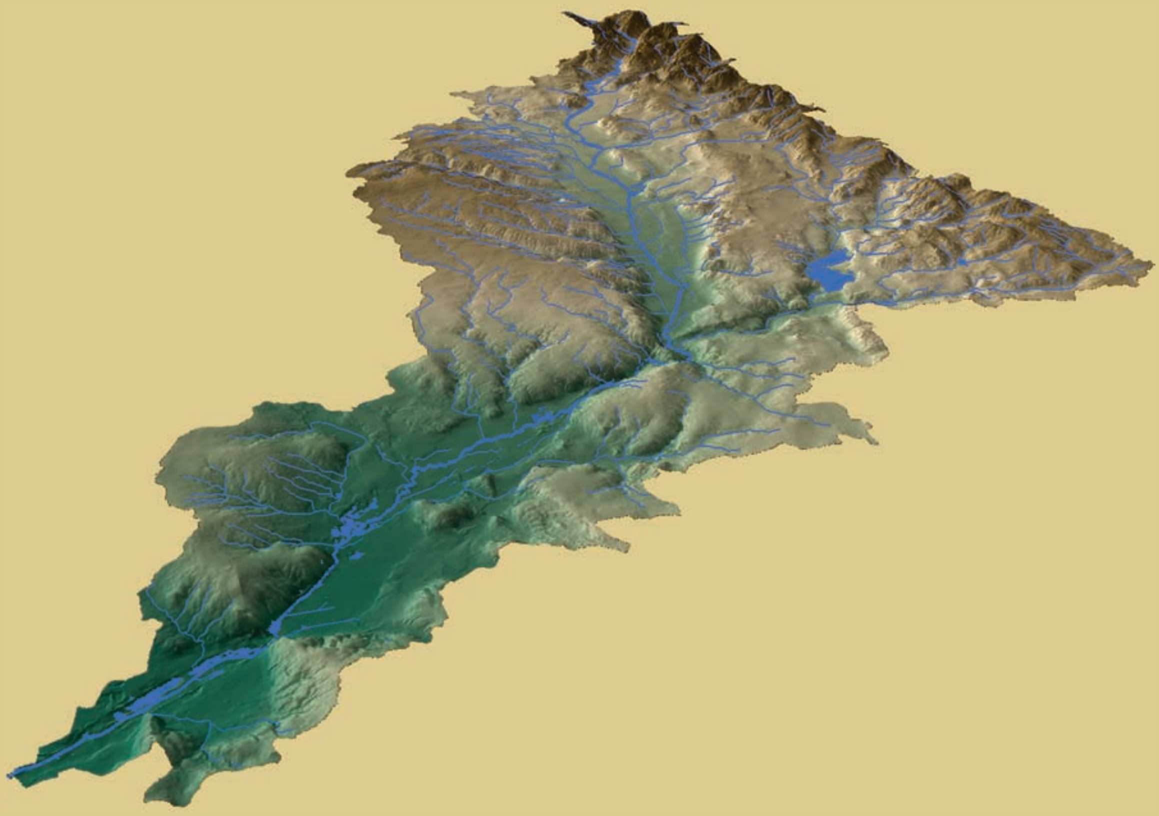
In cooperation with the Ohio Environmental Protection Agency

Simulation of Streamflow and Water Quality to Determine Fecal Coliform and Nitrate Concentrations and Loads in the Mad River Basin, Ohio



Scientific Investigations Report 2006–5160

U.S. Department of the Interior
U.S. Geological Survey

COVER IMAGE: Computer-generated three-dimentional perspective view of the Mad River Basin looking northward. Prepared by Barry M. Puskas, U.S. Geological Survey.

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By David C. Reutter, Barry M. Puskas, and Martha L. Jagucki

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Conversion Factors, Datums, and Abbreviations

Multiply	By	To obtain
	Length	
inch (in.)	2.54	centimeter (cm)
foot (ft)	0.3048	meter (m)
meter (m)	3.281	foot (ft)
mile (mi)	1.609	kilometer (km)
	Area	
acre	0.004047	square kilometer (km^2)
square mile (mi^2)	2.590	square kilometer (km^2)
	Volume	
milliliter (mL)	0.06102	cubic inch (in^3)
liter (L)	0.03531	cubic foot (ft^3)
gallon (gal)	3.785	liter (L)
million gallons (Mgal)	3,785	cubic meter (m^3)
	Flow rate	
gallon per day (gal/d)	0.003785	cubic meter per day (m^3/d)
million gallons per day (Mgal/d)	0.04381	cubic meter per second (m^3/s)

Temperature in degrees Fahrenheit (°F) may be converted to degrees Celsius (°C) as follows:

°C=(°F-32)/1.8

Vertical coordinate information is referenced to the North American Vertical Datum of 1988 (NAVD 88).

Horizontal coordinate information is referenced to the North American Datum of 1983 (NAD 83).

Altitude, as used in this report, refers to distance above the vertical datum.

Concentrations of chemical constituents in water are given in milligrams per liter (mg/L).

Concentrations of bacteria are given in colonies per 100 milliliters (col/100 mL).

Simulation of Streamflow and Water Quality to Determine Fecal Coliform and Nitrate Concentrations and Loads in the Mad River Basin, Ohio

By David C. Reutter, Barry M. Puskas, and Martha L. Jagucki

Abstract

The Hydrological Simulation Program–Fortran (HSPF) was used to simulate the concentrations and loads of fecal coliform and nitrate for streams in the Mad River Basin in west-central Ohio during the period 1999 through 2003. The Mad River Basin was divided into subbasins that were defined either by the 14-digit Hydrologic Unit (HU) boundaries or by streamflow-gaging-station locations used in the model. Model calibration and simulation processes required the formation of nine meteorologic zones to input meteorologic time-series data and water-quality data.

Sources of fecal coliform and nitrate from wastewater-treatment discharges and combined sewer overflow discharges (CSOs) within the City of Springfield were point sources simulated in the model. Failing septic systems and cattle with direct access to streams were nonpoint sources included in the study but treated in the model as point sources. Other nonpoint sources were addressed by adjusting interflow and ground-water concentrations in the subsurface and maximum storage capacities and accumulation rates of the simulated constituents on the land surface for each meteorologic zone. Simulation results from the calibrated model show that several HUs exceeded the water-quality standard of 1,000 colony-forming units per 100 mL for fecal coliform based on the maximum 30-day geometric mean. Most HUs with high fecal coliform counts were within or downstream from the City of Springfield. No water-quality standard has been set for instream nitrate concentrations; however, the Ohio Environmental Protection Agency (Ohio EPA) considered a concentration of 5 mg/L or greater to be of concern. Simulation results indicate that several HUs in the agricultural areas of the basin exceeded this level.

The calibrated model was modified to create scenarios that simulated loads of fecal coliform and nitrate that were either reduced or eliminated from selected sources. The revised models included the elimination of failing septic systems, elimination of direct access of cattle to streams, decrease in fecal coliform loads from the CSOs and selected wastewater-treatment facilities, and decrease in nitrate loads from land surfaces. The fecal coliform source-reduction model decreased the fecal coliform concentrations below a target concentration of 1,000 colonies per 100 milliliters for all HU outlets and decreased the load at the mouth of the Mad River by 73 percent. The nitrate source-reduction model decreased some HU mean concentrations to 5 milligrams per liter or less and decreased the load at the mouth of the Mad River by 52 percent. Other reduction scenarios may be run by Ohio EPA with the intent of identifying a management strategy that will attain a target concentration for the Mad River Basin.

Introduction

Stream waters of the Mad River Basin (fig. 1) are used for recreation, agricultural and industrial water supply, and support of aquatic life. Long-term availability of water for some of these uses is threatened, however, because several segments of the Mad River Basin are listed under Section 303(d) of the Federal Clean Water Act as not being in compliance with Ohio Water Quality Standards (WQS). An extensive evaluation of the Mad River Basin by Ohio Environmental Protection Agency (Ohio EPA) (2005a) found that, throughout the basin, ambient-water-quality standards for fecal coliform bacteria are exceeded (geometric mean of five or more samples within a 30-day period exceeds 1,000 col/100 mL and (or) more than 10 percent of samples within the 30-day period exceed 2,000 col/100 mL). Other causes of impairment to specific stream segments include nutrient and organic enrichment resulting from agricultural activities, urban runoff, or wastewater-treatment plants (Ohio Environmental Protection Agency, 1998, 2005a). Habitat alteration due to channelization also has degraded several stream segments in the watershed (Ohio Environmental Protection Agency, 1998, 2004, and 2005a).

To bring all streams in the basin into compliance with Ohio WQS will require quantification of contamination loads contributed by various sources, information regarding the effects of different land covers and other land-surface characteristics on water quality, and documentation of the response of contaminant loads to precipitation events and various flow conditions. Such information will serve as a basis for water-resource-management decisions in the basin.

To quantify loads and concentrations of nitrate and fecal coliform in the Mad River Basin and to estimate these concentrations over a range of hydrologic conditions, the U.S. Geological Survey (USGS), in cooperation with the Ohio EPA, used a watershed model called Hydrological Simulation Program–Fortran (HSPF). HSPF simulates transport and storage of water and associated water-quality constituents, as well as instream chemical reactions (Bicknell and others, 1997). HSPF is included as part of the U.S. Environmental Protection Agency (USEPA) Better Assessment Science Integrating point and Nonpoint Sources (BASINS) program. HSPF is also one of several principal models currently recommended by the USEPA Office of Water for determining the Total Maximum Daily Load (TMDL) of a pollutant that a stream can receive from point, nonpoint, and background sources and still meet state water-quality standards with an adequate margin of safety. The process of developing a TMDL for a pollutant helps the Ohio EPA identify the amount by which both point and nonpoint sources in impaired stream segments must be reduced. Subsequently, scientifically based restoration solutions can be implemented with the ultimate goal of reaching full attainment of biological and chemical WQS within each stream segment and, thereafter, removal of the waterbody or waterbodies from the 303(d) “impaired” list.

