but most of these TMDLs were developed independently of each other and focused on headwater stream segments. The process for development of these local TMDLs did not include considerations of downstream water quality consequences—for instance to the Chesapeake Bay. As of December 30, 2010, however, all of the waters in the Chesapeake Bay watershed, including the Moore's Creek watershed, also became subject to the provisions of the Chesapeake Bay TMDL, which includes a sediment load component. As a result, all TMDL target loads for the same pollutant in the same river basin must sum up to the TMDL load for each of the 92 impaired downstream Chesapeake Bay tidal segments. The disaggregate method arose from the need to maintain a degree of consistency between the development of local upstream TMDLs and the downstream Chesapeake Bay TMDLs.

The Moore's Creek watershed includes portions of two CBWM land–river segments, the smallest geographic units in the model. For load calculations, we applied the disaggregate method to each portion separately—the Albemarle County portion and the City of Charlottesville portion—and summed together the loads from each portion. This paper illustrates the application of the disaggregate method to quantify a long-term average annual TMDL target sediment load to address the aquatic life use impairment for the Albemarle County portion of Moore's Creek, referred to as "Moore's Creek (Alb)." This illustration uses CBWM-simulated, land-based pollutant load output from the Albemarle County land–river segment and applies it to the local land use inventory for the Moore's Creek (Alb) portion.

The disaggregate method arose from the need to maintain a degree of consistency…

The Disaggregate Method

The disaggregate method uses simulation inputs and outputs from an existing model, including pollutant loads by land use and land use areas, to calculate UALs in units of tons per acre per year for each land use within the smallest available geographical modeling segment. One then applies the UALs from the existing model to a spatially derived local land use inventory that is presumably more representative of the geographically smaller, impaired subwatershed to calculate pollutant loads. The disaggregate method allows one to determine loads for both existing (baseline) and future (target) conditions. The future conditions include a representation of management measures to achieve the required pollutant reduction. Below, we describe the disaggregate method in general and then illustrate each step using the CBWM data for the Moore's Creek (Alb) application example.

Step 1. Download Existing Model Land Use Data and Create Land Use Groups

In this step, one obtains the land use category and area distribution from existing model inputs for the smallest model segment that includes the subwatershed of interest. If all of the land use categories are not spatially explicit (derived from a hard copy or digital map source), some type of grouping of the land use categories may be necessary to provide a basis for matching with the local land use inventory and categories (see step 2).

In the case of Moore's Creek, we obtained land use category and area data (inputs to the CBWM) and simulated sediment loads (output from various CBWM simulation scenarios) using the online Virginia Assessment Scenario Tool developed for the Commonwealth of Virginia by the Interstate Commission on the Potomac River Basin (2011). We obtained output for two modeling scenarios: we used the 2009 Progress–VA scenario for existing (baseline) load calculations and the WIP 1–VA scenario (a November 7, 2011 modification of the Virginia Watershed Implementation Plan for the Chesapeake Bay TMDL) as the reference (target) scenario to quantify the TMDL endpoint.

The CBWM incorporates 31 land use categories (USEPA 2010b). Since the disaggregate method applies only to land-based pollutant sources, this paper does not discuss the four point source categories that are also included in the CBWM (details available in Yagow et al. 2011). USEPA's Chesapeake Bay Program created the CBWM's 31 land-based land use categories using a combination of digital spatial data, such as National Land Cover Data imagery; statistical data, such as the US Department of Agriculture's Census of Agriculture statistics data, by county; and state-specific databases describing the type and extent of implemented best management practices (BMPs). To relate the more detailed CBWM land use categories to fewer, less specific, locally developed land use categories, we combined many of the CBWM's 31 land use categories into broader agricultural and urban/residential land use groups (Table 1). Table 1 shows the distribution of specific land use categories within each land use group; the color coding used to distinguish land use groups in Table 1 is repeated in subsequent tables.

Table 1. Existing model (CBWM Albemarle segment) land use categories, aggregated land use groups, and land use category distributions within each land use group.

