Nutrient and Sediment Estimation Tools for Watershed Protection

March 3, 2018

Introduction

Nutrient and sediment pollution affects many of our local streams and lakes, and can lead to adverse impacts such as algal blooms, fish kills, and dead zones. Given the growing importance of managing nutrient and sediment pollution there is interest in tools that can help estimate and track nutrient losses as well as provide decision support for policy or investment options. The purpose of this document is to identify and catalog many of the tools that are currently in use to estimate nitrogen, phosphorus, and sediment losses and to identify the uses for which these tools are most appropriate. Estimation tools can vary widely in terms of the land uses to which they are applicable, the scale at which they can estimate losses, the data requirements, and the sophistication of their estimates. Deciding which tool is appropriate for a given project will depend largely on the purpose of the project and understanding the tradeoffs of data and level of effort vs. accuracy.

Example uses of nutrient and sediment loss estimation tools include:

- **Watershed Scale Planning** – Watershed scale tools vary in their capability of assessing the effectiveness of multiple best management practices (BMPs) or agricultural conservation practices. The size of the watershed will drive the need for accuracy, and higher or lower data needs and level of effort to operate the tool may vary.
- **Scenario Building** – Scenario building refers to process of identifying one or multiple sets of BMPs to achieve a desired load reduction. This can occur at the field or watershed scale. Users should consider a tool capable of estimating a wide range of BMPs that has sufficient accuracy to meaningfully compare one scenario against the other.
- **Water Quality Trading and Other Market-based Programs** – These programs involve financial payment to landowners in return for a load reduction outcome. Tools to support these programs are at the field scale and should be capable of routing flow through BMPs and calculating reduction estimates from a wide range of BMPs at high levels of accuracy. This implies that higher data needs and level of effort to operate the tool may be justified.
- **Targeting** – Targeting BMPs that offer the largest load reductions and/or most cost effective load reductions will guide implementation to the lands most in need of treatment. Scenario building tools are best suited to appropriately target BMPs.
- **Tracking and Reporting** – Reporting results, to programs and/or the public, requires tracking and reporting the cumulative load reductions from implementation over variable time scales at the watershed scale. Tracking tools are estimators and the outputs do not necessarily require watershed attributes as inputs.

Once the intended use of a nutrient and sediment estimation tool is determined, such as the above examples, identify a model(s) that best fits the need by referring to Table 1. Table 1 compares models in terms of scale, sophistication, sector applicability and their ability to model BMPs. The document also provides a one paragraph description of each model. Please note the list of estimation tools discussed in this document is not exhaustive, nor are the comparison criteria used in Table 1.

Models for Estimating Nutrient Loads and Load Reductions

Comparison categories appearing across the top of Table 1 are:

Field or Watershed: Identifies whether the tool is suited to field-scale or watershed-scale estimates. Field scale estimates typically estimate loads at the edge of a farm field or urban segment prior to then entering the waterbody. Watershed scale estimates typically estimate loads that enter the waterbody and flow within in the stream or river.

Land Use Urban or Rural: Identifies the type of land use to which the tool is applicable.

Pollutant: Indicates which pollutant(s) the tool is able to estimate. Some tools estimate other loads as well but are not listed.

Event or Continuous: Describes the duration of time that the model estimates. When using event-based models (e.g., individual representative storms during the year), the user may wish to extrapolate results (e.g., either by summing the results of all simulated events, or multiplying the results of the representative storm by the average number of occurrences) to arrive at a monthly or annual total load reductions. The preferred approach for monthly or annual loads would be to use a tool identified as continuous, meaning it uses hourly or daily simulation that is then summarized within the tool itself.

BMP: Identifies at a cursory level if the tool is able to simulate a comprehensive, moderate, or simple list of best management practices (BMPs). The tools can usually estimate load reductions from one BMP (e.g., a cover crop on a farm field, or stormwater retention on a parking lot) or multiple BMPs.

Data Needs: Provides a generalized estimate of the amount of data that is needed to provision the tool (high, medium or low).

Level of Effort: Provides a general estimate of the overall level of effort and sophistication required to operate the tool.

