Appendix C: Model Development for Bokes Creek

The Watershed Loading Model[1]

Introduction

This section describes the methods used in the loading analysis of phosphorus in the Bokes Creek TMDL. It is intended to be used as a supplement to the TMDL report and relies on the report to provide a description of the study area, project objectives and results. The purpose of this section is to document the steps and decisions made in the modeling process.

Model Structure and Approach

Loading of water, sediment, and nutrients in the Bokes Creek watershed was simulated using the Generalized Watershed Loading Function or GWLF model (Haith et al., 1992). The complexity of the loading function model falls between that of detailed, process-based simulation models and simple export coefficient models which do not represent temporal variability. GWLF provides a mechanistic, but simplified simulation of precipitation-driven runoff and sediment delivery, yet is intended to be applicable without calibration. Solids load, runoff, and ground water seepage can then be used to estimate particulate and dissolved-phase pollutant delivery to a stream, based on pollutant concentrations in soil, runoff, and ground water.

GWLF simulates runoff and streamflow by a water-balance method, based on measurements of daily precipitation and average temperature. Precipitation is partitioned into direct runoff and infiltration using a form of the Natural Resources Conservation Service's (NRCS) Curve Number method (SCS, 1986). The Curve Number determines the amount of precipitation that runs off directly, adjusted for antecedent soil moisture based on total precipitation in the preceding 5 days. A separate Curve Number is specified for each land use by hydrologic soil grouping. Infiltrated water is first assigned to unsaturated zone storage where it may be lost through evapotranspiration. When storage in the unsaturated zone exceeds soil water capacity, the excess percolates to the shallow saturated zone. This zone is treated as a linear reservoir that discharges to the stream or loses moisture to deep seepage, at a rate described by the product of the zone's moisture storage and a constant rate coefficient.

Flow in streams may derive from surface runoff during precipitation events or from ground water pathways. The amount of water available to the shallow ground water zone is strongly affected by evapotranspiration, which GWLF estimates from available moisture in the unsaturated zone, potential

[1] Much of the Part 2 verbiage provided by Tetra Tech, Inc. (Tetra Tech, 2000)

evapotranspiration, and a cover coefficient. Potential evapotranspiration is estimated from a relationship to mean daily temperature and the number of daylight hours.

The user of the GWLF model must divide land uses into “rural” and “urban” categories, which determines how the model calculates loading of sediment and nutrients. For the purposes of modeling, “rural” land uses are those with predominantly pervious surfaces, while “urban” land uses are those with predominantly impervious surfaces. It is often appropriate to divide certain land uses into pervious (“rural”) and impervious (“urban”) fractions for simulation. Monthly sediment delivery from each “rural” land use is computed from erosion and the transport capacity of runoff, whereas total erosion is based on the universal soil loss equation (USLE) (Wischmeier and Smith, 1978), with a modified rainfall erosivity coefficient that accounts for the precipitation energy available to detach soil particles (Haith and Merrill, 1987). Thus, erosion can occur when there is precipitation, but no surface runoff to the stream; delivery of sediment, however, depends on surface runoff volume. Sediment available for delivery is accumulated over a year, although excess sediment supply is not assumed to carry over from one year to the next. Nutrient loads from rural land uses may be dissolved (in runoff) or solid-phase (attached to sediment loading as calculated by the USLE).

For “urban” land uses, soil erosion is not calculated, and delivery of nutrients to the water bodies is based on an exponential accumulation and washoff formulation. All nutrients loaded from urban land uses are assumed to move in association with solids.

GWLF Model Inputs

GWLF application requires information on land use, land cover, soil, and parameters that govern runoff, erosion, and nutrient load generation.

Land Use/Land Cover

Digital land use/land cover (LULC) data for the Bokes Creek watershed were obtained from the National Land Cover Dataset (NLCD). The NLCD is a consistent representation of land cover for the conterminous United States generated from classified 30-meter resolution Landsat thematic mapper (TM) satellite imagery data. The NLCD is classified into urban, agricultural, forested, water, and transitional land cover subclasses. The imagery was acquired by the Multi-Resolution Land Characterization (MRLC) Consortium, a partnership of federal agencies that produce or use land cover data. The Landsat imagery for the Bokes Creek basin dates from 1990 to 1993. Table C1 summarizes the acreage in each land use category in the Bokes Creek watershed.

