

APPENDIX D. TMDL Methodology used in Pennsylvania

**STRATEGY FOR CONDUCTING NONPOINT SOURCE-RELATED
TMDL ASSESSMENTS WITHIN PENNSYLVANIA**

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Background

Nationwide recognition of the importance of non-point sources of pollution has led to increased efforts over the last two decades to identify and quantify non-point source pollutant loads, especially at the watershed level. Typical techniques for determining the extent and magnitude of non-point source pollution problems include long-term surface water monitoring and computer-based simulation modeling. Due to the time and expense associated with surface water monitoring, however, simulation modeling has been relied upon more frequently to provide needed information for the development and implementation of non-point source control programs (Novotny and Olem, 1994). Watershed simulation models, in fact, are commonly considered to be essential tools for evaluating the sources and controls of sediment and nutrient loading to surface waters. Such models provide a framework for integrating the data that describe the processes and land-surface characteristics that determine pollutant loads transported to nearby water bodies.

The utilization of watershed models, however, is a difficult, tedious task because of the broad spatial and temporal scales that must be considered, as well as the large amount of data that must be compiled, integrated, analyzed, and interpreted. Fortunately, the last two decades of model development have coincided with rapid advancements in the development and use of geographic information system (GIS) technology. This technology provides the means for compiling, organizing, manipulating, analyzing, and presenting spatially-referenced model input and output data. Due to the many inherent benefits, GIS software has been used to support literally hundreds of watershed modeling efforts over the last 10-15 years. Many state, regional, and federal environmental agencies, in fact, use this technology routinely to support ongoing watershed modeling and assessment programs (Samuels, 1998).

Over the last decade, the Pennsylvania Department of Environmental Protection (DEP) has recognized the indispensibility of GIS technology, and has endeavored to integrate it into all of the agency's internal program areas. Towards this end, researchers at Penn State's Environmental Resources Research Institute (ERRI) have been assisting DEP in the development and implementation of various GIS-based watershed assessment tools. One such tool facilitates the use of the GWLF (Generalized Watershed Loading Function) model developed by Haith and Shoemaker (1987) via a GIS software interface. As described below, this GIS-based modeling approach will be a key component in DEP's TMDL program.

The GWLF Model

The GWLF model provides the ability to simulate runoff, sediment, and nutrient (N and P) loadings from a watershed given variable-size source areas (e.g., agricultural, forested, and developed land). It also has algorithms for calculating septic system loads, and allows for the inclusion of point source discharge data. It is a continuous simulation model which uses daily time steps for weather data and water balance calculations. Monthly calculations are made for sediment and nutrient loads, based on the daily water balance accumulated to monthly values.

GWLF is considered to be a combined distributed/lumped parameter watershed model. For surface loading, it is distributed in the sense that it allows multiple land use/cover scenarios, but each area is assumed to be homogenous in regard to various attributes considered by the model.

Additionally, the model does not spatially distribute the source areas, but simply aggregates the loads from each area into a watershed total; in other words there is no spatial routing. For sub-surface loading, the model acts as a lumped parameter model using a water balance approach. No distinctly separate areas are considered for sub-surface flow contributions. Daily water balances are computed for an unsaturated zone as well as a saturated sub-surface zone, where infiltration is simply computed as the difference between precipitation and snowmelt minus surface runoff plus evapotranspiration.

With respect to the major processes simulated, GWLF models surface runoff using the SCS-CN approach with daily weather (temperature and precipitation) inputs. Erosion and sediment yield are estimated using monthly erosion calculations based on the USLE algorithm (with monthly rainfall-runoff coefficients) and a monthly composite of KLSCP values for each source area (e.g., land cover/soil type combination). A sediment delivery ratio based on watershed size and a transport capacity based on average daily runoff are then applied to the calculated erosion to determine sediment yield for each source area. Surface nutrient losses are determined by applying dissolved N and P coefficients to surface runoff and a sediment coefficient to the yield portion for each agricultural source area. Point source discharges can also contribute to dissolved losses and are specified in terms of kilograms per month. Manured areas, as well as septic systems, can also be considered. Urban nutrient inputs are all assumed to be solid-phase, and the model uses an exponential accumulation and washoff function for these loadings. Sub-surface losses are calculated using dissolved N and P coefficients for shallow groundwater contributions to stream nutrient loads, and the sub-surface sub-model only considers a single, lumped-parameter contributing area. Evapotranspiration is determined using daily weather data and a cover factor dependent upon land use/cover type. Finally, a water balance is performed daily using supplied or computed precipitation, snowmelt, initial unsaturated zone storage, maximum available zone storage, and evapotranspiration values.