Table 1. Comparison of models for estimating nutrient loads and load reductions

Model	Field or Watershed	Land Use Urban or Rural	Pollutant[1]	Event or Continuous	BMP[2]	Data Needs[3]	Level of Effort[4]
Simple							
CAST	Both	Both	P, N, S	Event	○	○	○
LTHIA	Both	Both	N, P, S	Event		○	○
NCANAT	Field	Rural	N, P, S	Event	○	○	○
Region 5	Field	Both	P, N, S	Event	○	○	○
SELDM	Both	Urban	N, P	Event	○	○	○
Simple Method	Watershed	Urban	N, P	Event	○	○	○
STEPL	Both	Both	P, N, S	Event	○	○ ◐	○ ◐
Mid-Range							
AGNPS	Both	Rural	N, P, S	Both	●	◐ ●	◐ ●
APEX	Field	Rural	N, P, S	Continuous	◐	●	●
EPIC	Field	Rural	N, P, S	Continuous	◐	●	●

Model	Field or Watershed	Land Use Urban or Rural	Pollutant[1]	Event or Continuous	BMP[2]	Data Needs[3]	Level of Effort[4]
GWLF	Watershed	Both	N, P, S	Both	○	○ ◐	○ ◐
MapShed	Watershed	Both	N, P, S	Both	○	○ ◐	○ ◐
NTT	Field	Rural	N, P, S	Continuous	◐	◐	◐
WARMF	Watershed	Both	N, P, S	Continuous		◐	◐
Detailed/Complex							
AGWA	Both	Both	N, P, S	Both	◐ ●	◐ ●	◐ ●
GLEAMS	Field	Rural	N, P, S	Both	●	◐ ●	◐ ●
HSPF	Both	Both	N, P, S	Both	●	◐ ●	◐ ●
KINEROS2	Both	Both	S	Event	◐	●	●
LSPC	Both	Both	N, P, S	Continuous	●	◐ ●	◐ ●
Opti-Tool	Watershed	Urban	N, P, S	Both	◐ ●	◐ ●	◐ ●
P8-UCM	Watershed	Urban	N, P, S	Continuous	●	◐	◐
PRMS	Watershed	Both	S	Both		◐ ●	◐ ●
REMM[5]	Field	Rural	N, P, S	Continuous	●	●	●
RZWQM2	Field	Rural	N	Event	●	◐ ●	◐ ●
SPARROW	Watershed	Both	N, P, S	Continuous	○	●	◐
SUSTAIN	Watershed	Urban	N, P, S	Both	●	●	●
SWAT	Both	Rural	N, P, S	Both	●	◐	◐
SWMM	Both	Urban	N, P, S	Both	◐ ●	◐ ●	◐ ●
TBET	Field	Rural	N, P, S	Both	◐	◐	◐
WEPP	Both	Rural	S	Continuous	●	○ ●	○ ●
Modeling Systems							
BASINS	Both	Both	N, P, S	Both	○ ●	○ ●	○ ●
Toolbox	Both	Both	N, P, S	Both	○ ●	◐ ●	◐ ●

Symbols: [1] N- Nitrogen, P - Phosphorus S - Sediment

[2] ● Detailed ◐ Medium ○ Simple

[3] and [4] ● High ◐ Medium ○ Low

[5] Only used for buffer strip

Simple Models

CAST. The Chesapeake Assessment and Scenario Tool (CAST) is a web-based nitrogen, phosphorus and sediment load estimator tool that streamlines environmental planning in the Chesapeake Bay watershed. CAST was originally developed in 2011 with funding provided by the EPA, to provide local jurisdictions with a tool to provide input into the Chesapeake Bay TMDL watershed implementation process. The Chesapeake Bay Program released an update in 2017 to reflect the conversion to the Phase 6 Chesapeake Bay watershed model (Chesapeake Bay Program 2017). The tool requires the user to specify a geographic area (such as a county), and then select BMPs to apply on that area, with options for urban, septic, forest, agriculture, animals, and manure transport. The estimated cost of BMPs is also provided by the tool, so users may select the most cost-effective practices to reduce pollutant loads. The user may alternatively provide their own estimated cost data. CAST builds the scenario and provides estimates of nitrogen, phosphorus, and sediment load reductions from all sectors and sources, acres of each BMP, and costs for the scenario. These loads are consistent with the Chesapeake Bay Program's Watershed Model. Users can create their own scenarios to develop an implementation strategy, calculate loading reductions and costs, or compare and modify existing scenarios to customize a watershed implementation analysis. CAST is free to the public and can be accessed at http://cast.chesapeakebay.net/.