Table C1. Land uses in Bokes Creek watershed, 1990-1993 (MRLC data).

Land Use	Acres	% of Total
Row Crops	43148	81.0%
Pasture/Hay	6167	11.6%
Deciduous Forest	3450	6.5%
Evergreen Forest	7.6	0.01%
Mixed Forest	0.2	0.0004%
Woody Wetlands	156	0.29%
Emergent Herbaceous Wetlands	32.2	0.06%
Open Water	70.6	0.13%
Low Intensity Residential	168	0.32%
High Intensity Residential	15.1	0.03%
Commercial/Industrial/Transportation	36.1	0.07%
Total:	**53250.8**	**100%**

Soil data for the Bokes Creek watershed were obtained from the ODNR GIMS web site (http://www.dnr.state.oh.us/gims). Attribute data associated with soil map units were used to assign soil hydrologic groups and to estimate values for some of the USLE parameters, as described in sections below.

The Bokes Creek watershed was divided up into three sub-basins to reflect the differences in measured concentrations between the Bokes Creek main stem and Powderlick Run. Subwatershed 1 covers the headwaters of Bokes Creek to Powderlick Run. Subwatershed 2 is Powderlick Run, and subwatershed 3 is Bokes Creek from its Powderlick Run confluence to the Scioto River. The subwatersheds, land uses, census information, and the soils coverages were overlain in a Geographic Information System (GIS) environment. For the purposes of the GWLF modeling of runoff and erosion, the land use categories were assigned to a rural or an urban category as shown in Table C2. Runoff and erosion potential are expected to be affected both by land use and by the soil hydrologic group, so each land use group was divided into sub-categories based on the hydrologic group (A, B, C or D) of the underlying soil type. (Dual soil hydrologic groups were assumed drained.)

Table C2. Land Use Groupings for GWLF Modeling

NLCD Land Use	Pollutant Simulation
Row Crops	Rural
Pasture/Hay	Rural
Deciduous Forest	Rural
Evergreen Forest	Rural
Mixed Forest	Rural
Woody Wetlands	Rural
Emergent Herbaceous Wetlands	Rural
Open Water	—
Low Intensity Residential	Urban
High Intensity Residential	Urban
Commercial/Industrial/Transportation	Urban

Rainfall and Runoff
Meteorology:
Hydrology in GWLF is simulated by a water-balance calculation, based on daily observations of precipitation and temperature. A search was made of available Midwestern Regional Climate Center reporting stations. Online daily precipitation and temperature data were found for the stations at Marysville and Delaware.

Table C3. Weather stations used in the Bokes Creek GWLF model

Station #	Station Name	Latitude	Longitude
334979	Marysville	40°14'	83°22'
332124	Delaware Lake	40°22'	83°04'

The model was run using the Marysville data, with Delaware Lake records used to fill in any missing gaps. Average monthly precipitation for the 1990 to 2000 time period is summarized in Table C4. Figure C1 shows the variability in monthly precipitation over the period. The weather data is organized by climatic year (April 1 to March 31 of the following year).

Table C4. Bokes Creek Average Monthly Precipitation for April 1990 to March 2000

Month	Average Total Precipitation (inches)
January	3.0
February	1.7
March	2.4
April	3.7
May	3.9
June	4.5
July	5.0
August	2.8
September	2.1
October	2.2
November	2.7
December	2.9