For execution, the model requires three separate input files containing transport-, nutrient-, and weather-related data. The transport (TRANSPRT.DAT) file defines the necessary parameters for each source area to be considered (e.g., area size, curve number, etc.) as well as global parameters (e.g., initial storage, sediment delivery ratio, etc.) that apply to all source areas. The nutrient (NUTRIENT.DAT) file specifies the various loading parameters for the different source areas identified (e.g., number of septic systems, urban source area accumulation rates, manure concentrations, etc.). The weather (WEATHER.DAT) file contains daily average temperature and total precipitation values for each year simulated.

GIS-Based Derivation of Input Data for GWLF

As described previously, the use of GIS software for deriving input data for watershed simulation models such as GWLF is becoming fairly standard practice due to the inherent advantages of using GIS for manipulating spatial data. To support watershed assessment projects, a customized interface for the ArcView GIS package was developed by Penn State for use in parameterizing input data for the GWLF model. In utilizing this interface, the user is prompted to identify required GIS files and to provide other information related to “non-spatial” model parameters (e.g., beginning and end of the growing season, the months during which manure is spread on agricultural land, and the names of nearby weather stations). This information is subsequently used to automatically derive

values for required model input parameters which are then written to the TRANSPRT.DAT, NUTRIENT.DAT and WEATHER.DAT input files needed to execute the GWLF model. For use in Pennsylvania, this ArcView-GWLF system (called AVGWLF) has been linked with statewide GIS data layers such as land use/cover, soils, topography, and physiography; and includes location-specific default information such as background N and P concentrations and cropping practices. Complete GWLF-formatted weather files are also included for seventy-eight weather stations around the state. A summary of the sources used to derive the input data is given in Table 1.

Table 1. Information sources for GWLF model parameterization.

<p>WEATHER.DAT file</p>	<p>Historical weather data from National Weather Service monitoring stations</p>
<p>TRANSPORT.DAT file</p> <p>Basin size Land use/cover distribution Curve numbers by source area USLE (KLSCP) factors by source area ET cover coefficients Erosivity coefficients Daylight hrs. by month Growing season months Initial saturated storage Initial unsaturated storage Recession coefficient Seepage coefficient Initial snow amount (cm water) Sediment delivery ratio Soil water (available water capacity)</p>	<p>GIS/derived from basin boundaries GIS/derived from land use/cover map GIS/derived from land cover and soil maps GIS/derived from soil, DEM, and land cover GIS/derived from land cover GIS/ derived from physiography map Computed automatically for state Input by user Default value of 10 cm (GWLF Manual) Default value of 0 cm (GWLF Manual) Default value of .1 (GWLF Manual) Default value of 0 (GWLF Manual) Default value of 0 (GWLF Manual) GIS/based on basin size GIS/derived from soil map</p>
<p>NUTRIENT.DAT file</p> <p>Dissolved N in runoff by land cover type Dissolved P in runoff by land cover type N/P concentrations in manure runoff N/P buildup in urban areas N and P point source loads Background N/P concentrations in GW Background N/P concentrations in soil Months of manure spreading Population on septic systems Per capita septic system loads (N/P)</p>	<p>Default values (GWLF Manual) Default values (GWLF Manual) Default values (GWLF Manual) Statewide atmospheric deposition layer GIS/derived from NPDES point coverage GIS layer derived from USGS sample data GIS layer derived from soil test data Input by user GIS/derived from census tract map Default values (GWLF Manual)</p>