A variation of this tool allows users to define the boundaries of a parcel and the land use areas within that parcel, called the Chesapeake Bay Facility Assessment Scenario Tool (BayFAST). (http://www.bayfast.org). The Maryland Scenario Assessment Tool (MAST) is the Maryland-specific version of CAST (http://www.mastonline.org). MAST has some Maryland-specific geographies available through the interface and also has loads available for historical years to assist with local TMDL watershed planning.

L-THIA. The Long Term Hydrologic Impact Analysis (L-THIA) model, developed by Purdue University, is a quick and accessible tool to estimate runoff, recharge, and nonpoint source (NPS) pollution resulting from past or proposed land use changes. L-THIA is available in three forms: L-THIA WWW, a spreadsheet version that models runoff and NPS pollution changes; ArcL-THIA, a set of Avenue scripts that automate the process of runoff impact modeling within ArcGIS (Park et al. 2013); and L-THIA GIS WWW, a form of L-THIA GIS that allows interactive mapping of an area of interest with a custom Java interface within a web browser (Lim et al 1999). L-THIA produces long-term average annual runoff, and associated nitrogen, phosphorus and suspended sediment loads (as well as bacteria and metals) for a given land use configuration based on long-term climate data for that area. Due to the use of long-term data, L-THIA focuses on average impact as opposed to a specific storm or an extreme year. Model inputs include location data, land use data, hydrologic soil groups, and land area. The model also produces graphical and tabular representations of output data to assist in the interpretation of results and to compare outputs from several runs to determine the best possible land use scenario. More information about L-THIA and L-THIA WWW can be found: https://engineering.purdue.edu/~lthia/. ArcL-THIA can be downloaded from: https://engineering.purdue.edu/mapserve/LTHIA7/arclthia/.

NCANAT. The North Carolina Nutrient Assessment Tool is a North Carolina-specific model that contains two agricultural field-scale tools, a Nitrogen Loss Estimation Worksheet (NLEW) and Phosphorus Loss Assessment Tool (PLAT). NCANAT was developed by North Carolina State University in collaboration with the North Carolina Department of Agriculture & Consumer Services, North Carolina Department of Environment and Natura Resources, and US Department of Agriculture (USDA) – Natural Resources Conservation Service (The N.C. PLAT Committee 2005). The agricultural nitrogen accounting tool, NLEW, uses a modified N-balance equation that accounts for nitrogen inputs and nitrogen reductions from nutrient management and BMPs. NLEW works at the field and county-level scales. PLAT is a mechanistic model that estimates potential loss of phosphorus from a field by considering particulate phosphorus, dissolved phosphorus, leachate phosphorus, and phosphorus source effects on phosphorus loss. The model allows you to run each tool independently or together. Inputs include crop and field information, BMP types, nutrient application rate, soil data, drainage information, and hydrologic conditions. The outputs are phosphorus indexed ratings for each of the four loss pathways expressed verbally and numerically, total phosphorus rating, and total nitrogen loss for the various BMP scenarios. To find more information and download the model, visit: http://nutrients.soil.ncsu.edu/software/ncanat/

Region 5 Model. Region 5 Model (MDEQ 1999) is an Excel workbook that provides a gross estimate of sediment and nutrient load reductions from the implementation of agricultural and urban BMPs. The algorithms for non-urban BMPs are based on the "Pollutants controlled: Calculation and documentation for Section 319 watersheds training manual". The algorithms for urban BMPs are based on the data and calculations developed by Illinois EPA. A recent version of the Region 5 Model estimates the flow volume captured and treated by urban stormwater controls (infiltration practices) and adds the functionality of estimating baseline load based on the annual rainfall and event mean concentration in the surface runoff. The Region 5 Model is available to the public at http://it.tetratech-ffx.com/steplweb.

