Appendix C

Nutrient Model Development for Upper Salt Creek and Beech Fork

Introduction

This section describes the methods used in the loading analysis of nutrients in the Upper Salt Creek and Beech Fork TMDLs. 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 Upper Salt Creek and Beech Fork watersheds 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 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 determine 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

The 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 Upper Salt Creek and Beech Fork watersheds was 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, and water land cover subclasses. The imagery was acquired by the Multi-Resolution Land Characteristics (MRLC) Consortium, a partnership of federal agencies that produce or use land cover data. The Landsat imagery used for the Upper Salt Creek and Beech Fork watersheds is the MRLC 2001 data. Tables C1 and C2 summarize the acreage in each land use category in the Upper Salt Creek and Beech Fork basins.

Table C1. Land uses in the Upper Salt Creek watershed, 05060002 070 010 (MRLC 2001 data.)

Land Use	**Acres**	**% of Total**
Cultivated Crops	5226	71.0%
Pasture/Hay	132	1.8%
Deciduous Forest	1526	20.7%
Evergreen Forest	9.9	0.14%
Mixed Forest	1.3	0.02%
Grassland/Herbaceous	10.8	0.15%
Shrub/Scrub	1.7	0.02%
Developed, Open Space	405	5.5%
Developed, Low Intensity	49.9	0.68%
Developed, Medium Intensity	1.3	0.02%
Total:	**7363**	**100%**

Table C2. Land uses in the Beech Fork watershed 05060002 070 030 (MRLC 2001 data.)

Land Use	Acres	% of Total
Cultivated Crops	5777	45.4%
Pasture/Hay	4036	31.7%
Deciduous Forest	2287	18.0%
Evergreen Forest	34.7	0.27%
Mixed Forest	5.9	0.05%
Grassland/Herbaceous	59.2	0.47%
Shrub/Scrub	12.9	0.10%
Woody Wetlands	1.3	0.01%
Open Water	2.5	0.02%
Developed, Open Space	479	3.8%
Developed, Low Intensity	17.1	0.13%
Developed, Medium Intensity	1.3	0.01%
Total:	**12714**	**100%**

Soil data for the Upper Salt Creek and Beech Fork watersheds was obtained from SSURGO GIS data on the ODNR GIMS web site (http://www.dnr.state.oh.us/gims). (STATSGO soil data was also used, in deriving the curve numbers.) 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 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 C3. 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 C3. Land Use Groupings for GWLF Modeling

NLCD Land Use	Pollutant Simulation
Cultivated Crops	Rural
Pasture/Hay	Rural
Deciduous Forest	Rural
Evergreen Forest	Rural
Mixed Forest	Rural
Grassland/Herbaceous	Rural
Shrub/Scrub	Rural
Woody Wetlands	Rural
Open Water	—
Developed, Open Space	Urban
Developed, Low Intensity	Urban
Developed, Medium Intensity	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. For the Upper Salt Creek basin, daily precipitation and temperature data were based on a weighted average for the Circleville and Laurelville meteorological stations. For Beech Fork, data from the Laurelville station was used. Some weather data from Chillicothe and Lancaster was used to fill in any missing gaps.

Table C4. Weather stations used in the Upper Salt Creek and Beech Fork GWLF models

Station #	Station Name	Latitude	Longitude
334434	Laurelville	39°28'	82°43'
331592	Circleville	39°36'	82°56'
334403	Lancaster	39°43'	82°36'
331528	Chillicothe Mound City	39°22'	83°00'

Average monthly precipitation for the 1996 to 2007 time period is summarized in Table C5. Figure C1 shows the variability in monthly precipitation over the period. The weather data was input into the model by climatic year (April 1 to March 31 of the following year).

Table C5. Upper Salt Creek and Beech Fork Average Monthly Precipitation for April 1996 to March 2007

Month	Beech Fork Average Total Precipitation (inches)	Upper Salt Creek Average Total Precipitation (inches)
January	3.1	3.1
February	2.2	2.1
March	2.8	3.0
April	4.2	4.0
May	5.2	5.0
June	4.0	4.1
July	4.0	3.9
August	4.3	3.9
September	3.4	3.4
October	3.1	3.1
November	3.1	2.9
December	2.8	2.7