A new module for “BMP Analysis” is presently being developed for AVGWLF. When completed, this module will provide the capability to conduct “what if” analyses for the purpose of determining the potential effects that various best management practices (BMPs) might have on nutrient and sediment loads produced within a given watershed. More specifically, the user will be able to select from a list of possible BMPs and to identify critical source areas within a watershed to which such BMPs would be applied. Subsequent to making selections for one or more “scenarios”, the GWLF-simulated loads are then re-calculated using “efficiency” coefficients associated with each BMP type. The capability to view the results for each scenario, and to compare them against the original model results, will also be provided. (Note: This new module will probably not be available until early 2003).

General Approach to TMDL Analyses

As mentioned earlier, the GIS-based modeling approach described above (i.e., AVGWLF) will be used to perform nonpoint source-related TMDL analyses in Pennsylvania. The general sequence of steps will be as follows:

- AVGWLF will be used to derive input data for GWLF, which will sub-sequently be used to simulate nutrient and sediment loads within the “impacted” watershed.
- The pollutant loads simulated will be compared to those calculated (using GWLF) for a nearby “reference” watershed that exhibits similar landscape, development and agricultural patterns, but which also meets selected stream quality criteria.
- If needed, adjustments will be made to parameter values in either or both watersheds to better reflect conditions observed in the field.
- Using an Excel-based program, load reduction factors will be calculated for the impaired watershed to match similar loads calculated within the reference watershed. This process is called “load allocation”. (A more in-depth description of this process is included in the AVGWLF Users Guide).
- A report will be prepared which contains a description of the watershed, results of the modeling conducted (along with the appropriate tables), and the results from the load allocation process.

As an aid in conducting this type of analysis, Table 2 gives reasonable values to use for N and P concentration in runoff over agricultural and manured areas based on animal density, and Table 3 gives reasonable values for background P concentrations in soil based on existing fertilizer application rates. These values are actually calculated automatically by AVGWLF based on various input layers, but there may be some need to revise these values based on better local information. Table 4 has suggested reduction coefficients for some selected BMP strategies to reduce nonpoint source nutrient loads. A more in-depth look at BMP strategies and reduction efficiencies is provided in the following section.

Table 2. Suggested N and P Values (mg/l) Based on Animal Density

GWLF Parameter	Animal Equivalent Units		
	≤ 1.5	1.5 – 2.5	≥ 2.5
N in agricultural areas	1.9	2.9	4.4
N in runoff from manured areas	8.1	12.2	18.3
P in agricultural areas	0.1	0.2	0.3
P in runoff from manured areas	0.2	0.4	0.6

Table 3. Suggested P Values (mg/kg) Based on Fertilizer Loading

GWLF Load (mg/kg)	Pounds Per Acre
500	40 – 60
700	60 – 80
900	80 – 100
1100	100 – 120
1300	120 – 140
1500	140 – 160
1700	160 – 180
2000	>180

Table 4. Nutrient Reduction Coefficients for Various BMP Strategies

BMP	Reduction Factor (%)		
	<i>N</i>	<i>P</i>	<i>Sediment</i>
Conventional to conservation tillage	4	8	8
Incorporation of hayland in crop rotation	4	8	8
Incorporation of pasture in crop rotation	20	14	14
Streambank stabilization and fencing	75 ¹	75 ¹	75
Nutrient management plan	75 ²	75 ²	75

¹ Only applies to surface component of nutrient loads

² Reduction factor should only be used for either N or P, not both

References

Haith, D.A. and L.L. Shoemaker, 1987. Generalized Watershed Loading Functions for Stream Flow Nutrients. *Water Resources Bulletin*, 23(3), pp. 471-478.

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Samuels, W., 1998. Case Studies: Solving Watershed-Based Problems Through the Use of GIS, Internet and EPA National Data Bases. In: *Watershed Management: Moving from Theory to Implementation*, Water Environment Federation, Denver, CO, pp. 1175-1182.