Purpose and Scope

This report describes the development and calibration of an HSPF model to simulate streamflow and the transport of fecal coliform bacteria and nitrates. The model was developed under the USEPA 319 grant program in support of a TMDL that will be prepared by the Ohio EPA. The model simulation period is January 1999 through December 2003, based on availability of both streamflow and water-quality data. Current water-quality conditions in the Mad River Basin are described. Locations of point sources and their fecal coliform and nitrate loads are presented, as well as estimates of fecal coliform and nitrate loads from nonpoint sources, including ground-water discharge to streams. The calibrated model is used to calculate the loads of fecal coliform bacteria and nitrate in the Mad River Basin and to evaluate where these loads exceed the targets established by Ohio EPA. Load-reduction scenarios prescribed by Ohio EPA are simulated, and the resulting loads are presented. Loads are converted to mean annual nitrate and 30-day geometric mean fecal coliform concentrations to assess whether the source-reduction scenarios will achieve Ohio EPA target concentrations.

Several topics are beyond the scope of this report, and will be addressed instead in the Ohio EPA TMDL report for the Mad River Basin. For example, stream impairment caused by habitat alteration is not addressed in this report. Designation of specific load-reduction scenarios as the TMDLs for fecal coliform and nitrate in the Mad River Basin will be addressed by Ohio EPA. Similarly, an implementation plan for achieving TMDL targets is excluded from this report but will be addressed by Ohio EPA in their TMDL report to USEPA.

Previous Studies

The information base for the Mad River Basin is relatively rich. Several studies on a variety of water-resources topics have focused on all or part of the Mad River Basin (table 1). Because it has long been documented that the Mad River has an unusually large base-flow component (Leverett, 1902), the interaction of ground water and surface water has been of special interest in the area.

One reason for the abundance of information in the area is the presence of the Miami Conservancy District (MCD). The MCD was established in 1915 to provide flood protection for citizens in the Great Miami River Basin (which includes the Mad River Basin) (Miami Conservancy District, 2005c). With this goal in mind, the USGS and MCD currently operate streamflow-gaging stations (“streamflow gages” hereafter) at four locations on the Mad River. In addition, a crest-stage gage (which is used to determine peak streamflow) is operated on the Mad River near Urbana. Since its founding, MCD has assumed the additional responsibilities of preserving surface- and ground-water resources and enhancing river corridors. In support of these expanded responsibilities, a surface-water-quality monitoring station was operated for 3 years at one of the four active streamflow gages (the Mad River near Eagle City, in Clark County), ground-water quality and quantity have been regularly monitored since 1997, and precipitation amounts have been recorded at precipitation gages across the basin (Miami Conservancy District, 2000, 2002, 2003, 2004, 2005b).

Another source of information in the Mad River Basin is the National Water-Quality Assessment (NAWQA) Program. This USGS program was established to describe current water-quality conditions in major river basins and aquifer systems across the Nation, assess how water quality is changing over time, and investigate factors that affect water-quality conditions. Intensive water-quality analysis of the Mad River at St. Paris Pike was done from October 1998 through 2004 as part of the NAWQA program (Shindel and others, 2000, 2001, 2002, 2003, 2004; and 2005, p. 134–138).

Water quality in the Mad River Basin has also been studied by Ohio EPA, Ohio Department of Natural Resources, and other agencies and researchers. Results of these studies are detailed in the “Water-Quality Characterization” section of this report.

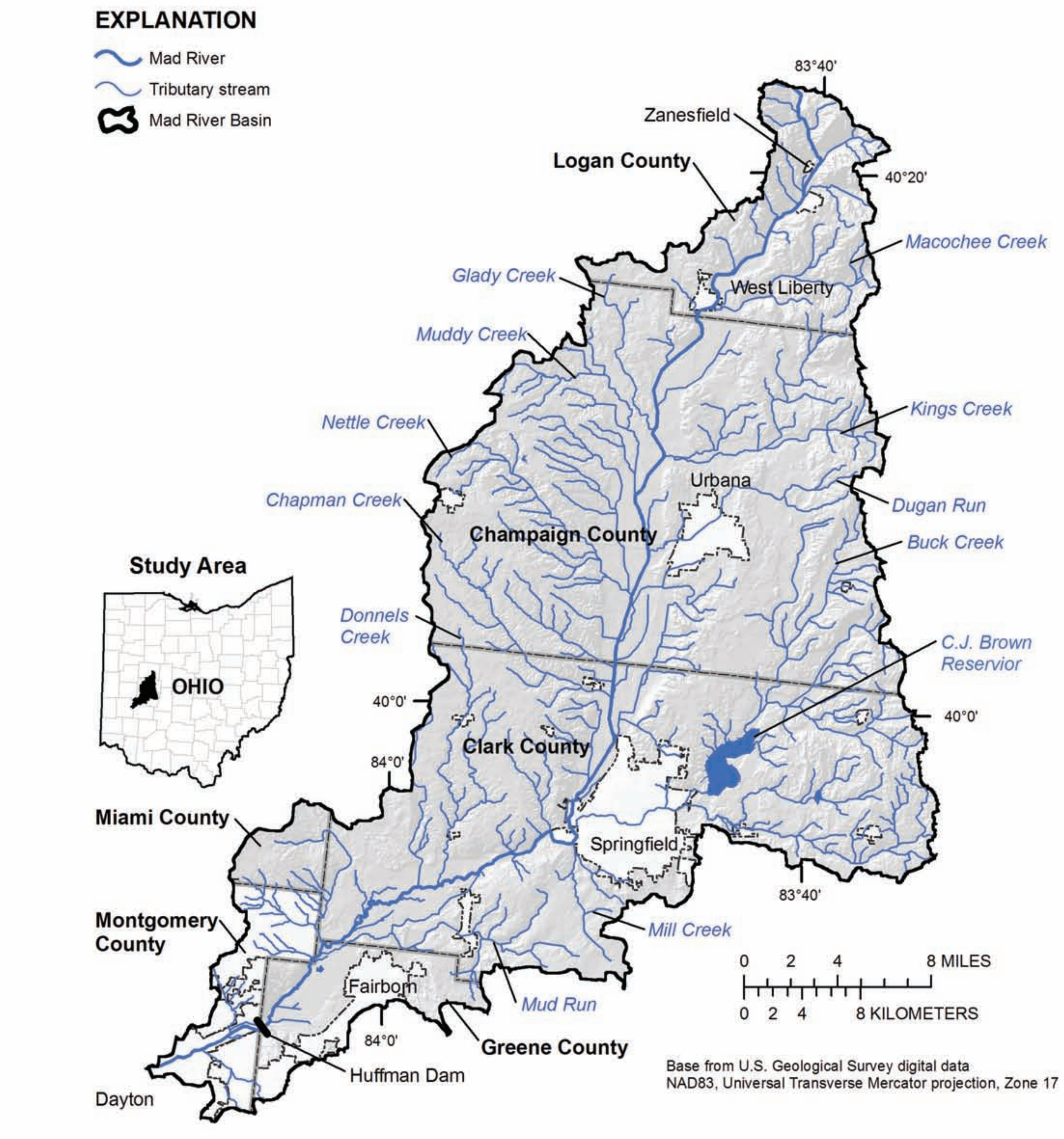

Figure 1. Mad River Basin, Ohio. (Only major streams are labeled; small streams and watersheds are identified in fig. 7.)

Table 1. Selected previous studies including all or part of the Mad River Basin.

[Full citations for each reference are included in the "References Cited" section of this report]

Topic	Reference
Water resources of all or part of Mad River Basin	Leverett (1897, p. 457); Fuller and Clapp (1912), Harker and Bernhagen (1943), Norris and others (1948, 1952, 1956), Feulner (1960), and Schmidt (1982, 1985, 1991)
Geology	Orton (1874), Hill (1878), Forsyth (1956), and Quinn and Goldthwait (1979)
Delineation of the Teays River Valley	Norris and Spicer (1958)
Ancestral drainage paths of the Mad River near Dayton	Richard and others (1979)
Geohydrology	Speiker and Durrell (1961) and Smindak (1992)
Interaction of ground water and surface water	Cross and Feulner (1964), Norris and Eagon (1971), Sheets and Yost (1994), Koltun (1995), Yost (1995), Jones and others (1996), and Dumouchelle (2001)
Transport of hypothetical contaminants in the hydraulically connected stream-aquifer system	Hussein and Schwartz (2003)
Water (resource/quality) monitoring	Miami Conservancy District (2002, 2003, 2004, 2005b), Debrewer and others (2000), Jones and others (1996), Rankin and others (1997), Reutter (2003), Rowe and others (2004), U.S. Geological Survey (2000, 2005c), and Ohio Environmental Protection Agency (1986, 1994, 2005a)
Temporal water-quality trends	Pennino (1984)
Effects of urban stormwater runoff	Burton and others (2001)
Assessments of biota, fish tissue, and stream sediment	Janosy (2003), and Ohio Environmental Protection Agency (1986, 1994, 2005a)
Effects of Wright-Patterson Air Force Base on the biology, sediment, and water quality of the Mad River	Ohio Environmental Protection Agency (1994)

Basin Description

The Mad River is in west-central Ohio and drains approximately 657 mi^2. From its headwaters in Logan County, the Mad River flows south and west through Champaign, Clark, and Greene Counties to its confluence with the Great Miami River in Montgomery County (fig.1). Tributaries to the Mad River with drainage areas greater than 20 mi^2 are Buck Creek, Chapman Creek, Donnels Creek, Dugan Run, Kings Creek, Muddy Creek, and Nettle Creek. The urban areas of Dayton, Fairborn, Springfield, Urbana, and West Liberty are partly or wholly contained within the Mad River Basin. C.J. Brown Reservoir, constructed on Buck Creek in Clark County in 1972 (Koltun, 1995), is a deep-water lake that covers 2,120 acres and is the sole large reservoir in the study area (U.S. Army Corps of Engineers, 2005; Dayton Audubon Society, 2005). For temporary storage of floodwaters, Huffman Dam was built across the Mad River near Fairborn in northwestern Greene County; however, Huffman Dam has no permanent pool. Under normal flow conditions, waters of the Mad River pass through conduits at the base of the dam; only in times of excess flow do waters back up behind the dam (Miami Conservancy District, 2005a).