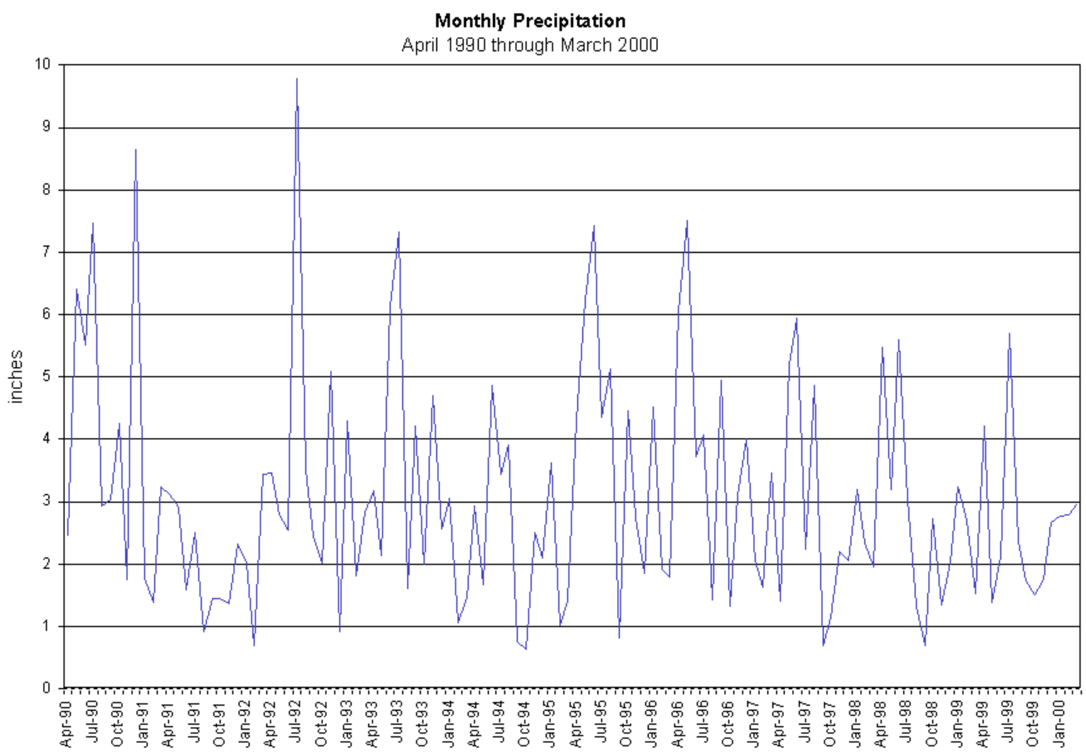

Figure C1. Bokes Creek Area Monthly Total Precipitation, April 1990 to March 2000.

Evapotranspiration Cover Coefficients:
The portion of rainfall returned to the atmosphere is determined by GWLF based on temperature and the amount of vegetative cover. For urban land uses, the cover coefficient was calculated as (1 - impervious fraction). For row crops and pasture/hay, the monthly ET was based on crop acreages from the 2000 tillage transect survey, and values recommended in the GWLF manual for each crop type. For all other land uses it was assumed that land had vegetative cover during the growing season (cover coefficient = 1), and limited vegetative cover during the dormant season (cover coefficients ranging from 0.3 to 1 depending on land use). Monthly area-weighted cover coefficients were calculated for each of the three subwatersheds.

Soil Water Capacity:
Water stored in soil may evaporate, be transpired by plants, or percolate to ground water below the rooting zone. The amount of water that can be stored in soil (the soil water capacity) varies by soil type and rooting depth. Based on the GWLF user's manual recommendations, the GWLF default soil water capacity of 10 cm was used.

Recession and Seepage Coefficients:
The GWLF model has three subsurface zones: a shallow unsaturated zone, a shallow saturated zone, and a deep aquifer zone. Behavior of the second two stores is controlled by a ground water recession and a deep seepage coefficient. The recession coefficient was set to 0.18 per day and the deep seepage coefficient to 0.02, based on several calibration runs of the model.