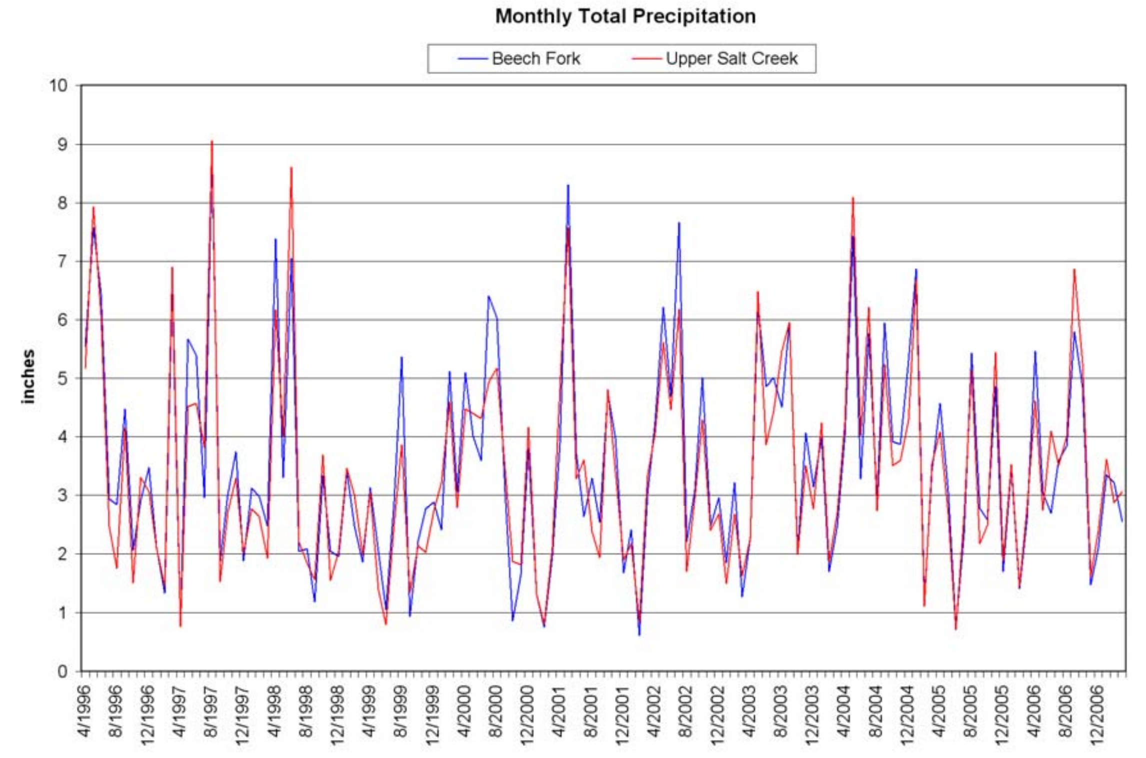

Figure C1. Upper Salt Creek and Beech Fork Monthly Total Precipitation, April 1996 to March 2007

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 cultivated crops and pasture/hay, the monthly ET was based on average crop acreages from tillage transects for the period 1996-2004, and values recommended in the GWLF manual for each crop type. For deciduous forest and scrub/shrub it was assumed that the 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). Evergreen forest and grassland were assigned a value of 1 year-round. A single area-weighted ET value was calculated for each month.

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 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 ground water recession and deep seepage coefficients. The recession coefficient was set to 0.21 per day and the deep seepage coefficient to 0.0.

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 groups. Curve numbers vary from 30 for forest or grassland on well-drained soils, to 98 for paved areas. The hydrologic soil group was determined from available STATSGO soils data, and curve numbers were calculated for each combination of land use / soil hydrologic group. The KLSCP (see next section) and curve numbers calculated for the Upper Salt Creek and Beech Fork watersheds are summarized in Tables C6 and C7. 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 C6. KLSCP Values and Runoff Curve Numbers for Upper Salt Creek

Land Cover	**KLSCP** (weighted average)*	**Curve Number** (weighted average)*	**Methodology**
Cultivated Crops	0.028	81	USLE
Pasture/Hay	0.0021	74	USLE
Deciduous Forest	0.00092	70	USLE
Evergreen Forest	0.00061	70	USLE
Mixed Forest	7.6e-5	70	USLE
Grassland/Herbaceous	0.0012	74	USLE
Shrub/Scrub	0.0059	72	USLE
Developed, Open space	—	77	Buildup-Washoff
Developed, Low Intensity	—	82	Buildup-Washoff
Developed, Medium Intensity	—	90	Buildup-Washoff

Table C7. KLSCP Values and Runoff Curve Numbers for Beech Fork

Land Cover	**KLSCP** (weighted average)*	**Curve Number** (weighted average)*	**Methodology**
Cultivated Crops	0.020	77	USLE
Pasture/Hay	0.0017	73	USLE
Deciduous Forest	0.0020	69	USLE
Evergreen Forest	0.0011	69	USLE
Mixed Forest	7.4e-5	58	USLE
Grassland/Herbaceous	0.00092	73	USLE
Shrub/Scrub	0.0033	72	USLE
Woody Wetlands	0.0052	100	USLE
Open Water	—	100	—
Developed, Open space	—	74	Buildup-Washoff
Developed, Low Intensity	—	82	Buildup-Washoff
Developed, Medium Intensity	—	90	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 Tables C6 and C7, solids loads are generated separately, as described below in the section entitled “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.

<u>Rainfall Erosivity (RE):</u>

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 Ross, Pickaway, and Fairfield SSURGO databases.