Physical and Hydrologic Setting

Topography at the northern end of the Mad River Basin (fig. 1) consists of gently rolling hills dissected by steep-walled river valleys. The highest point in the study area (and in Ohio) is in Logan County, with an altitude of 1,539 ft near the headwaters of the basin. Further south in Champaign and Clark Counties, the land is relatively flat and consists of some of the richest farmland in Ohio (Mad River Steering Committee, 2003b); however, very steep valley walls can be found along the major drainageways. The lowest altitude (712 ft) is near the mouth of the Mad River in Montgomery County.

The natural flow of the Mad River was altered at the beginning of the 20th century with the advent of flood control. Levees were constructed, and reaches of the Mad River and its tributaries were channelized. Besides altering streamflow, flood-control measures allowed for agricultural development of many additional acres, bringing about degradation of surface- and ground-water quality and subsequent alteration of the native fish population (Mad River Steering Committee, 2003b). Dredging in the Mad River in the period 1955–80 created further change in fish communities. Straightening of channels and the elimination of pools and riffles altered stream habitats (Harrington, 1999). Deepening of the channels from Buck Creek to the headwaters has caused greater influx of ground water to the streams, resulting in cooler stream-water temperatures (Ohio Environmental Protection Agency, 2005a).

Climate

Average annual air temperatures in the Mad River Basin range from about 51 to 53°F (Harstine, 1991). Average annual precipitation ranges from 36.7 to 39.6 in. Long-term precipitation averages are based on the entire period of record (in many cases greater than 80 years) at nine stations, as recorded by MCD observers (Miami Conservancy District, 2000). March through August tend to be the wettest months, with peak precipitation occurring in May and June, whereas February is the driest month (Miami Conservancy District, 2000). Debrewer and others (2000), when examining precipitation data in the Great and Little Miami Watersheds over a 30-year period (1961–90), found that precipitation events in spring and summer have usually been associated with thunderstorms that tend to be short and intense. In contrast, precipitation events in the fall and winter have usually been longer and of mild intensity.

Hydrogeology

The Mad River occupies an area that was affected by Pleistocene glaciation. Most of its course lies between what were historically the Miami and Scioto lobes of the Wisconsinan glacier (Cross and Hedges, 1959). As the lobes advanced or as stagnant ice melted, a blanket of till (an unsorted mixture of clay, silt, sand, and gravel) was deposited over the area (fig 2). Later, large volumes of glacial meltwater filled erosional valleys carved in the till and bedrock with coarse-grained, stratified sediments called outwash. Outwash terraces and extensive outwash deposits up to 3 mi wide characterize much of the Mad River Basin (Cross and Feulner, 1964). The fine-grained stratified sediments between Dugan Run and Buck Creek were deposited in a lacustrine setting, perhaps in a basin or valley dammed by glacial ice (Debrewer and others, 2000).

Outwash deposits are highly permeable and readily transmit ground water. Ground water is the primary source of drinking water for residents in the upper part of the basin; the aquifer system has been designated as a Sole-Source Aquifer for the region and named the “Mad River Buried Valley Aquifer” (Mad River Steering Committee, 2003b). Ground water also discharges to the Mad River in amounts that are uncommonly large compared to other rivers in Ohio (Leverett, 1902; Koltun, 1995). Koltun (1995) reports that the median percentage of annual total streamflow contributed by base flow from ground water ranges from 61.8 (at Zanesfield) to 76.1 percent (near Urbana). Because the permeable glacial deposits are not uniformly distributed, contribution of ground water to the tributaries within the Mad River Basin is variable. Jones and others (1996) measured instantaneous discharge of the Mad River and various tributaries during low-flow conditions. Gains in flow between upstream and downstream reaches were computed for the tributaries and were attributed to ground-water discharge to the stream. The highest base flows per square mile of surface drainage area were found in the subbasins of Kings Creek, Macochee Ditch, and Mad River north of West Liberty. Base flows are lowest in Glady Creek and Muddy Creek. Jones and others (1996) also note large base-flow gains on the Mad River between West Liberty and Urbana and attribute the gains to high rates of ground-water recharge along the low terraces bordering the river in this area. In contrast, poorly permeable strata line reaches of the Mad River near Springfield and also at Huffman Dam, near the boundary between Greene and Montgomery Counties (Cross and Feulner, 1964). In these locations, valley fill is constricted by bedrock gorges. The gorge through which the stream passes at Springfield is approximately 1/8 mi wide (Cross and Feulner, 1964) and is cut into Silurian limestone, whereas the gorge at Huffman Dam cuts through Ordovician limestone and shale.

Because of the high amount of ground-water contribution to streamflow in areas where permeable glacial deposits are present, the upper part of the Mad River and selected tributaries have been designated as cold-water habitat (Ohio Environmental Protection Agency, 2005a). Cold-water habitat describes those waters capable of supporting native populations of cold-water fish, plants, and other organisms on an annual basis or waters that support trout stocking and management (Ohio Environmental Protection Agency, 2002).

Soils

Soils in the Mad River Basin have been classified into hydrologic groups by the National Resources Conservation Service (NRCS) (U.S. Department of Agriculture, 1991a). When storm and cover conditions are similar, soils within a single hydrologic group have similar runoff potential. Runoff potential refers to the likelihood that precipitation and snowmelt will flow over the land surface rather than infiltrate into the ground, and it is based on surface slope and saturated hydraulic conductivity of the upper 1 meter of soil or bedrock material. Runoff potential is estimated for bare, thoroughly wetted, and unfrozen soils. Runoff potential is influenced by “depth to a seasonally high water table, saturated hydraulic conductivity after prolonged wetting, and depth to a layer

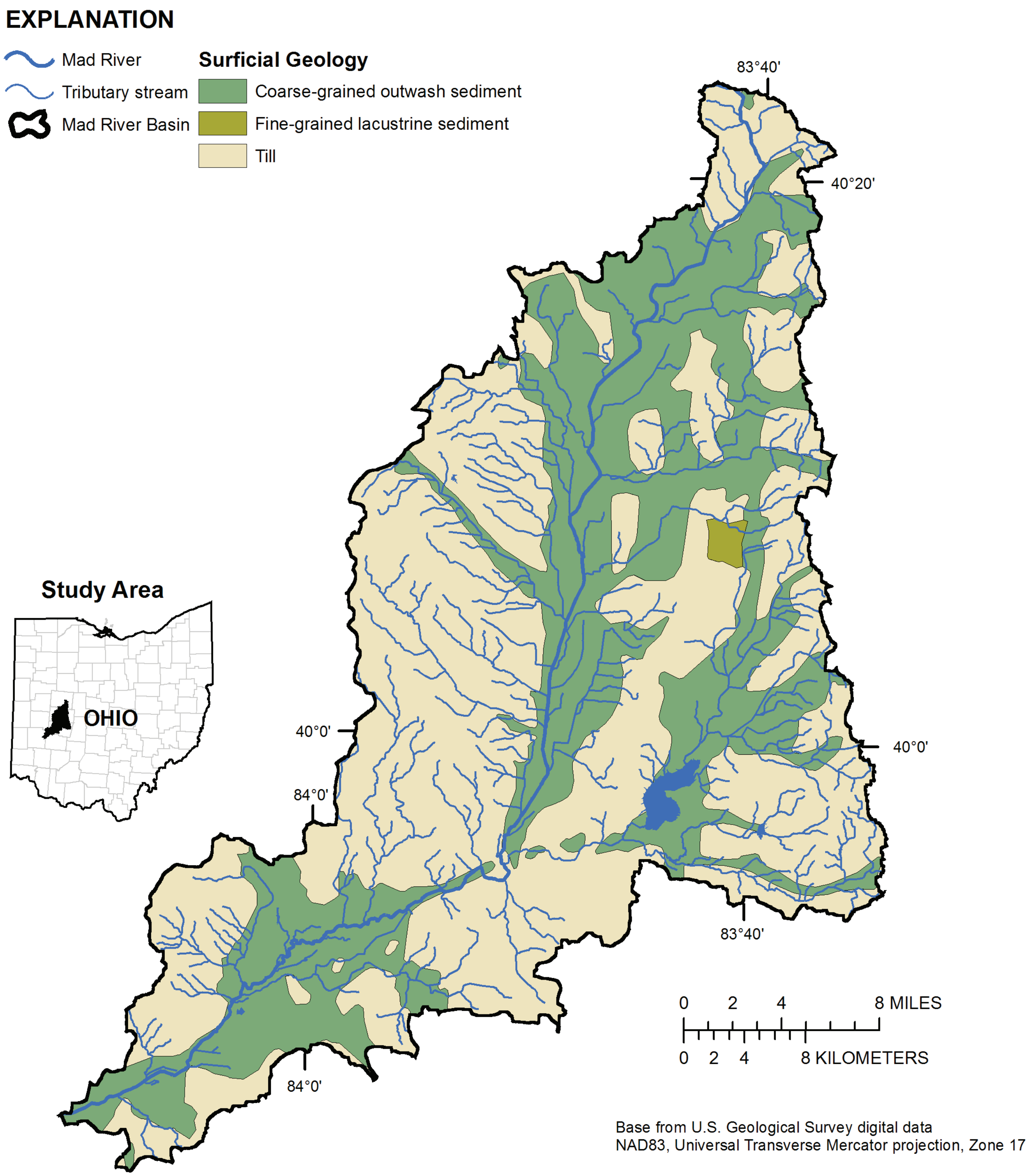

Figure 2. Generalized surficial geology in the Mad River Basin. (Data from Soller, 1993, 1998 as reported by Debrewer and others, 2000.)