Runoff Curve Numbers:
The direct runoff fraction of precipitation in GWLF is calculated using the curve number method from the SCS TR55 method literature based on land-use and soil hydrologic group (SCS, 1986). Curve numbers vary from 25 for undisturbed woodland with good soils, to, in theory, 100, for impervious surfaces. The hydrologic soil group was determined from available soils data and curve numbers were calculated for each land use category/soil hydrologic group. The KLSCP (see next section) and curve numbers calculated for the Bokes Creek watershed are summarized in Table C5. These numbers represent the weighted average per soil type and land use area. For each land use, the table also indicates whether GWLF simulates nutrient loading via the USLE equation ("rural" areas) or a buildup-washoff formulation ("urban" areas).

Table C5. Runoff Curve Numbers for Bokes Creek Subwatersheds.

Land Cover	**KLSCP** (weighted average)*	**Curve Number** (weighted average)*	**Methodology**
Row Crops	0.012 - 0.017	82 - 83	USLE
Pasture/Hay	0.00035 - 0.00049	77 - 79	USLE
Deciduous Forest	0.000083 - 0.00013	69 - 71	USLE
Evergreen Forest	0.00012 - 0.0002	72 - 73	USLE
Mixed Forest	0.00004	70	USLE
Woody Wetlands	0.00054 - 0.00069	100	USLE
Emergent Herbaceous Wetlands	0.00029 - 0.00037	100	USLE
Open Water	0.0000	100	USLE
Low Intensity Residential	—	79 - 82	Buildup-Washoff
High Intensity Residential	—	90 - 91	Buildup-Washoff
Commercial/Industrial/Transportation	—	93 - 94	Buildup-Washoff

* Weighted averages based on soil type and area of land use.

Erosion
GWLF simulates rural soil erosion using the Universal Soil Loss Equation (USLE). [Note: For land uses indicated as "Buildup-Washoff" in Table 5, solids loads are generated separately, as described below in the section entitled Parameters Governing Nutrient Load Generation.] This method has been applied extensively, so parameter values are well established. This computes soil loss per unit area (sheet and rill erosion) at the field scale by

$$A = RE * K * LS * C * P$$

where
- A = rate of soil loss per unit area,
- RE = rainfall erosivity index,
- K = soil erodibility factor,
- LS = length-slope factor,
- C = cover and management factor, and
- P = support practice factor.

Soil loss or erosion at the field scale is not equivalent to sediment yield, as substantial trapping may occur, particularly during overland flow or in first-order tributaries or impoundments. GWLF accounts for sediment yield by (1) computing transport capacity of overland flow, and (2) employing a sediment delivery ratio (SDR) which accounts for losses to sediment redeposition.

Rainfall Erosivity (RE):
Rainfall erosivity accounts for the impact of rainfall on the ground surface, which can make soil more susceptible to erosion and subsequent transport. Precipitation-induced erosion varies with rainfall intensity, which shows different average characteristics according to geographic region. The factor is used in the Universal Soil Loss Equation and is determined in the model as follows:

$$RE_t = 64.6 * a_t * R_t 1.81$$

where
RE_t = Rainfall erosivity (in megajoules mm/ha-h),
a_t = Location- and season-specific factor, and
R_t = Rainfall on day t (in cm).

The erosivity coefficient (a_t) was assigned a value of 0.3 for the growing season and 0.12 for the dormant season, based on erosivity coefficients provided in the GWLF User's Manual.

Soil Erodibility (K) Factor:
The soil erodibility factor indicates the propensity of a given soil type to erode, and is a function of soil physical properties and slope. Soil erodibility factors were obtained for each soil type from the Logan, Union, and Delaware County Soil and Water Conservation Districts.

Length-Slope (LS) Factor:
Erosion potential varies by slope as well as soil type. The above Soil and Water Conservation Districts provided a table of average LS factors for each soil type.

Cover and Management (C) and Practice (P) Factors:
The mechanism by which soil is eroded from a land area and the amount of soil eroded depends on soil treatment resulting from a combination of land uses (e.g., forestry versus row-cropped agriculture) and the specific manner in which land uses are carried out (e.g., no-till agriculture versus non-contoured row cropping). Land use and management variations are represented by cover and management factors in the universal soil loss equation and in the erosion model of GWLF. Cover and management factors were drawn from several sources (Wischmeier and Smith, 1978; Haith et al., 1992; Novotny and Olem, 1994) and from communications with USDA, NRCS, and SWCD staff involved with the watershed. The values used in the modeling are summarized in Table 6. The C factor for row crop is the sum of the C factors per cover and management practice multiplied by the estimated percent of the watershed that utilized that particular cover and management practice. Practice (P) factors were generally set to 1, consistent with recommendations for non-agricultural land.