Length-Slope (LS) Factor:

Erosion potential varies by slope as well as soil type. The above SSURGO databases provided slope and slope-length values, which were used to calculate length-slope factors for each soil type using the USLE LS-Factor equation.

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 county NRCS staff. The values used in the modeling are summarized in Tables C8 and C9. 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 set to 1.

Table C8. Cover and Management Factors and Practice Factors for Upper Salt Creek Watershed Land Uses*

Land Use	C	P
Cultivated Crops	0.1175	1
Pasture/Hay	0.004	1
Deciduous Forest	0.001	1
Evergreen Forest	0.001	1
Mixed Forest	0.001	1
Grassland/Herbaceous	0.003	1
Shrub/Scrub	0.0065	1
Developed, Open space	—	—
Developed, Low Intensity	—	—
Developed, Medium Intensity	—	—

Table C9. Cover and Management Factors and Practice Factors for Beech Fork Watershed Land Uses*

Land Use	C	P
Cultivated Crops	0.11	1
Pasture/Hay	0.004	1
Deciduous Forest	0.001	1
Evergreen Forest	0.001	1
Mixed Forest	0.001	1
Grassland/Herbaceous	0.011	1
Shrub/Scrub	0.003	1
Woody Wetlands	0.0065	1
Open Water	—	—
Developed, Open space	—	—
Developed, Low Intensity	—	—
Developed, Medium Intensity	—	—

* 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 Upper Salt Creek watershed was calculated at 0.17 and for Beech Fork watershed was calculated at 0.15.

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 groundwater concentrations for total nitrogen and total phosphorus were based on low-flow samples collected in 2005 for each watershed.

Dissolved and Solid Phase Nutrient Concentrations for Rural Land Uses:

GWLF requires a particulate concentration and 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. Sediment concentrations were estimated at 3000 mg/kg and about 1300 mg/kg for nitrogen and phosphorus, respectively, as recommended in the manual. Dissolved concentrations were selected for each land use based on the GWLF User's Manual. These are given in Table C10.

Table C10. Dissolved Phase Nutrient Concentrations for Rural Land Uses.

GWLF Land Use Group	Nitrogen	Phosphorus
	Dissolved Phase (mg/L)	**Dissolved Phase (mg/L)**
Cultivated Crops	2.9	0.26
Pasture/Hay	2.9	0.2
Deciduous Forest	0.19	0.006
Evergreen Forest	0.19	0.006
Mixed Forest	0.19	0.006
Grassland/Herbaceous	0.19	0.006
Shrub/scrub	0.19	0.006
Woody Wetlands	0.19	0.006

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 90% 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 C11.

Table C11. Pollutant Buildup Rates for Urban Land Uses.

Land use	Nitrogen build up (kg/ha-d)	Phosphorus build up (kg/ha-d)
Developed, Open space	0.015	0.0019
Developed, Low Intensity	0.023	0.0026
Developed, Medium Intensity	0.066	0.0086

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 Upper Salt Creek and Beech Fork basins, and the populations estimated from the proportion of the tracts within the two basins. 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 judgment 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.
- Five percent of the septic systems were assumed short-circuited.
- All others were considered normally operating systems.

Table C12 summarizes the results of these assumptions.

Table C12. Estimated number of people (per capita) served by various types[1] of septic systems in the Upper Salt Creek and Beech Fork watersheds.

Subwatershed	Normal	Ponded	Short circuited	Direct
Upper Salt Creek	388	541	52	24
Beech Fork	222	490	41	33

[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:

There are no point sources in either watershed.

Comparison of Observed and Modeled Data

There is no USGS gaging station in either basin. A USGS gaging station, Salt Creek at Richmond Dale, was in sporadic operation from 2005 through 2007. The large difference in drainage areas between the gage and the sub-watersheds make any comparison qualitative, especially since Salt Creek at the gage is mostly forested, in contrast to Upper Salt Creek and Beech Fork. With streamflow expressed in centimeters, the gage flows are qualitatively similar to the sub-watersheds though correlation is poor. The recession ratio at the gage was used to set the recession ratio for the two sub-watersheds.

Model values of nitrogen and phosphorus are low, in general agreement with the samples collected in 2005.

Summary

The Upper Salt Creek and Beech Fork watersheds were 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.

References

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7. National Land Cover Database 2001 (NLCD 2001), MRLC Consortium, U.S. Department of the Interior, U.S. Geological Survey, http://www.mrlc.gov/mrlc2k_nlcd.asp.

8. SSURGO Digital Soils Information for Fairfield County (Sept. 2003), Pickaway County (Dec. 2004) and Ross County (Feb. 2004), downloaded from the Ohio Department of Natural Resources (ODNR) web site.

9. CTIC tillage transect information, 1996 through 2004. (Data collected in cooperation with the USDA Natural Resources Conservation Service and the Local Conservation Partnership.)