with a very slow water transmission rate” (U.S. Department of Agriculture, 2005). Soils with a low runoff potential have a high infiltration rate; those with a high runoff potential have a low infiltraton rate. Distribution of soils by hydrologic group (table 2) are shown in figure 3 and were obtained from the State Soil Geographic (STATSGO) database created by the NRCS (U.S. Department of Agriculture, 1991a). This database, designed for regional and river-basin-level planning and monitoring, was created by generalizing more detailed soil-survey maps. The STATSGO database was the most recent dataset available for all counties in the Mad River Basin when the study began. Of the hydrologic soil groups found in the Mad River Basin, group B soils generally have the lowest runoff potential. These soils are found along much of the main stem of the Mad River and in the vicinity of some tributaries, including Buck Creek and Kings Creek, and generally coincide with the presence of outwash in the basin (fig. 2). Group C soils cover much of the basin and are generally associated with till deposits. Group D soils (which cover a very small area at the north end of the basin, as well as areas in the Mill Creek and Mud Run Subbasins) have the greatest runoff potential.

Table 2. Hydrologic soil groups in the Mad River Basin.

[Information obtained from U.S. Department of Agriculture (2005) and Purdue Research Foundation (2004). Infiltration is the rate at which water enters the soils at the surface and is controlled by surface conditions. Transmission is the rate at which water moves in the soil and is controlled by soil properties. Location of hydrologic soil groups shown in fig. 3. Group A soils are not found in the Mad River Basin and therefore are not described below. Soils with a dual grouping in fig. 3 are wet soils that are rated D in their natural condition (hence the second letter of the dual grouping) but for which tile drainage is feasible. The first letter of the dual grouping applies to the drained condition.]

Hydrologic group	Definition
B	Silt loam or loam. Moderate infiltration rate when thoroughly wetted. Moderately deep to deep, moderately well drained to well drained soils that have moderately fine to moderately coarse texture. Moderate rate of water transmission.
C	Sandy clay loam. Slow infiltration rates when thoroughly wetted. Soils chiefly have a layer that impedes downward movement of water or have moderately fine to fine texture. Slow rate of water transmission.
D	Clay loam, silty clay loam, sandy clay, silty clay, or clay. Very slow infiltration rates when thoroughly wetted. Soils chiefly have a high swelling potential, have a permanent high water table, have a claypan or clay layer at or near the surface, or are shallow soils over nearly impervious material. Very slow rate of water transmission.

Table 3. Land-cover data for the Mad River Basin.

[Land-cover data obtained from U.S. Geological Survey, 1992. Some categories were reclassified for the model, as indicated below. NLCD, National Land Cover Dataset 1992; HSFP, Hydrological Simulation Program—Fortran]

NLCD classification	Percent	HSPF model aggregate classification	Percent	Percent impervious
Open water	0.91	Water	0.91	0
Low-intensity residential	5.20	Low-intensity residential	5.20	5
High-intensity residential	1.29	High-intensity residential	1.29	15
Commercial/industrial/transportation	2.67	Commercial/industrial/transportation	2.67	60
Quarries/strip mines/gravel pits	0.00			
Transitional	0.04	Urban or built-up land	2.24	10
Urban/recreational grasses	2.20			
Deciduous forest	12.42			
Evergreen forest	0.15			
Mixed forest	0.02	Forest land	12.93	0
Woody wetlands	0.24			
Emergent herbaceous wetlands	0.10			
Pasture/hay	17.74	Pasture	17.74	0
Row crops	57.01	Agricultural land	57.01	0

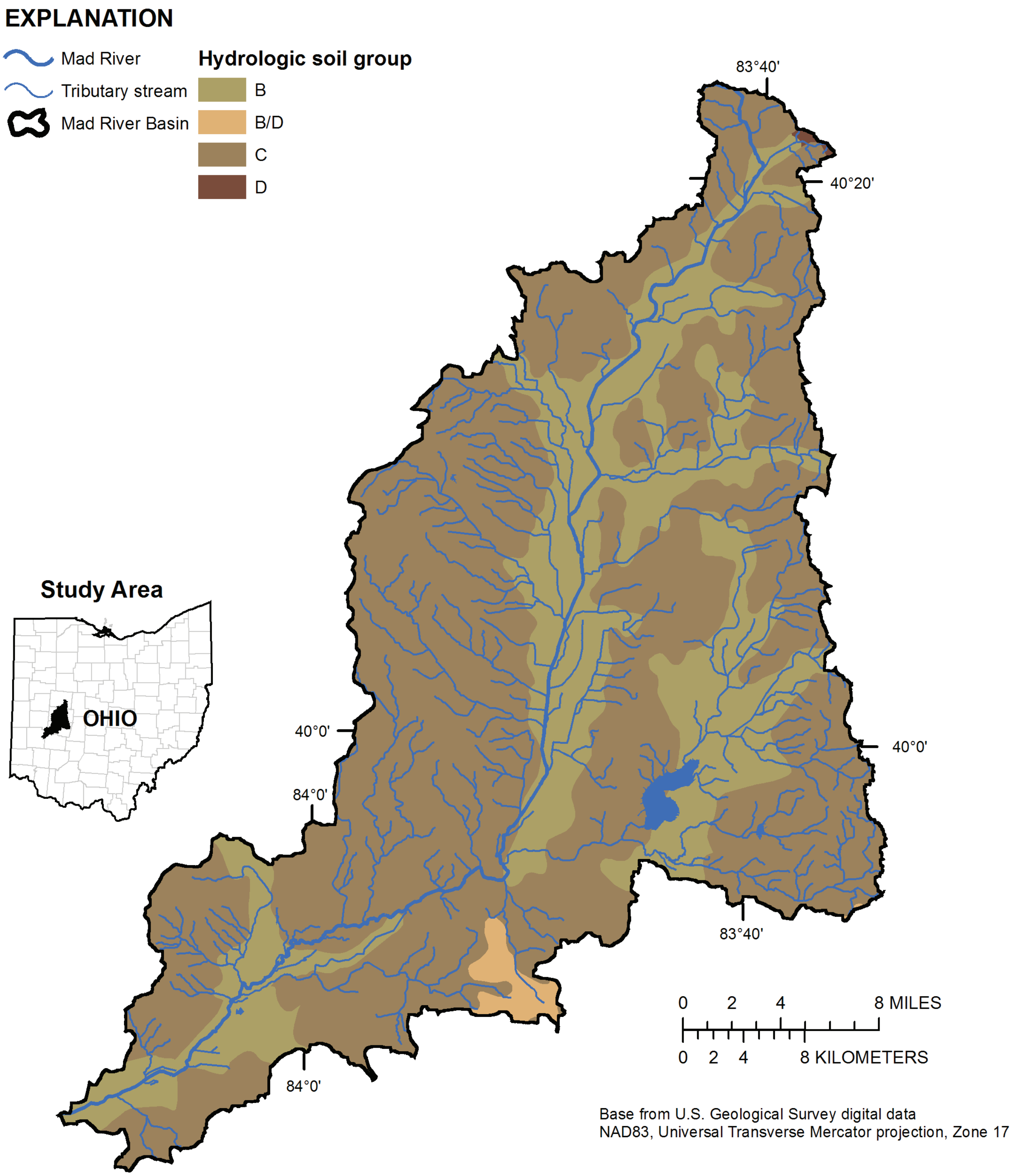

Figure 3. Hydrologic soil groups in the Mad River Basin. (Data from U.S. Department of Agriculture, 1991a.)