SELDM. The Stochastic Empirical Loading and Dilution Model (SELDM), an update to the FHWA Pollutant Loading Model for Highway Stormwater Runoff, was developed jointly by USGS and Federal Highway Administration (FHWA) in 2013 (Granato 2013). The new model incorporates the existing model in a new software platform and calculates the risk of exceeding water quality criteria with and without defined BMPs. SELDM calculates annual runoff loads and can run simple annual lake-loading analyses. The model provides information on the probability distributions of the following: precipitation characteristics, highway runoff volumes, highway runoff concentrations, upstream flow, upstream receiving-water concentrations, and structural BMP performance. Through USGS, national data sets are available for users to choose the most representative data for their site to use in the model. The available data includes highway-runoff quality, precipitation, streamflow, runoff coefficients, and background water quality. The most recent version includes a different formula to calculate exceedance percentiles. More information is available on the USGS site: https://webdmamrl.er.usgs.gov/g1/ggranato/Software/seldm.html

Simple Method. The Simple Method (Schueler 1987) is an empirical approach developed for estimating pollutant export from urban and developing areas. It is used at the site-planning level to predict pollutant loadings under a variety of development scenarios. This method is best used for a development site, watershed or subwatershed and when data availability is limited, as it requires a modest amount of information. The inputs include: drainage area, pollutant concentrations, a runoff coefficient, which uses impervious cover data, and precipitation data. Pollutant concentrations of phosphorus, nitrogen, chemical oxygen demand, biochemical oxygen demand, and metals are calculated from flow-weighted concentration values for new suburban areas, older urban areas, central business districts, hardwood forests, and urban highways. The method relies on the National Urban Runoff Program (NURP) data for default values. Information on The Simple Method can be found at the following web locations. https://www.des.nh.gov/organization/divisions/water/stormwater/documents/wd-08-20a_ch8.pdf or https://www.hydrocad.net/pdf/NY-Simple-Method.pdf

STEPL. Spreadsheet Tool for Estimating Pollutant Load (STEPL) employs simple algorithms to calculate nutrient and sediment loads from different land uses and the load reductions that would result from the implementation of various BMPs (Tetra Tech 2011). STEPL provides a user-friendly Visual Basic (VB) interface to create a customized spreadsheet-based model in Microsoft Excel. It computes watershed surface runoff; nutrient loads, including nitrogen, phosphorus, and 5-day biological oxygen demand (BOD5); and sediment delivery based on various land uses and management practices.

For each watershed, the annual nutrient loading is calculated based on the runoff volume and the pollutant concentrations in the runoff water as influenced by factors such as the land use distribution and management practices. The annual sediment load (sheet and rill erosion only) is calculated based on the Universal Soil Loss Equation (USLE) and the sediment delivery ratio. The sediment and pollutant load reductions that result from the implementation of BMPs are computed using the known BMP efficiencies. The STEPL package is available to the public at http://it.tetratech-ffx.com/steplweb.

Mid-Range Models

AGNPS. Agricultural Non-Point Source Pollution Model (AGNPS) (Young 1989), developed by the USDA Agricultural Research Service (ARS), is designed to estimate loads from agricultural watersheds and to assess the relative effects of alternative management programs. The term "AGNPS" no longer refers to the single event AGNPS of the mid-1990's, but now refers to the system of modeling components. The model simulates surface water runoff along with nutrient (nitrogen, phosphorus, and organic carbon) and sediment constituents associated with agricultural nonpoint sources, as well as point sources such as feedlots, wastewater treatment plants, and streambank or gully erosion.