CBWM Land Use Code	CBWM Land Use Category	Area (acres)	Land Use Group	Distribution within Each Group (%)
hom	High-till without manure	282.7	Conventional tillage, no manure	95.9
nho	High-till without manure NM	12.1		4.1
hwm	High-till with manure	49.9	Other row crops	46.6
nhi	High-till with manure NM	2.1		2.0
lwm	Low-till with manure	52.7		49.3
nlo	Low-till with manure NM	2.3		2.1
hyw	Hay with nutrients	4,262.4	Hay	72.3
nhy	Hay with nutrients NM	182.2		3.1
alf	Alfalfa	123.5		2.1
nal	Alfalfa NM	5.3		0.1
hyo	Hay without nutrients	1,325.8		22.5
pas	Pasture	8,400.3	Pasture	93.3
npa	Pasture NM	359.1		4.0
trp	Pasture corridor	245.9		2.7
afo	Animal feeding operation	39.0		0.0
cfo	Confined animal feeding operation	0.0		0.0
for	Forest	68,032.1	Forest	99.0
hvf	Harvested forest	685.8		1.0
cid	CSS impervious developed	0.0	Impervious developed	0.0
rid	Regulated impervious developed	766.0		29.2
nid	Nonregulated impervious developed	1,858.0		70.8
cpd	CSS pervious developed	0.0	Pervious developed	0.0
rpd	Regulated pervious developed	3,762.0		43.5
npd	Nonregulated pervious developed	4,712.0		54.5
ccn	CSS construction	0.0		0.0
rcn	Regulated construction	166.2		1.9
cex	CSS extractive	0.0	Extractive	0.0
rex	Regulated extractive	0.0		0.0
nex	Nonregulated extractive	219.4		100.0
urs	Nursery	15.8	Nursery	100.0
atdep	Atmospheric deposition	870.7	Water	100.0

Notes: 1 acre ≈ 0.4046 ha; CBWM, Chesapeake Bay Watershed Model; CSS, combined sewer system; NM, nutrient management.

Step 2. Obtain Local Land Use Data for Baseline Scenario and Assign Land Use Groups

One can often obtain local land use data from a variety of sources, including National Land Cover Data (USEPA 2006), the cropland data layer from the National Agricultural Statistics Service (e.g., NASS 2009), and local sources such as county-level land use data derived from satellite and/or aerial imagery. When land use categories obtained from local sources differ from those used by the larger-scale model, grouping the land use categories into common, broadly defined land use groups allows for matching between the data sources.

We compiled local land use data for the Moore's Creek (Alb) watershed from the Rivanna River Basin Commission's (RRBC) Rivanna Watershed and Vicinity Land Use/Land Cover Map geodatabase (RRBC 2009) and the NASS cropland data layer (NASS 2009). In general, we used the RRBC land use data as the primary source for nonagricultural land uses and the NASS data to quantify agricultural sources. Additional details about the land use data are available in the draft Moore's Creek TMDL report (Yagow et al. 2011). Table 2 summarizes the Moore's Creek (Alb) land use categories and their corresponding assigned land use group.

Step 3. Distribute Locally Derived Land Use Data to Existing Model Land Use Categories

In this step, one sums the areas for each of the land use groups from the locally derived land use data (Table 2) and then redistributes the total area to the existing model's land use categories, using the land use category distribution within each land use group (Table 1).

For the Moore's Creek (Alb) example, we summed the relevant areas from Table 2 for each land use group and redistributed the total area according to the land use category distribution within each land use group from the CBWM land–river segment (Table 1). We calculated the area assigned to animal feeding operations ("afo" in Table 1) based on actual numbers of livestock farms of each animal type, also described in the draft TMDL report (Yagow et al. 2011). We subtracted the afo acreage calculated by this method from the total "Pasture" group acreage. Table 3 shows the summed group areas and the distributed areas. Based on input from local stakeholders, we determined that some of the land use categories in the CBWM Albemarle segment were not present in the Moore's Creek (Alb) watershed.

Table 2. Moore's Creek (Alb) watershed: Local land use categories and corresponding land use groups.

Local Land Use Category	Land Use Data Source	Area (acres)	Land Use Group
Orchard/vineyard	RRBC	60.6	Conventional till., no manure
Corn	NASS	7.2	Other row crops
Soybeans	NASS	3.0	
Hay	NASS	781.5	Hay
Pasture	NASS	207.5	Pasture
Deciduous tree	RRBC	11,097.7	Forest
Evergreen tree	RRBC	1,763.4	
Pine plantation	RRBC	199.9	
Forest harvest	RRBC	20.7	
Urban impervious	RRBC	1,44.6	Impervious developed
Golf course	RRBC	155.4	Pervious developed
Urban pervious	RRBC	4,346.2	
Bare earth	RRBC	47.9	
Water	RRBC	227.7	Water
Total areas (acres)		19,963.4	

Note: T1 acre ≈ 0.4046 ha.