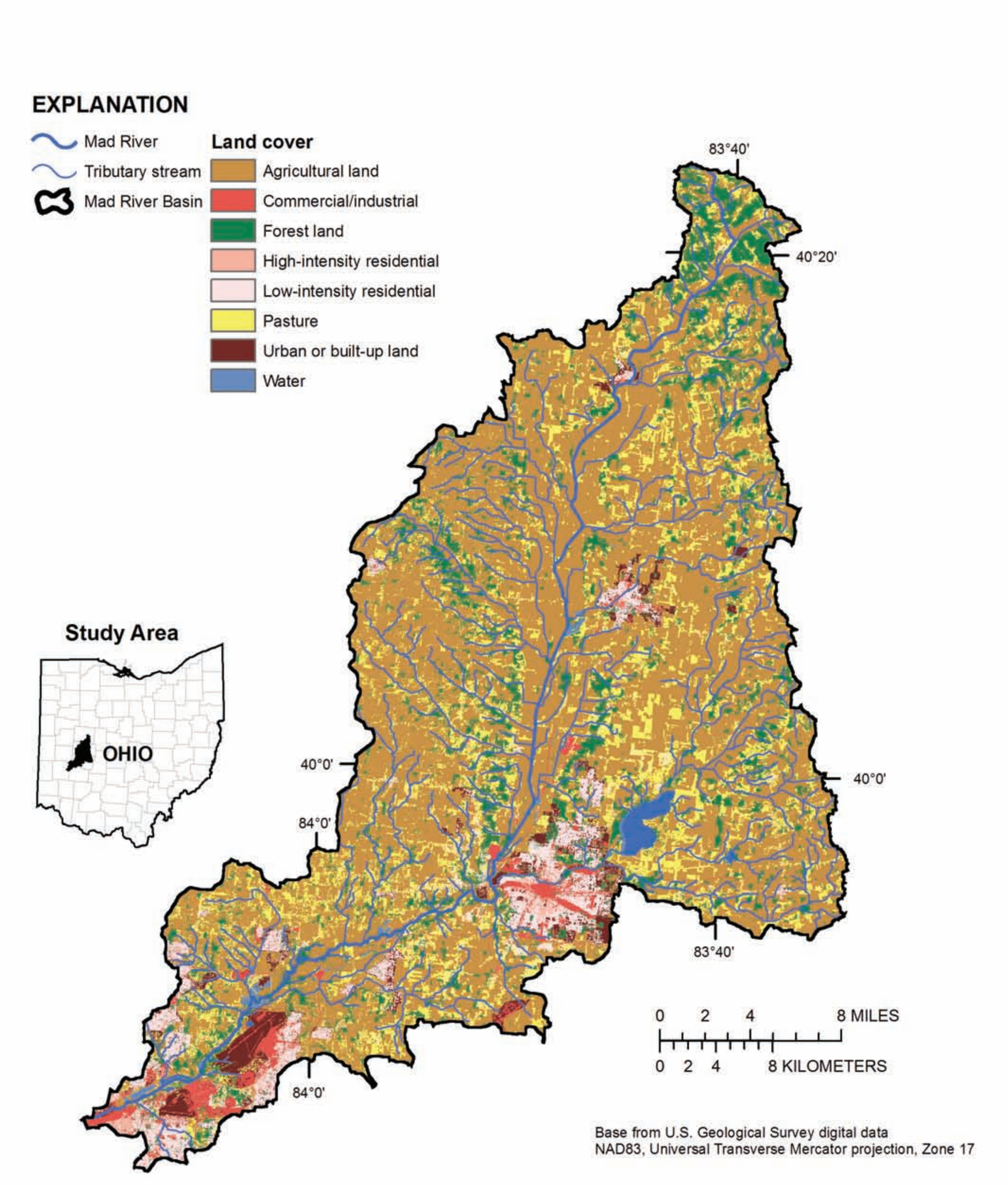

Figure 4. Land cover in the Mad River Basin. (Data from U.S. Geological Survey, 1992.)

Land cover

Land-cover data in the Mad River Basin were derived from the National Land Cover Dataset (NLCD) (U.S. Geological Survey, 1992). This was the most recent dataset available when the study began.

Land cover in the Mad River Basin, as described in table 3 (p. 7) and figure 4 (p. 9), is primarily agricultural, with approximately 57 percent of the land planted in row crops and almost 18 percent used for pasture. Approximately 13 percent of the basin is forested. Land-cover percentages calculated for each subbasin (Appendix 1) indicate that the percentage of forest is highest in the headwaters region of the Mad River, from the Machochee Creek Subbasin north.

Residential properties cover approximately 6.5 percent of the Mad River Basin, but most of this is land classified as low-intensity residential, which commonly includes single-family housing units in areas with a mixture of constructed materials and vegetation. Less than 2 percent of the land cover is classified as high-intensity residential, where people live in high numbers and vegetation accounts for less than 20 percent of the land cover (U.S. Geological Survey, 2003). Most of the high-intensity residential land cover is in the Dayton and Springfield areas. Springfield is in the Buck Creek Subbasin.

Water Quality

The Mad River and its tributaries are affected by point and nonpoint sources of pollution. Point sources are those that discharge from a discrete location, such as a pipe or drainage ditch. Nonpoint-source pollution does not have a single point of origin but rather comes from diffuse sources over a relatively large area. Contaminants from nonpoint sources reach a stream either in surface runoff, interflow, or seepage to ground water from precipitation on a land cover; through air pollution; or from malfunctioning septic systems. Typical nonpoint-source contaminants include fertilizer and pesticides applied to agricultural fields or suburban lawns. Agencies and individuals who have previously investigated water quality in the Mad River Basin agree that nonpoint sources of pollution have significantly affected the basin's water quality (Pennino, 1984; Rankin and others, 1987; Reutter, 2003; Miami Conservancy District, 2004; Rowe and others, 2004). Ohio EPA has been tasked with assessing the effects of both point and nonpoint sources of pollution on the quality of water in the Mad River Basin (as well as other waterbodies in Ohio) and ensuring that the chemical, physical, and biological integrity of the State's waters are restored and maintained (Section 101a of Public Law 92-500).

Designated Uses

Ohio EPA has done several assessments of streams in the Mad River Basin beginning in 1986 to evaluate whether particular waterbodies are achieving Clean Water Act goals of being fishable and swimmable. First, Ohio EPA must establish designated uses for each stream segment, meaning that the waterbody has the potential to support that use. Use designations are divided into three categories: (1) aquatic life habitat, indicating the types of organisms the waters are capable of supporting, (2) water supply, indicating the type of consumptive use by humans for which the waters are suitable, and (3) recreation, designating the type of body contact for which the waters are suitable. The type of use designation given to a waterbody affects the criteria applied to ensure that the waters are fishable and swimmable, thus affecting the target concentrations assigned later in this report.

The two use designations pertinent to this report are aquatic life use and recreational use. For aquatic life use, Ohio EPA has designated the Mad River main stem (from the headwaters to Buck Creek) and several tributaries as cold-water habitat; downstream from Buck Creek, the aquatic-life use designation of the Mad River main stem is warm-water habitat. For recreational water use, all waters except West Liberty Tributary have been designated as primary contact waters (Ohio Environmental Protection Agency, 2005a).

The most recent evaluation of the Mad River Basin by Ohio EPA was done, in part, to facilitate the TMDL calculation. Ohio EPA (2005a) did a basinwide assessment of fish and macroinvertebrate communities, water chemistry, and sediment chemistry from June to October 2003. General findings were that extensive channelization to facilitate agricultural production from Buck Creek to the headwaters has affected fish communities in the upper part of the basin. Deepening of the channels has caused greater influx of ground water to the streams and, as a result, has made the water temperatures cooler. In some cases (Macochee Ditch, Kings Creek, Dugan Run, Muddy Creek, tributary to Nettle Creek, Buck Creek downstream from C.J. Brown Reservoir, Moore Run, and Kenton Creek), limited sinuosity and lack of instream cover have adversely affected the fish and macroinvertebrate communities.

Fecal Coliform

Concentration of fecal coliform bacteria is one measure used to assess recreational water quality. However, information on fecal coliform bacteria in the Mad River Basin is limited. Fecal coliform concentrations in the Mad River at St. Paris Pike have been determined by Ohio EPA since 1999. In 2003, the Upper Mad River Steering Committee began monthly sampling for fecal coliform bacteria at 10 sites throughout the basin (Mad River Steering Committee, 2003a; data on file at the The Oho State University Extension, Champaign County). Although no published studies have resulted from these analyses, the raw fecal coliform data from both of these groups were used in this study for model calibration purposes.

Camp Dresser & McKee (1997) evaluated the effects of combined-sewer overflows (CSOs) on recreational use of streams in the Springfield area. Stream samples were collected at six sites within the City of Springfield (in the Buck Creek Basin) and from the Mad River downstream from the Springfield wastewater-treatment plant (WWTP) during the months of May through October 1997. Ten samples were collected during dry weather and three during wet weather (the day of a rain event and for three consecutive days thereafter). Dry-weather samples contained from 24 to 2,267 colonies of fecal coliform bacteria per 100 mL of water and were within water-quality standards (fewer than 10 percent of samples within a 30-day period exceeded 2,000 col/100 mL). Wet-weather samples revealed that water-quality standards for fecal coliform were exceeded for one to two days after a rainfall event in response to CSO discharges. A maximum concentration of 238,000 col/100 mL of water was observed during the wet-weather sampling on the Mad River downstream from the WWTP bypass (Camp Dresser & McKee, 1997).

A basinwide assessment of recreational water quality by Ohio EPA from June to October 2003 (Ohio Environmental Protection Agency, 2005a) found elevated concentrations of fecal coliform and *Esherichia coli* (*E. coli*) bacteria throughout the study area. These elevated concentrations were primarily associated with high streamflows after precipitation events. Bacteria concentrations were especially high on Buck Creek at RM 0.60, downstream from Springfield's numerous CSOs, after a precipitation event. However, the highest median concentration of fecal coliform bacteria in the entire basin (4,900 col/100 mL) was found in Lily Creek.

Other potential sources of fecal coliform bacteria in the basin are discussed in the "Source Representations" section of this report. These sources include WWTP discharges and failure of a proportion of the 28,000 septic systems in the basin. Additional sources include wildlife, livestock grazing in the 18 percent of the basin that is pasture, and manure applications to land planted in row crops.