Several versions that integrate the model with geographic information system (GIS) and Windows-based graphical user interfaces are available. For instance, the Annualized AGNPS (AnnAGNPS) is a continuous-simulation, multi-event modification of the single-event model AGNPS, which can be used to estimate annualized loads and load reductions (Binger, Theurer and Yuan 2015). AnnAGNPS versions 5.0 and later incorporate enhanced features for many input and output options including ephemeral gullies, automated calibration for pollutants, actual or potential evapotranspiration climate files, and the ability to enter unlimited climate stations with any naming convention. AnnAGNPS also now has the capabilities of the revised universal soil loss equation (RUSLE), an erosion model that evaluates the degree of soil erosion caused by rainfall and associated overland flow and which is often used as a regulatory and conservation planning tool. Additionally, the capability of importing RUSLE2 databases into AnnAGNPS is now available. RUSLE2 is the advanced erosion model that extends the basic USLE structure but with a more user-friendly interface and that uses more physically meaningful input values that are widely available and easily obtained.

AnnAGNPS can now run more comprehensive evaluations of stream systems in regard to channel evolution, erosion, or in-stream structures with the integration of a channel network evolution model, CCHE1D, and a stream corridor model, CONCEPTS. The most recent version of AnnAGNPS also includes an updated output processer. For more information, visit https://www.nrcs.usda.gov/wps/portal/nrcs/detailfull/null/?cid=stelprdb1042468

APEX. The Agricultural Policy/Environmental eXtender (APEX) model (Gassman et al., 2010) was developed by the Blackland Research and Extension Center in Temple, Texas (http://epicapex.tamu.edu/apex/). The APEX model is a flexible and dynamic tool that can perform long-term simulations to addresses the impacts of management on environmental and production issues for whole farms and small watersheds. The modeling framework can evaluate a wide array of management strategies applied to crop, pasture, and grazing lands and estimates long-term sustainability of land management with respect to erosion due to water and wind, economics, water supply, water quality, soil quality, plant competition, weather and pests for crop land as well as grazing and pasture land. Management capabilities simulated include: irrigation; surface and subsurface drainage; furrow diking; buffer strips; terraces; waterways; windbreaks; fertilization and manure management, lagoons and water retention reservoirs, crop selection and rotation; fertilizer, nutrient and pesticide fate and application; grazing management; tillage timing and intensity; and harvest timing and methods. Furthermore, APEX can address strategic implications of global climate/CO_2 changes; confined animal feeding facilities, production systems for bioenergy; and other spin off applications.

APEX's unique feature is the ability to subdivide farms or fields by soil type, landscape position, surface hydrology or management configuration represent crop diversity and landscape characteristics within a field or farm. Each subarea may be linked with each other according to the water routing direction in the farm or watershed, starting from the most distant subarea towards the watershed outlet. Several APEX interfaces and tools have been developed to support the development of APEX application such as i_APEX, ArcGIS APEX, WinAPEX-GIS, and SWAT-APEX. A brief description of these tools can be found in Gassman et al., 2010. The APEX model can be downloaded from http://epicapex.tamu.edu/model-executables/.

EPIC. The Erosion Productivity Impact Calculator (EPIC) is a field-scale continuous simulation model that assesses the effects of soil erosion on agricultural productivity and water quality (Sharpley and Williams 1990). It can predict the effects of management decisions on soil, water, nutrient, and pesticide movements and their combined impacts on soil loss, water quality, and crop yields for areas of homogeneous soils and management. The model includes two options of estimating the peak runoff rate – the modified rational formula and the SCS TR-55 method. The EPIC wind erosion model, WECS (Wind Erosion Continuous Simulation), is used to calculate wind characteristics, including erosion due to wind. The model simulates several contamination processes including denitrification, mineralization, nitrate losses, organic nitrogen transport, nitrification, soluble phosphorus loss in surface runoff, and mineral phosphorus cycling. All forms of phosphorus can be differentiated within the model. EPIC has been improved over the years through additions of algorithms to simulate water quality, nitrogen and carbon cycling, climate change, and the effects of atmospheric carbon dioxide. The model can be configured for a wide range of crop rotations and other vegetative systems, tillage systems, and other management practices. The model can also assess the cost of erosion for determining optimal management strategies. A copy of EPIC can be obtained from http://epicapex.tamu.edu/model-executables/.