Table C6. Cover and Management Factors for Bokes Creek Watershed Land Uses*

Land Use	C	P
Row Crops	0.14	1
Pasture/Hay	0.003	1
Deciduous Forest	0.001	1
Evergreen Forest	0.001	1
Mixed Forest	0.001	1
Woody Wetlands	0.011	1
Emergent Herbaceous Wetlands	0.003	1
Open Water	0	1
Low Intensity Residential	—	—
High Intensity Residential	—	—
Commercial/Industrial/Transportation	—	—

* C and P factors are not required for the "urban" land uses which are modeled in GWLF via a buildup-washoff formulation rather than USLE.

Sediment Delivery Ratio:
The sediment delivery ratio (SDR) converts erosion to sediment yield, and indicates the portion of eroded soil that is carried to the watershed mouth from land draining to the watershed. The BasinSim program (a Windows version of GWLF) includes a built-in utility which calculates the sediment delivery ratio based an empirical relationship of SDR to watershed area (SCS, 1973). The sediment delivery ratio for the entire Bokes Creek watershed was calculated as 0.10.

Nutrient Load Generation
Groundwater Nutrient Concentrations:
The GWLF model requires input of groundwater nutrient concentrations excluding loads due to septic systems, which are accounted for separately. Even in the absence of septic system loads, groundwater concentrations are expected to increase with a shift from forest to either agriculture or development, due to the input of fertilizer on crops, lawns, and gardens. The effect is greatest for nitrate, which is highly soluble, but some elevation of groundwater concentrations of phosphorus is also expected with increased development.

The GWLF manual contains a table of recommended nitrogen and phosphorus groundwater concentrations. These values vary based on location and the proportion of forest/agriculture landuse. In the Bokes Creek basin, about

80% of the landuse is in agriculture. The recommended groundwater concentrations were therefore based on the recommended values for the central US, for the 75%-90% agriculture range.

Dissolved and Solid Phase Nutrient Concentrations for Rural Land Uses:
GWLF requires a dissolved phase concentration for surface runoff from rural land uses. Particulate concentrations are taken as a general characteristic of area soils, determined by bulk soil concentration and an enrichment ratio indicating preferential association of nutrients with the more erodible soil fraction, and not varied by land use. The estimates of dissolved phase concentrations were selected based on the GWLF User's Manual and measured instream concnetrations in Bokes Creek and Powderlick Run. These are given in Table C7.

Table C7. Dissolved and Solids Phase Nutrient Concentrations for Rural Land Uses.

GWLF Land Use Group	Nitrogen		Phosphorus	
	Dissolved Phase (mg/L)	Solids Phase (mg/kg)	Dissolved Phase (mg/L)	Solids Phase (mg/kg)
Row Crops	1-6	1000-3000	0.1-0.26	200-900
Pasture/Hay	1-6	1000-3000	0.1-0.2	200-900
Deciduous Forest	0.25	1000-3000	0.015	200-900
Evergreen Forest	0.25	1000-3000	0.015	200-900
Mixed Forest	0.25	1000-3000	0.015	200-900
Woody Wetlands	0.25	1000-3000	0.01	200-900
Emergent Herbaceous Wetlands	0.25	1000-3000	0.01	200-900
Open Water	0	—	0	—

Buildup/Washoff Parameters for Urban Land Uses:
Nutrients and solids generated from urban land uses are described by a buildup/washoff formulation. Pollutant accumulation is summarized by an exponential buildup rate, and GWLF assumes that 95% of the limiting pollutant storage is reached in a 20-day period without washoff. The resulting buildup parameters (from the GWLF User's Manual) are summarized in Table 8.