Table 3. Moore's Creek (Alb) watershed: Local land use group areas distributed to CBWM land use categories.

Land Use Group	Group Area (acres)	CBWM Land Use Code	CBWM Land Use Category Name	Distribution within Each Group (%)	Distributed Area (acres)
Conventional tillage, no manure	60.6	hom	High-till without manure	95.9	58.1
		nho	High-till without manure NM	4.1	2.5
Other row crops	10.3	hwm	High-till with manure	46.6	4.8
		nhi	High-till with manure NM	2.0	0.2
		lwm	Low-till with manure	49.3	5.1
		nlo	Low-till with manure NM	2.1	0.2
Hay	781.5	hyw	Hay with nutrients	72.3	564.7
		nhy	Hay with nutrients NM	3.1	24.1
		alf	Alfalfa	2.1	16.4
		nal	Alfalfa NM	0.1	0.7
		hyo	Hay without nutrients	22.5	175.6
Pasture	207.5	pas	Pasture	93.3	189.5
		npa	Pasture NM	4.0	8.1
		trp	Pasture corridor	2.7	5.5
		afo	Animal feeding operation	0.0	4.4
Forest	13,081.7	for	Forest	0.0	12,951.2
		hvf	Harvested forest	99.0	130.6
Impervious developed	1,044.6	cid	CSS impervious developed	0.0	0.0
		rid	Regulated impervious developed	29.2	304.9
		nid	Nonregulated impervious developed	70.8	739.7
Pervious developed	4,549.5	cpd	CSS pervious developed	0.0	0.0
		rpd	Regulated pervious developed	43.5	1,980.9
		npd	Nonregulated pervious developed	54.5	2,481.1
		ccn	CSS construction	0.0	0.0
		rcn	Regulated construction	1.9	87.5
Water	227.7	atdep	Atmospheric deposition	100.0	227.7
Total	19,963.4				19,963.4

Notes: 1 acre ≈ 0.4046 ha; CBWM, Chesapeake Bay Watershed Model; CSS, combined sewer system; NM, nutrient management.

Step 4. Calculate Local Land Use Distribution for a Target Pollutant Reduction Scenario

In step 1, one obtains existing model data for a baseline scenario. In this step, one obtains similar data for a target scenario. In some cases, the baseline and target land use categories and the areal distributions may be the same. However, in many cases, one may need to use additional land use categories, or shift land use areas from one category to another, to represent the management changes that result in the pollutant load reductions associated with the target scenario.

The baseline and target scenarios each simulated different combinations and extents of implemented BMPs.

In the Moore's Creek (Alb) watershed, the CBWM runs we used in creating the targeted TMDL scenario were based on land use categories that incorporated BMPs. Some of these BMPs were represented as a change in area from one land use to another, while other BMPs were represented as reductions in load—either applied to the land surface, or delivered to the edge-of-stream. BMPs simulated as load reductions resulted in changes in the UALs for the applicable land use. The baseline and target scenarios each simulated different combinations and extents of implemented BMPs. The disaggregate method represents the shift in acreage between the baseline and target scenarios, both as changes in the percentage of land use group acreages (Table 4) and as changes in the percentage distributions of land use categories within each land use group (Table 5). The "nursery" and "extractive" land use categories in Table 4 were not present in the Moore's Creek (Alb) watershed, so they do not appear in subsequent tables.

Table 4. CBWM Albemarle segment: Percentage change in land use group acreage between baseline and target scenarios.

Land Use Group	Baseline Scenario (acres)	Target Scenario (acres)	Change as % of Total Area
Conventional tillage, no manure	294.8	259.2	–0.037
Other row crops	107.0	100.1	0.007
Pasture	9,044.3	7,611.3	–1.486
Hay	5,899.2	6,231.5	0.345
Forest	68,717.9	70,069.2	1.401
Impervious developed	2,624.0	2,427.2	–0.204
Pervious developed	8,640.2	8,837.0	0.204
Extractive	219.4	11.2	0.216
Nursery	15.8	15.8	0.000
Water	870.7	870.7	0.000
Total area	96,433.2	96,433.2	

Notes: 1 acre ≈ 0.4046 ha; CBWM, Chesapeake Bay Watershed Model.