GWLF. The Generalized Watershed Loading Functions (GWLF) model was developed at Cornell University to assess the point and nonpoint loadings of nitrogen and phosphorus from a relatively large, agricultural and urban watershed and evaluate the effectiveness of certain land use management practices (Haith and Shoemaker. 1997). One advantage of this model is that it was written with the express purpose of requiring no calibration, making extensive use of default parameters. The GWLF model includes rainfall/runoff and erosion and sediment generation components, total and dissolved nitrogen and phosphorus loadings, and septic system loads and point source discharge data. The simulation results can be used to identify and rank pollution sources and evaluate basin-wide management programs and land use changes. The model also includes several reporting and graphical representations of simulation output to aid in interpretation of the results. For more information, download the document from this link http://cwam.ucdavis.edu/pdfs/GWLF.pdf.

Versions that integrate the model with GIS and Windows-based graphical user interfaces are available. BasinSIM 1.0 is a model that was developed at the Virginia Institute of Marine Science, College of William and Mary (http://web.vims.edu/bio/vimsida/bsabout.html), which predicts sediment and nutrient loads for small to mid-sized watersheds using the GWLF, a graphic Windows interface, and extensive databases. An in-stream routing and sediment transport component in BasinSIM 1.0 employs the algorithms in AnnAGNPS to simulate sediment transport.

MapShed. Pennsylvania State University developed a GIS-based tool that incorporates GWLF and enhances the functionality using a free GIS software package called MapWindow (Evans and Corradini 2016). MapShed replaces AVGWLF, which used proprietary ArcView software. Moving the tool to a free GIS platform makes it more accessible to a larger number of users. MapShed has enhanced capabilities, such as improved simulation of pollutant transport processes in urban settings, improved assessment of the effects of BMPs on pollutant load reduction, and the inclusion of streambank erosion, agricultural tile drainage routines. The tool automatically derives values for the required model input parameters for the watershed model. Through the interface the user can also access regional climate data to create weather data for a given watershed simulation. The latest version of MapShed includes more direct simulation of loads from farm animals and a new pathogen load estimation. MapShed also includes the GWLF-e model, which uses the algorithms previously included in PRedICT to evaluate the implementation of both rural and urban pollution reduction strategies at the watershed level. GWLF-e compares point and nonpoint pollution loads between scenarios of current and "future" conditions. Future scenarios could include different pollution reduction strategies, stream protection activities, septic system conversions to centralized wastewater treatment, and treatment plant upgrades. For more information, visit http://www.mapshed.psu.edu/index.htm.

MapShed is scheduled to be phased out by late 2018 and replaced by a web-based platform called Model My Watershed, which is a component of a larger application called Wikiwatershed. More information on these tools can be found at wikiwatershed.org.

NTT. The Nutrient Tracking Tool is a farm-scale tool developed by the Texas Institute of Applied Environmental Research (TIAER) at Tarleton State University in collaboration with USDA-NRCS (Saleh et al., 2011 and 2015). NTT is a user-friendly web-based platform to access the underlying APEX (Agricultural Policy Environmental eXtender) tool, which is a process-based model that uses soil, weather and management information to estimate on farm losses of sediment, nitrogen and phosphorus, through leaching and runoff, and to predict yields on cropland and pasture. APEX is described in more detail elsewhere within this document. NTT was designed to be accessible to the typical farmer and features a user-friendly interface and simplified inputs. The NTT interface allows users to delineate their field(s) using an interactive map for any location in the mainland U.S. and Puerto Rico. The interactive map captures the soils, slope, and weather specific to the selected area. The user can enter field management characteristics, including crop schedule, planting and harvesting dates, grazing operations, fertilizer/manure operations and tillage operations. The user may also indicate one or more conservation practices present on the field, including tile drains, irrigation, buffers, etc. In addition, there are many conservation practices that are represented as part of the field management information entered by the user, e.g. tillage, nutrient management and cover crops. NTT allows the user to enter multiple management scenarios for any field and compare losses between the baseline and conservation management scenarios. Users may choose to run fields individually, or simulate routing by linking the fields. The estimated losses are the result of a 30+ year simulation over historic weather and thus represent the average annual losses for the field given the crop rotation and management practices. Simulation results can be viewed as monthly averages or annual averages. The model can be accessed at http://nn.tarleton.edu/NTT/.