Nitrate

Because agricultural land cover is prevalent in the study area, nitrogen has been a focus of many water-quality studies in the Mad River Basin. The predominant form of nitrogen in the Mad River is dissolved nitrate (Reutter, 2003), so the following discussion includes studies that analyzed for nitrogen as well as those that analyzed for nitrate.

Rowe and others (2004) examined surface- and ground-water quality as a function of land cover in the Great Miami and Little Miami River Basins from 1999 through 2000. They found that streams draining agricultural land had the highest mean concentration of nitrogen. The major source of nitrogen in agricultural areas was attributed to commercial fertilizer and manure applications.

Reutter (2003) quantified loads of nitrogen and phosphorus in the Mad River contributed by point sources and nonpoint sources. The loads were computed by use of the ESTIMATOR program (Cohn and others, 1992) from data collected during 51 visits to the Mad River at St. Paris Pike near Eagle City streamflow gage during water years 1999 and 2000. At this location, only 2 percent of the total nitrogen load was contributed by major point-source dischargers (defined by the author as dischargers of 0.5 Mgal/d or more). Nonpoint sources and minor point sources (defined by the author as dischargers of less than 0.5 Mgal/d) contributed 98 percent of the total nitrogen load. Even so, the nonpoint-source load reaching the Mad River represents only a fraction of the nitrogen deposited on land surface within the basin; only 18 percent of the nitrogen load from land-surface applications of manure and commercial fertilizer and from atmospheric deposition in the Mad River Basin was estimated to enter the Mad River (Reutter, 2003, p. 37). Reutter's analysis did not include contributions of nitrogen from urban runoff, CSOs, failing septic systems, or cattle in streams. Reutter also noted that, in the Mad River Basin and other drainage areas, higher median nitrogen concentrations were typically associated with higher percentages of land planted in corn and soybeans.

A significant amount of the total nitrogen load to the Mad River appears to be contributed by shallow ground water discharging to the main stem and many of the tributaries (Miami Conservancy District, 2004). Rowe and others (2004) noted a significant correlation between average nitrate[1] concentration in surface water during periods of low flow and the amount of base flow for streams in the Great and Little Miami River Basins. The Mad River had both the highest average nitrate concentration and the greatest base flow compared to other streams (Rowe and others, 2004, p. 22). Reutter (2003) observed that, compared to other streams in the Great Miami River Basin, there was much less difference between minimum and maximum monthly loads of nitrate in the Mad River at St. Paris Pike. Minimum monthly loads were about 15 percent of the corresponding maximum monthly load, compared to other sites where minimums ranged from about 0.2 to 2 percent of the corresponding maximum monthly loads. It is possible that fertilizer-derived nitrogen infiltrates more quickly in the soils of the Mad River Basin, which are permeable relative to soils in other subbasins of the Great Miami River Basin (Debrewer and others, 2000) and are underlain by an extensive, high-yielding aquifer composed of glacial outwash (Reutter, 2003). Therefore, less nitrogen is left at land surface to be transported to streams during runoff events. Instead, the nitrate-bearing shallow ground water continuously discharges to the Mad River as base flow, providing a stable input of nitrate to the Mad River.

Concentrations of nitrate in shallow ground water appear to be higher than those in surface water. Ground-water samples were collected from 33 wells in the Mad River Basin in summer 2003 (Miami Conservancy District, 2004). Although the median concentration for all wells was 0.5 mg/L, the median concentration of nitrate for the 13 wells installed at

[1]Actual analyte was nitrate plus nitrite. Because nitrite concentrations are generally very small compared to nitrate in both surface water (Reutter, 2003, p. 15) and shallow ground water (U.S. Geological Survey, 2000), nitrate plus nitrite will hereafter be referred to as "nitrate" in this report.

depths of 50 ft or less was 6.0 mg/L. Three samples exceeded the USEPA Maximum Contaminant Level for nitrate in drinking water (10 mg/L as N). Comparatively, concentrations of nitrate in surface water at the Mad River near Huffman Dam (collected in 8-hour increments between July 14 and August 18, 2003) ranged from 1.32 mg/L to 4.06 mg/L, with a median value of 3.07 mg/L. Nitrate concentrations were inversely correlated to river discharge (Miami Conservancy District, 2004). Jones and others (1996) examined nitrate contamination from nonpoint sources in ground water and surface water in the Mad River Basin. They found nitrate concentrations to be routinely higher in the Kings Creek Subbasin than elsewhere in the basin.

Ohio EPA (2005a) did a basinwide assessment of fish and macroinvertebrate communities, water chemistry, and sediment chemistry in the Mad River Basin from June to October 2003. Elevated nitrate concentrations found in Kings Creek and two of its tributaries (median, 7.1 mg/L), as well as in Dugan Run and Buck Creek above C.J. Brown Reservoir, were attributed to high volumes of ground-water inflow to streams in areas where agriculture is the predominant land cover and ground water is near land surface. Elevated nitrate concentrations in other stream reaches (St. Paris tributary to Nettle Creek, Stony Creek, and Mud Creek) were attributed to point sources. Elevated nitrate concentrations in Clear Creek (RM 0.50, median concentration 7.45 mg/L) may have been due to cattle in a pasture upstream from the sampling location.

Simulation of Streamflow and Water Quality

Description of Model

The HSPF model used for this study was developed with BASINS using several Geographical Information System (GIS) input datasets. The GIS datasets used to construct the model include the National Land Cover Dataset (NLCD) (U.S. Geological Survey, 1992), the National Elevation Dataset (NED) (U.S. Geological Survey, 2005a), and the National Hydrography Dataset (NHD) (U.S. Geological Survey, 2005b). Other GIS data were used to assist with model parameter estimation but were not necessary to create the model. WinHSPF version 2.3 is an interactive Windows interface to HSPF developed to assist the user in building and editing user control input (UCI) files. Furthermore, WinHSPF was used primarily for model manipulation and simulation. Use of HSPF provides a maximum amount of flexibility to address complex issues. HSPF uses hourly and (or) daily time series of rainfall and other meteorologic records to simulate the transport and storage of water and associated water-quality constituents. Precipitation can be routed from pervious and impervious land areas as a combination of surface runoff, interflow through various subsurface layers, and base flow (ground-water discharge). Assigned hydrologic response parameters (based on land cover, slope, soil properties, and other characteristics) control how precipitation is partitioned into these possible flow routes. In addition to infiltration of precipitation, the model accounts for impervious surfaces (for example, tops of buildings and pavement), interception of precipitation by plant materials before it reaches the ground, surface-detention storage, evaporation, transpiration, and storage in soil zones or ground water.

Routing of water in the stream channel is controlled by channel characteristics in each of the model subbasins. Flow in the channel is assumed to be unidirectional and to follow the kinematic wave function (Martin and McCutcheon, 1999). Inflows to each subbasin include flow from the land area (pervious and impervious) draining to that subbasin, water from upstream subbasins, precipitation falling directly on the stream surface in the subbasin, and point sources discharging to the subbasin. Outflows from a subbasin include flow to the downstream subbasin, evaporation, transpiration, loss to ground water (deep percolation), and point-source withdrawals. For each subbasin, a function table (FTABLE) summarizes the relation among water depth (stage), surface area, volume, and discharge on the basis of geometric and hydraulic properties used for channel and reservoir routing.

Only after the hydrologic model has been calibrated can water quality be accurately simulated. HSPF simulates transport and chemical reactions of constituents from land draining to a stream reach and water temperature within a reach (as well as the temperature of runoff to a reach). Chemical constituents can be transported in surface runoff, interflow, or ground water. On impervious land, constituents can accumulate on the surface and later be washed into the stream reach during a rainfall event. Predation and die-off of bacteria within the stream also can be modeled.

The HSPF model requires a significant amount of input data to effectively simulate hydrologic conditions. The input requirements consist of observed meteorologic time-series data from numerous sources, including precipitation, cloud cover, air temperature, wind movement, solar radiation, dewpoint temperature, and estimation of potential evapotranspiration. These data are assembled and stored in a binary database using watershed data management (WDM) format. The data can be created, imported, edited, displayed, and modified by use of the program/software package WDMUtil (Hummel and others, 2001). The model requires an hourly time step for the input precipitation dataset; all other datasets can be at a daily time step.

The Bacterial Indicator Tool (BIT) is a spreadsheet that was used to estimate fecal coliform contributions from multiple sources. The BIT estimates the monthly accumulation rate of fecal coliform produced by wildlife, grazing livestock, and manure applications, as well as the asymptotic limit for that accumulation should no washoff occur. The BIT also estimates the direct inputs of fecal coliform to streams from grazing animals and failing septic systems (U.S. Environmental Protection Agency, 2000b). The BIT user must supply the land-cover distribution and livestock population for each meteorologic zone and wildlife densities for forest, agricultural land, and pasture in the study area. The BIT user must also supply the number of septic systems, population served by septic systems, and the failure rate of septic systems in the study area. The animal-waste production rates and fecal coliform content, the fraction of each manure type applied each month, and the fraction of each manure type incorporated into the soil were default values in the BIT that were not modified for this model.

The model simulation period, January 1999 through December 2003, was selected on the basis of the availability of information for streamflow and water quality. This period includes water-quality data for simulating, calibrating, and validating the modeled results.

Meteorologic Data

Several meteorologic stations were identified in the study area. Precipitation station data from the National Oceanic and Atmospheric Administration (NOAA) and MCD were evaluated for type, length, and continuity of record, and data from four stations were selected for final application (table 4; fig. 5). These four stations were well distributed spatially, and missing data were minimal. Daily precipitation data from one NOAA station had to be disaggregated to hourly data on the basis of data from the nearest hourly precipitation station.