Table 5. CBWM Albemarle segment: Percentage change in land use category acreage within each group between baseline and target scenarios.

Land Use Group	Land Use Categories in Each Group	Baseline Scenario (% of Group)	Target Scenario (% of Group)	Change as % of Baseline
Conventional tillage, no manure	hom	95.9	0.0	–100.0
	nho	4.1	100.0	2,339.0
Other row crops	hwm	46.6	0.0	–100.0
	nhi	2.0	10.0	402.0
	lwm	49.3	0.0	–100.0
	nlo	2.1	90.0	4,169.8
Pasture	pas	93.3	87.5	–6.3
	npa	4.0	12.2	208.2
	trp	2.7	0.3	–88.8
	afo	0.0	0.0	—
Hay	hyw	72.3	0.0	–100.0
	nhy	3.1	62.7	1,929.7
	alf	2.1	0.0	–100.0
	nal	0.1	1.8	1,929.7
	hyo	22.5	35.5	57.9
Forest	for	99.0	99.0	0.0
	hvf	1.0	1.0	–1.9
Impervious developed	cid	0.0	0.0	—
	rid	29.2	29.2	0.0
	nid	70.8	70.8	0.0
Pervious developed	cpd	0.0	0.0	—
	rpd	43.5	43.2	–0.7
	npd	54.5	54.9	—
	ccn	0.0	0.0	—
	rcn	1.9	1.9	–2.2

Note: CBWM, Chesapeake Bay Watershed Model.

The large percentage increases for several land uses in Table 5 result from the application of nutrient management (NM) control measures to agricultural land uses. The use of such measures leads to large shifts of area from a land use without NM, such as "high-till without manure" (hom) to its counterpart with NM, "high-till without manure NM" (nho). The change percentages are especially large where the initial baseline group percentages were very small. Table 6 shows the resulting land use distributions for both the baseline and target scenarios.

Table 6. Moore's Creek (Alb) watershed: Summary of CBWM land use distributions between baseline and target scenarios.

CBWM Land Use Code	CBWM Land Use Category	Baseline Scenario (acres)	Target Scenario (acres)
hom	High-till without manure	58.1	0.0
nho	High-till without manure NM	2.5	60.1
hwm	High-till with manure	4.8	0.0
nhi	High-till with manure NM	0.2	1.0
lwm	Low-till with manure	5.1	0.0
nlo	Low-till with manure NM	0.2	9.2
hyw	Hay with nutrients	564.7	0.0
nhy	Hay with nutrients NM	24.1	487.4
alf	Alfalfa	16.4	0.0
nal	Alfalfa NM	0.7	14.1
hyo	Hay without nutrients	175.6	275.9
pas	Pasture	185.4	169.4
npa	Pasture NM	7.9	23.7
trp	Pasture corridor	5.4	0.6
afo	Animal feeding operation	8.8	8.8
for	Forest	12,951.2	13,004.5
hvf	Harvested forest	130.6	128.5
cid	CSS impervious developed	0.0	0.0
rid	Regulated impervious developed	304.9	301.7
nid	Nonregulated impervious developed	739.7	731.8
cpd	CSS pervious developed	0.0	0.0
rpd	Regulated pervious developed	1,980.9	1,953.1
npd	Nonregulated pervious developed	2,481.1	2,480.8
ccn	CSS construction	0.0	0.0
rcn	Regulated construction	87.5	85.0
atdep	Atmospheric deposition	227.7	227.7
Total		19,963.4	19,963.4

Notes: 1 acre ≈ 0.4046 ha; CBWM, Chesapeake Bay Watershed Model; CSS, combined sewer system.

Step 5. Obtain Model Load Data and Calculate Unit-Area Loads

In this step, one obtains annual loads (in tons per year) corresponding to each land use category for the appropriate model segment and calculates UALs by dividing the loads by the corresponding acreage for each land use category.