WARMF. The Watershed Analysis Risk Management Framework was developed by Systech Water Resources to support a watershed approach to simulating hydrologic, physical, chemical and biological processes to help users understand their watershed (Systech Engineering 2001). The model has a graphic user interface making it user-friendly. Land uses are represented at the catchment scale and multiple land uses, including urban and agricultural types, can be represented as a percentage of each catchment; point and non-point sources are represented spatially; and the user defines the routing through the watershed. Watershed physical processes can be simulated on a one minute up to a daily time step. Water volume and approximately 40 water quality parameters, including pH, metals, pesticides, nutrients, turbidity, algae, bacteria and mercury bioaccumulation, are simulated. WARMF can represent land use, river segments, canopy, bed sediment, and up to five soil layers. CE-QUAL-W2 was added to WARMF to include 2D reservoir modeling. The TMDL module allows users to define target criteria and WARMF to calculate the point and non-point source loading reductions and whether criteria are met. Multiple allocation scenarios can be run and displayed in the Consensus module, which presents the modeled data in a format suitable for technical and non-technical stakeholders. More information and a copy of the WARMF can be obtained at http://systechwater.com/warmf_software/.

Lowrance, R., L.S. Altier, R.G. Williams, S.P. Inamdar, J.M. Sheridan, D.D. Bosch, R.K. Hubbard, and D.L. Thomas. 2000. REMM: The Riparian Ecosystem Management Model. *Journal of Soil and Water Conservation*. 55(1):27-34.

Ma, L., L.R. Ahuja, B.T. Nolan, R.W. Malone, T.J. Trout and Z. Qi. 2012. Root zone water quality model (RZWQM2): model use, calibration, and validation. *Transactions of the ASABE*. 55(4): 1425-1446.

MDEQ (Michigan Department of Environmental Quality). 1999. Pollutants Controlled Calculation and *Documentation for Section 319 Watersheds Training Manual*. Lansing, MI.

Neitsch, S.L., J.G. Arnold, J.R. Kiniry, J.R. Williams. 2011. *Soil and Water Assessment Tool Theoretical Documentation Version 2009*. Texas Water Resources Institute Technical Report No. 406. Texas A&M University System, College Station, TX.

Park, Y.S., K.J. Lim, L. Theller, and B.A. Engel. 2013. *L-THIA GIS Manual*. Department of Agricultural and Biological Engineering, Purdue University.

Rossman, L.A. 2015. *Storm Water Management Model User's Manual Version 5.1*. U.S. Environmental Protection Agency, Office of Research and Development, National Risk Management Laboratory. Cincinnati, OH.

Saleh, A. O. Gallego, and E. Osei. 2015. Evaluating Nutrient Tracking Tool and Simulated Conservation Practices. *Journal of Soil and Water Conservation*. 70(5):115A-120A.

Saleh, A., O. Gallego, E. Osei, H. Lal, C. Gross, S. McKinney, and H. Cover. 2011. Nutrient Tracking Tool –a user-friendly tool for calculating nutrient reductions for water quality trading. *Journal of Soil and Water Conservation*. 66(6):400-410.

Schueler, T. 1987. *Controlling Urban Runoff: A Practical Manual for Planning and Designing Urban BMPs*. Metropolitan Washington Council of Governments. Washington, DC.

Sharpley, A.N. and J.R. Williams, eds. 1990. *EPIC- Erosion/Productivity Impact Calculator: 1 Model Documentation*. U.S. Department of Agriculture Technical Bulletin No. 1768. Agricultural Research Service.

Shoemaker, L., J. Riverson, K. Alvi, J. X. Zhen, R. Murphy, B. Wood. 2013. *Stormwater Management for TMDLs in an Arid Climate: A Case Study Application of SUSTAIN in Albuquerque, New Mexico*. EPA/600/R-13/004. U.S. Environmental Protection Agency, Water Supply and Water Resources Division, National Risk Management Research Laboratory, Cincinnati, OH.