Other meteorologic data such as air temperature, wind movement, solar radiation, dewpoint temperature, cloud cover, and computed potential evapotranspiration were obtained from nearest first-order NOAA station; such stations are usually fully instrumented to record a complete range of meteorologic parameters. These data were acquired from NOAA station 332075 at Dayton Airport, about 5 mi west of the lower Mad River Basin.

Streamflow Data

Fifteen USGS streamflow gages are within the study area. All 15 gages were analyzed for length of record, data gaps, and basin distribution. Data from four of these gages were judged adequate for calibration of both water quantity and water quality (fig. 5). Daily streamflow data from these gages were obtained from the U.S. Geological Survey (2005c) and used for model calibration.

Model Segmentation

Segmentation of the basin is an important component of HSPF modeling for controlling parameter manipulation and assigning multiple spatially distributed input time series. The Mad River Basin was divided into 52 subbasins with drainage areas ranging from 79 to 11,355 acres. The subbasins initially consisted of 14-digit hydrologic units (HU) as defined by Seaber and others (1987). In some cases, subbasins were then further subdivided to coincide more closely with critical water-quality data collection sites and streamflow gages (fig. 6).

The model calibration and simulation process required formation of regions with homogeneous meteorologic characteristics for input of meteorologic time series. These regions are referred to as “meteorologic zones.” Four meteorologic zones were constructed for the hydrologic simulation by grouping subbasins on the basis of centroid location relative to precipitation station thiessen-polygon coverage area. To facilitate adjustment of parameters for water-quality modeling, it was necessary to subdivide the original four meteorologic zones further, resulting in a total of nine meteorologic zones (fig. 7). The additional five meteorologic zones retain the initial meteorologic time-series definition and precipitation correction factors.

Table 4. Annual and total precipitation at meterological stations near the Mad River basin, 1999–2003.

[NOAA, National Oceanic and Atmospheric Administration; MCD, Miami Conservancy District]

Station	Correction factor	1999	2000	2001	2002	2003	Total
330563 NOAA - Belfontaine	1.05	36.2	44.6	43.6	42.7	54.2	221.3
5000 MCD - Springfield	1.00	27.6	41.8	46.5	44.3	51.2	211.4
5020 MCD - Urbana	1.12	29.1	41.0	41.6	40.5	51.6	203.8
332075 NOAA - Dayton Airport	1.00	28.2	33.7	42.2	38.7	44.0	186.8

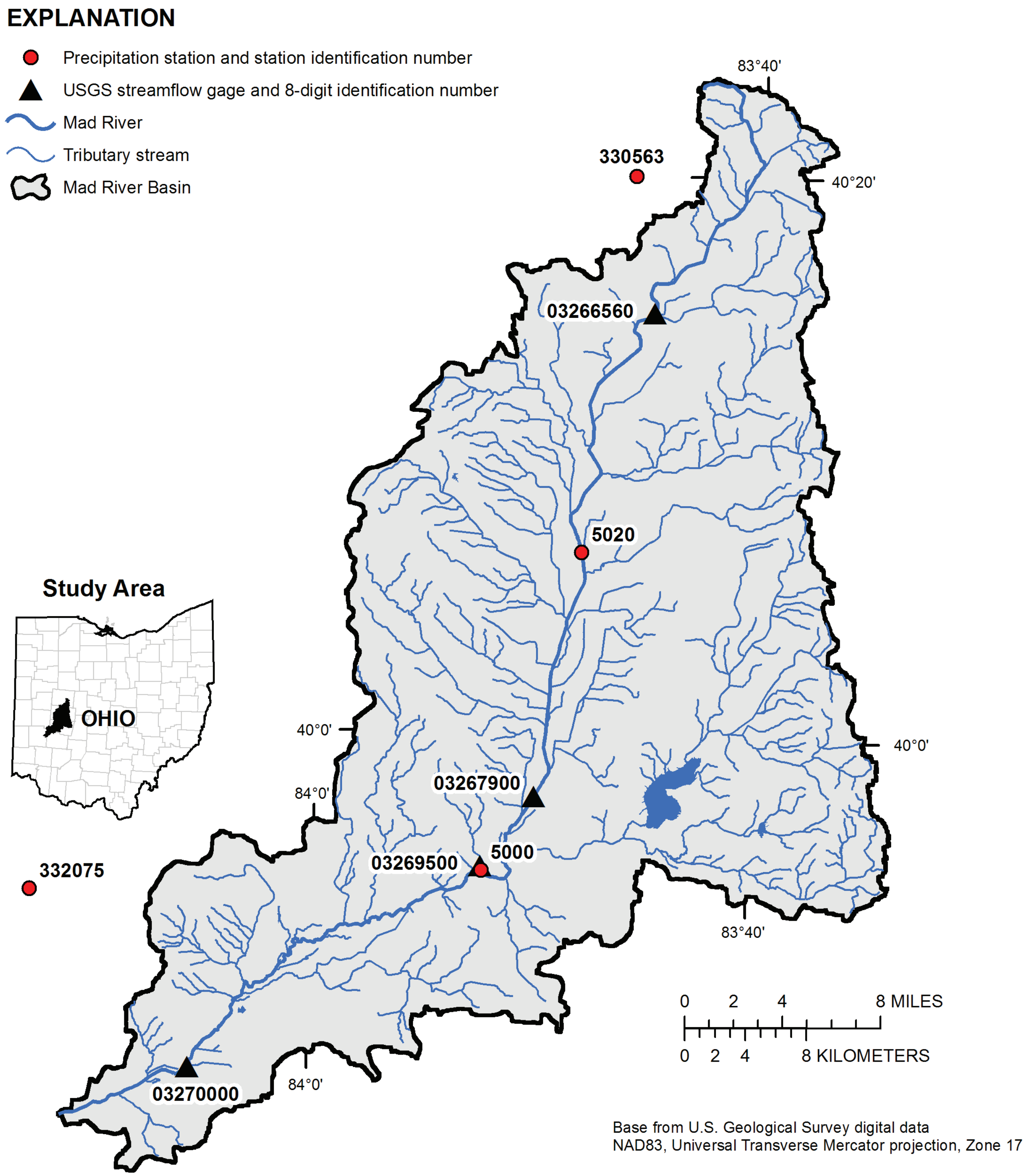

Figure 5. Location of streamflow gages and precipitation stations used for construction of the hydrologic model of Mad River Basin. (Station names given in tables 4 and 5.)

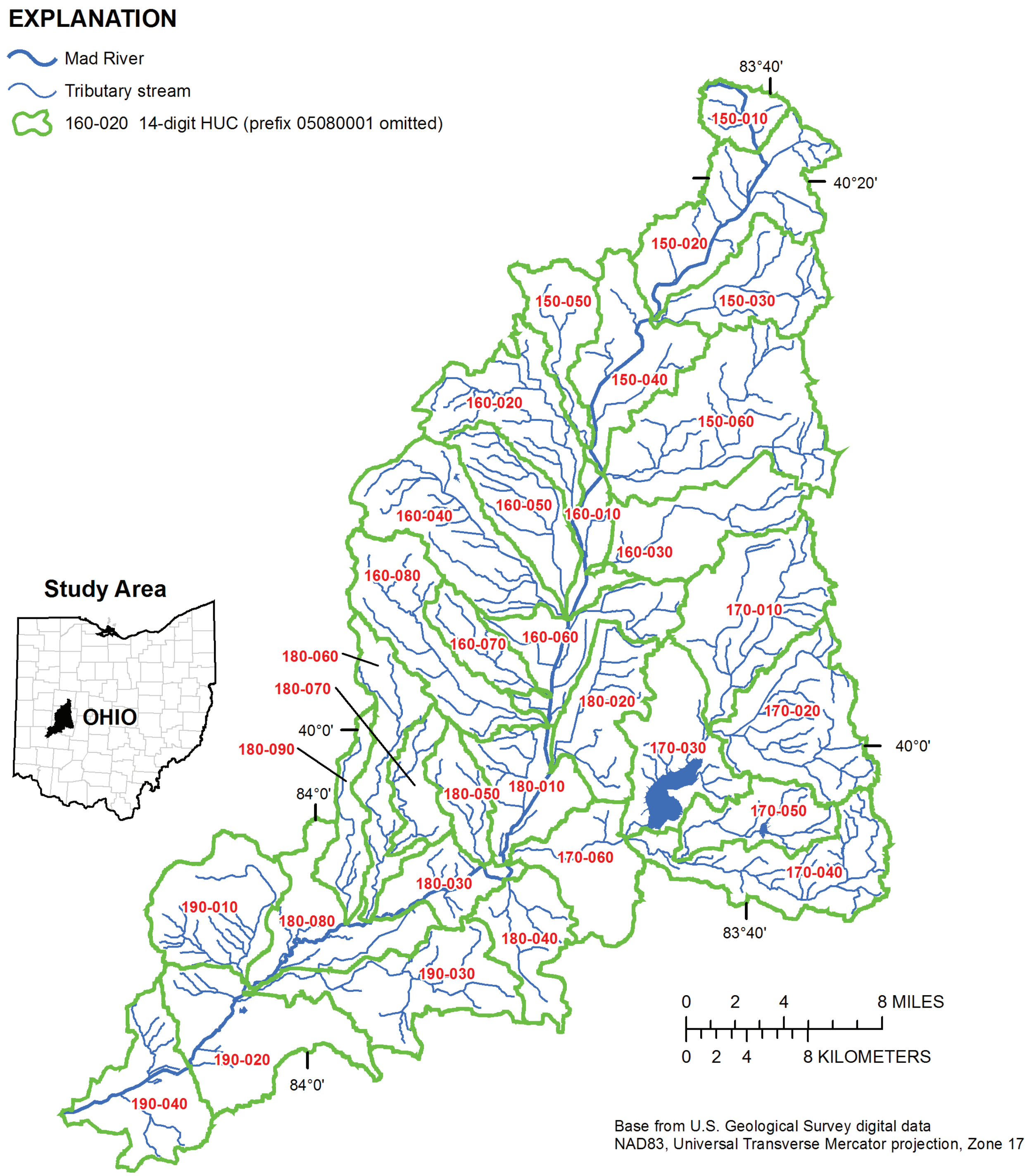

Figure 6. Location of 14-digit hydrologic units (HUs) in Mad River Basin. (HUC data from U.S. Department of Agriculture, 1991b.)