For application in the Moore's Creek watershed, we obtained UALs by dividing CBWM-simulated average annual load data, corresponding to the model segments that included Moore's Creek, by their respective areas for each applicable land use category. Table 7 shows an example of the data used for the baseline scenario in the CBWM Albemarle segment. We used similar data and calculations from simulated output for the target scenario.

Table 7. CBWM Albemarle segment: Baseline scenario areas, loads, and unit-area loads.

CBWM Land Use Code	CBWM Land Use Category	Area (acres)	TSS (tons/year)	TSS UAL (tons/acre/year)
hom	High-till without manure	282.7	38.3	0.14
nho	High-till without manure NM	12.1	1.7	0.14
hwm	High-till with manure	49.9	5.5	0.11
nhi	High-till with manure NM	2.1	0.2	0.11
lwm	Low-till with manure	52.7	3.6	0.07
nlo	Low-till with manure NM	2.3	0.2	0.07
hyw	Hay with nutrients	4,262.4	165.4	0.04
nhy	Hay with nutrients NM	182.2	7.1	0.04
alf	Alfalfa	123.5	4.8	0.04
nal	Alfalfa NM	5.3	0.2	0.04
hyo	Hay without nutrients	1,325.8	50.4	0.04
pas	Pasture	8,400.3	7,991.5	0.95
npa	Pasture NM	359.1	346.0	0.96
trp	Pasture corridor	245.9	2,917.2	11.86
afo	Animal feeding operation	39.0	120.2	3.08
cfo	Confined animal feeding operation	0.0	0.0	—
for	Forest	68,032.1	2,203.9	0.03
hvf	Harvested forest	685.8	136.8	0.20
cid	CSS impervious developed	0.0	0.0	—
rid	Regulated impervious developed	766.0	618.5	0.81
nid	Nonregulated impervious developed	1,858.0	1,500.3	0.81
cpd	CSS pervious developed	0.0	0.0	
rpd	Regulated pervious developed	3,762.0	482.7	0.13
npd	Nonregulated pervious developed	4,712.0	604.6	0.13
ccn	CSS construction	0.0	0.0	—
rcn	Regulated construction	166.2	389.8	2.35
cex	CSS extractive	0.0	0.0	—
rex	Regulated extractive	0.0	0.0	—
nex	Nonregulated extractive	219.4	716.5	3.27
urs	Nursery	15.8	67.9	4.30
atdep	Atmospheric deposition	870.7	0.0	0.00

Notes: 1 acre ≈ 0.4046 ha; 1 ton ≈ 0.9072 metric tons; 1 ton/acre/year ≈ 2.2422 metric tons/ha/year; CBWM, Chesapeake Bay Watershed Model; CSS, combined sewer system; TSS, total suspended sediment. Land uses without UAL values were not represented in the Albemarle segment.

Step 6. Calculate Local Subwatershed Pollutant Loads

In this step, one calculates local subwatershed pollutant loads by multiplying the redistributed land use category areas for each scenario by their corresponding UALs. Table 8 illustrates the UAL calculations for the Moore's Creek (Alb) baseline scenario.

Table 8. Moore's Creek (Alb) watershed: Local sediment loads calculated from CBWM unit-area loads and redistributed areas.

CBWM Land Use Code	CBWM Land Use Category	Redistributed Area (acres)	CBWM UAL (tons/acre/year)	Total Suspended Sediment (tons/year)
hom	High-till without manure	58.1	0.14	7.9
nho	High-till without manure NM	2.5	0.14	0.3
hwm	High-till with manure	4.8	0.11	0.5
nhi	High-till with manure NM	0.2	0.11	0.0
lwm	Low-till with manure	5.1	0.07	0.3
nlo	Low-till with manure NM	0.2	0.07	0.0
hyw	Hay with nutrients	564.7	0.04	21.9
nhy	Hay with nutrients NM	24.1	0.04	0.9
alf	Alfalfa	16.4	0.04	0.6
nal	Alfalfa NM	0.7	0.04	0.0
hyo	Hay without nutrients	175.6	0.04	6.7
pas	Pasture	189.5	0.95	180.3
npa	Pasture NM	8.1	0.96	7.8
trp	Pasture corridor	5.5	11.86	65.5
afo	Animal feeding operation	4.4	3.08	13.6
for	Forest	12,951.2	0.03	419.6
hvf	Harvested forest	130.6	0.20	26.0
rid	Regulated impervious developed	304.9	0.81	246.2
nid	Nonregulated impervious developed	739.7	0.81	597.3
rpd	Regulated pervious developed	1,980.9	0.13	254.2
npd	Nonregulated pervious developed	2,481.1	0.13	318.3
rcn	Regulated construction	87.5	2.35	205.2
		19,963.4		2,373.3