Shoemaker, L., J. Riverson, K. Alvi, J. X. Zhen, and R. Murphy. 2012. *Report on Enhanced Framework (SUSTAIN) and Field Applications to Placement of BMPs in Urban Watersheds*. EPA/600/R-11/144. U.S. Environmental Protection Agency, Washington, DC.

Shoemaker, L., J. Riverson, K. Alvi, J. X. Zhen, S. Paul, and T. Rafi. 2009. *SUSTAIN—A Framework for Placement of Best Management Practices in Urban Watersheds to Protect Water Quality*. EPA/600/R-09/095. U.S. Environmental Protection Agency, Washington, DC.

Skaggs, R. W. 1980. *A Water Management Model for Artificially Drained Soils*. Tech. Bulletin No. 267. Raleigh, N.C.: North Carolina State University, North Carolina Agricultural Research Service.

Smith, R.A., G.E. Schwarz, and R.B. Alexander. 1997. Regional interpretation of water quality monitoring data. *Water Resources Research*. 33(12):2781-2798.

Systech Engineering. 2001. *Watershed Analysis Risk Management Framework: Update One: A Decision Support System for Watershed Analysis and Total Maximum Daily Load Calculation, Allocation and Implementation*. Prepared for EPRI, Palo Alto, CA. Prepared by Systech Engineering, San Ramon, CA.

Tetra Tech, Inc. 2009. *Loading Simulation Program in C++ (LSPC) Version 3.1 User's Manual*. Fairfax, VA.

Tetra Tech, Inc. 2010. *Stormwater Best Management Practices (BMP) Performance Analysis*. Prepared for: U.S. EPA Region 1, Boston, MA. Prepared by: Tetra Tech, Inc. Fairfax, VA.

Tetra Tech, Inc. 2011. *User's Guide Spreadsheet Tool for the Estimation of Pollutant Load (STEPL) Version 4.1*. Prepared for U.S. Environmental Protection Agency, Washington, DC. Prepared by Tetra Tech, Inc. Fairfax, VA.

Tetra Tech, Inc. 2016. *Opti-Tool for Stormwater and Nutrient Management User's Guide*. Prepared for U.S. Environmental Protection Agency, Region 1. Boston, MA. Prepared by Tetra Tech, Inc., Fairfax, VA.

The N.C. PLAT Committee. 2005. *North Carolina Phosphorus Loss Assessment: I. Model Description and II. Scientific Basis and Supporting Literature*. North Carolina Agricultural Research Service Technical Bulletin 323. North Carolina State University, Raleigh, NC.

USDA Agricultural Research Service (ARS). RZWQM – Root Zone Water Quality Model website. http://www.ars.usda.gov/Main/docs.htm?docid=17740. Last accessed June 02, 2017.

USDA ARS National Soil Erosion Research Laboratory. 1995. *Technical Documentation USDA-Water Erosion Prediction Project (WEPP)*. West Lafayette, IN.

USDA ARS Southwest Watershed Research Center, USEPA Office of Research and Development and University of Wyoming Rangeland Ecology and Watershed Management. N.D. Automated Geospatial Watershed Assessment (AGWA) 3.X User Guide.

Walker, W.W. and J.D. Walker. 2015. *P8 Urban Catchment Model Version 3.5*. Concord, MA.

White, M. and D. Harmel. 2012. *Texas BMP Evaluation Tool (TBET) Users Guide Version 0.2*. U.S. Department of Agriculture Grassland Soil and Water Research Laboratory. Temple, TX.

Woolhiser, D.A., R.E. Smith, and D.C. Goodrich. 1990. *KINEROS, A Kinematic Runoff and Erosion Model: Documentation and User Manual*. U.S. Department of Agriculture, Agricultural Research Service, ARS-77, 130pp.

Young, R.A., C.A. Onstad, D.D. Bosch, and W.P. Anderson. 1989. AGNPS: A nonpoint-source pollution model for evaluating agricultural watersheds. *Journal of Soil and Water Conservation*. Vol 44 (2) 168-173.