Table C8. Pollutant Buildup Rates for Urban Land Uses.

Land use	Nitrogen build up (kg/ha-d)	Phosphorus build up (kg/ha-d)
Low Intensity Residential	0.020	0.0023
High Intensity Residential	0.066	0.0086
Commercial/Industrial/Transportation	0.088	0.0098

Septic Systems:

GWLF contains routines for the simulation of nutrient loading from both normal and failing septic systems. The number of septic systems in each subwatershed was estimated by laying the subwatershed boundaries over the 1990 Census information via a GIS platform. Census information is stored in geographic tracts that did not exactly match the watershed boundaries. The population density was calculated for each census tract intersecting the Bokes Creek basin, and the Bokes Creek population estimated from the proportion of the tract within Bokes Creek. (For the tracts containing West Mansfield and Magnetic Springs, the city population was subtracted when calculating average population density, then added back to obtain the total within-Bokes population.) The census includes a basic inventory of the number of septic, public, and other sewage systems per tract. The number of septic systems in each subwatershed was then assumed to be the sum of the septic and the other sewage categories (anything that was not recorded as a public system). Several assumptions had to be made to categorize the systems according to their performance. These assumptions were based on the data provided by the public health departments, where available, and best professional judgement otherwise. The basic classification method used is as follows:

- All systems listed as 'other' in the census were assumed to be direct discharges.
- A majority of the systems built before 1970 were assumed to be ponded based on lack of construction guidance/regulations before 1974.
- Assumed five percent of the septic systems were short-circuited.
- All others were assumed normally operating systems.

Table 9 summarizes the results of these assumptions.

Table C9. Estimated number of people (per capita) served by various types[1] of septic systems in the Bokes Creek watershed.

Subwatershed		Normal	Ponded	Short circuited	Direct
1	Bokes Creek, Headwaters to Powderlick Run	943	828	54	22
2	Powderlick Run	34	78	6	4
3	Bokes Creek, Powderlick Run to Scioto River	488	914	75	73
Entire watershed:		*1465*	*1820*	*135*	*99*

[1] Normal: Septic systems conform to EPA standards and operate efficiently.
Ponded: System failure results in surfacing of effluent.
Short-circuited: Systems are close to surface water (< 15 meters); negligible absorption of phosphorus takes place.

Direct Discharge: Systems improperly discharging effluent directly into surface waters.

Parameter values affecting nutrient loading from septic systems were based on the GWLF User's Manual. Effluent phosphorus from failing septic systems was set to 2.5 g/day, while effluent nitrogen was set to 12.0 g/day. Plant uptake rates were assumed to be 1.6 g/day nitrogen and 0.4 g/day phosphorus.

Point Sources:
Nutrient loads from point sources are calculated outside of the GWLF model and are added in directly. Only the largest facility (the Camp Christian package plant, design flow = 0.015 mgd) was included in the model. Median values of total nitrogen and phosphorus were based on recommended values for activated sludge in the 1985 Water Quality Assessment (p. 257). Nutrient contributions from the package plant were found to be insignificant in comparison with non-point sources, even at its design flow year-round.

Comparison of Observed and Modeled Data

A USGS gaging station, Bokes Creek near Warrensburg, was in operation at the mouth of Bokes Creek until September 1997. The GWLF model was calibrated to the gage by comparing observed flow data from climatic year 1990 through water year 1997 to predicted data for the same time period. The GWLF model agricultural parameters are based on current practices in the Bokes Creek watershed, and predicted gage flows are best for the most recent flow data. The correlation coefficient R^2 is about 0.71 for the gage period of record, but improves to 0.90 for the last 2 years.

Summary

The Bokes Creek watershed was modeled using GWLF and data from a wide range of sources. The predicted nutrient loadings and flow compare reasonably well with observed data, and the model can be relied on to give credible results for its intended applications. The model results are based on 1990-1997 instream flow and 1999 phosphorus data. The model was used to determine the existing loading for phosphorus in the Bokes Creek watershed.