Notes: 1 acre ≈ 0.4046 ha; 1 ton ≈ 0.9072 metric tons; 1 ton/acre/year ≈ 2.2422 metric tons/ha/year; Chesapeake Bay Watershed Model; CSS, combined sewer system.

Step 7. Compare Baseline and Target Scenario Pollutant Loads

In the example presented here, we developed the Moore's Creek TMDL for sediment. Sediment fate and transport are simulated similarly for many of the 31 land-based land use categories used in the CBWM. We aggregated the land use categories reported in Table 9 across those land use categories for which the sediment simulation was the same (e.g., we aggregated the various hay land use categories into the "hay" land use category and aggregated the pasture and pasture NM categories into the "pasture" land use category). Additionally, we consolidated urban land use categories into the "pervious developed," "impervious developed," and "construction" categories. Table 9 illustrates the simulated sediment loads (tons per year) for the Moore's Creek (Alb) baseline and target scenarios.

Table 9. Moore's Creek (Alb) watershed: Comparison of baseline and target scenario sediment loads.

CBWM Land Use Category	Baseline Scenario		Target Scenario	
	Area (acres)	Total Suspended Sediment (tons/year)	Area (acres)	Total Suspended Sediment (tons/year)
Conventional tillage, no manure	60.6	8.2	60.1	6.3
High-till cropland	5.0	0.5	1.0	0.1
Low-till cropland	5.3	0.4	9.2	0.6
Hay	781.5	30.2	777.4	26.7
Pasture, other	193.3	183.9	193.2	126.0
Pasture corridor	5.4	64.1	0.6	7.0
Animal feeding operation	8.8	27.2	8.8	16.8
Forest	12,951.2	419.6	13,164.3	421.3
Harvested forest	130.6	26.0	130.1	23.0
Impervious developed	1,044.6	843.5	1,630.9	692.0
Pervious developed	4,462.0	572.5	5,561.9	472.0
Construction	87.5	205.2	90.6	199.3
Average annual sediment load		2,381.3		1,991.1

Notes: 1 acre ≈ 0.4046 ha; 1 ton ≈ 0.9072 metric tons; CBWM, Chesapeake Bay Watershed Model.

Based on the target scenario load, the long-term target average annual sediment load for Moore's Creek (Alb) watershed is about 2,000 tons/year (1,814,360 kg/year). The comparison between the baseline and target scenarios indicates that a sediment load reduction of 16.4% is needed to achieve restoration conditions. The load reductions are effected through the simulation of management practices that take the form of both land use changes (reflected in land use category area changes) and load reductions (reflected in UAL changes). In the actual Moore's Creek sediment TMDL, Yagow et al. (2011) calculated land-based loads for both the Albemarle County and City of Charlottesville portions of Moore's Creek watershed and also included point source loads.

The disaggregate method promotes consistency between TMDLs developed for localized impairments and those required …by basin-scale modeling.

Summary

We developed the disaggregate method to leverage output from an existing, publicly available, basin-scale model to assist in developing spatially consistent TMDL loads for upstream subwatersheds in the Chesapeake Bay watershed. In general, however, one could apply this method in any area for which publicly available, basin-scale modeling has been performed and more detail is desired in a particular subwatershed. TMDL development in smaller, upstream subwatersheds is one general application in which one can use the disaggregate method. In the Moore's Creek example, this method allowed for refinements to the land use distributions in the CBWM by incorporating locally available land use data. Although we used sediment in the Moore's Creek example, a similar procedure could be used for any land-based pollutant simulated by an existing basin-scale model. The disaggregate method promotes consistency between TMDLs developed for localized impairments and those required to meet downstream target pollutant loads established by basin-scale modeling. In addition, it provides an alternative to the reference watershed approach for quantifying target loads for pollutants without numeric water quality standard criteria.

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