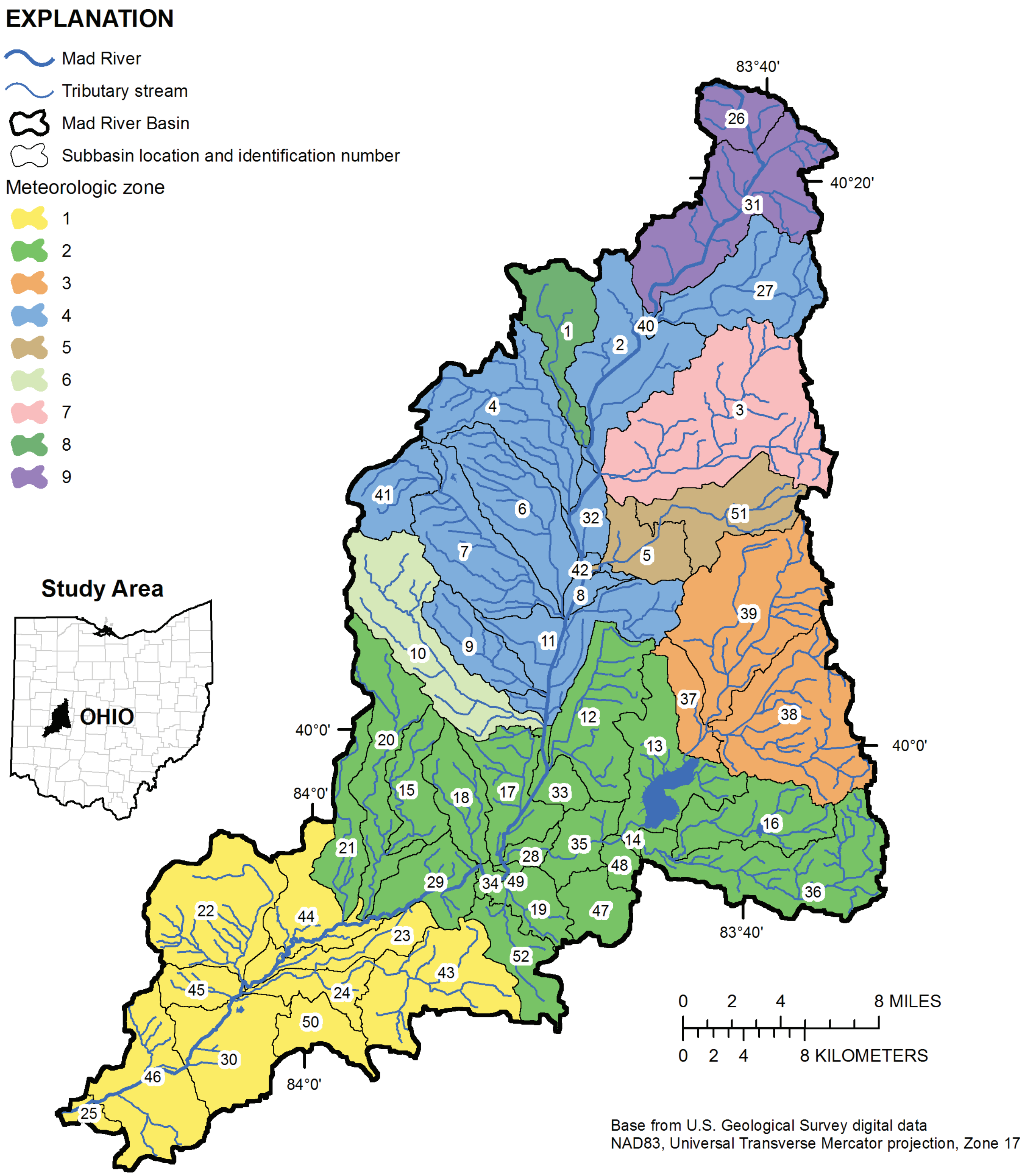

Figure 7. Location of 52 modeled subbasins and 9 meteorologic zones in the Mad River Basin.

Model Limitations

The hydrologic model constructed for this study was developed to simulate daily mean discharge and ultimately to estimate water-quality loads of fecal coliform bacteria and nitrate. The calibration and simulation were prepared to support the specific requirements of this study.

HSPF models have the potential to be used for many water-resource management applications. This model was constructed specifically for simulating daily streamflow and constituent loading in the Mad River Basin. Therefore, use of this model for other applications could produce inaccurate or deceiving hydrologic response and results. Uses of the model outside the constraints of this study could require additional calibration and (or) parameter modification.

Hydrologic Simulation

Hydrologic simulation combines the physical characteristics of the watershed and the observed meteorologic data series to produce the simulated hydrologic response (Donigian, 2002). Daily mean streamflows were simulated for the period January 1999 to December 2003. This 5-year period comprises sufficient data to evaluate parameters within a variety of hydrologic conditions (Donigian, 2002). Subbasin characteristics such as channel slope, average land slope, and depth-volume relation were computed by extracting information from the 30-meter NED (U.S. Geological Survey, 2005a). The NED also aided in producing the FTABLEs discussed previously.

The land-cover characteristics for each subbasin were differentiated by 14 land-cover classes from the National Land Cover Dataset (U.S. Geological Survey, 1992). These classes were analyzed and aggregated into eight general categories based on hydrologic response similarities (table 3). The contribution of impervious land cover in the model was estimated by applying a percentage of impervious surface based on the land-cover class and amount of effective imperviousness. The percent impervious area used in this study was based on final calibrated percentages derived from similar land-cover classes in a study reported by Zarriello and Ries (2000) (table 3). Appendix 1 details land-cover information for the 14-digit Hydrologic Unit and subbasin boundaries used in the model.

Hydrologic Calibration

The Mad River Basin model was calibrated for the 4-year period January 1, 1999, through December 31, 2002; results were output at a daily time step. The calibration approach used for this study included use of GenScn (Kittle and others, 1998) for comparing observed and simulated results and HSPEXP (Lumb and others, 1994), an expert system for hydrologic calibration that incorporates parameter-adjustment assistance and comparative statistics.

The hydrologic calibration for this study involved examination of the following model response characteristics: (1) annual water balance and volume, (2) monthly and seasonal flow volume, (3) base flow, and (4) storm volume. The calibration focus was aimed at providing accurate flow simulations, especially for the annual period and the recreational season (May 1 through October 15) so that constituent loading also could be simulated accurately. The observed and simulated values for these flow characteristics were compared and parameters were adjusted iteratively by use of HSPEXP and manual edits until simulated values met the acceptable criteria chosen for this study. Parameters were modified for each meteorologic zone to simulate surface runoff, interflow, base flow, and total runoff. Values of the principal hydrologic parameters modified during calibration are listed in Appendix 2. The comparison of simulated and observed streamflow included evaluation of total volume; seasonal volume; storm volume for normal, low, and high flow regimes; seasonal variability; and 20 selected storm events. Plots of daily mean streamflow were used to compare simulated and observed results for the calibration time period (fig. 8). Flow-duration plots of simulated flows are reasonable in comparison to the observed flows during the calibration period (fig. 9). Table 5 lists the streamflow calibration results for the 4-year period, including the acceptable criteria used in this study.

In addition to model-parameter adjustment, precipitation data were adjusted by the use of a correction factor or multiplier to account for under-registering of precipitation gages with a tipping-bucket mechanism (Kuligowski, 1997). The precipitation correction factors ranged from 1.0 to 1.12 for hourly values (table 4, p. 13). The final determination of the correction factor was derived from an annual volume calibration for four USGS streamflow gages.

The large base-flow component of the Mad River required use of the upper range of parameter values for the AGWRC parameter (ground-water recession rate) to accurately simulate hydrograph-recession characteristics. A quantitative analysis of surface runoff and base flow to gross streamflow was documented in a USGS study (Koltun, 1995). Table 6 lists the percentage difference between modeled median annual base flow and results from Koltun (1995) for the four streamflow gages in the Mad River Basin. In addition, interflow and surface-runoff annual contribution to total simulated flow ranged from 23.0 to 26.3 percent and 5.3 to 9.9 percent, respectively. However, flow contribution from interflow and surface runoff for individual storm events varied widely depending on antecedent moisture condition, precipitation intensity, storage capacity, infiltration capacity, and other factors.

The model was validated by simulating streamflow for calendar year 2003. Once parameter values were established for the calibration period, the model was rerun by including calendar year 2003. Annual streamflow statistics and validation results for the four streamflow gages are listed in table 5. The calibration and validation aggregate simulation periods explain the total error, whereas the annual statistics are evidence of the accuracy. Verification of streamflow response was acceptable by meeting either of the two criteria for the

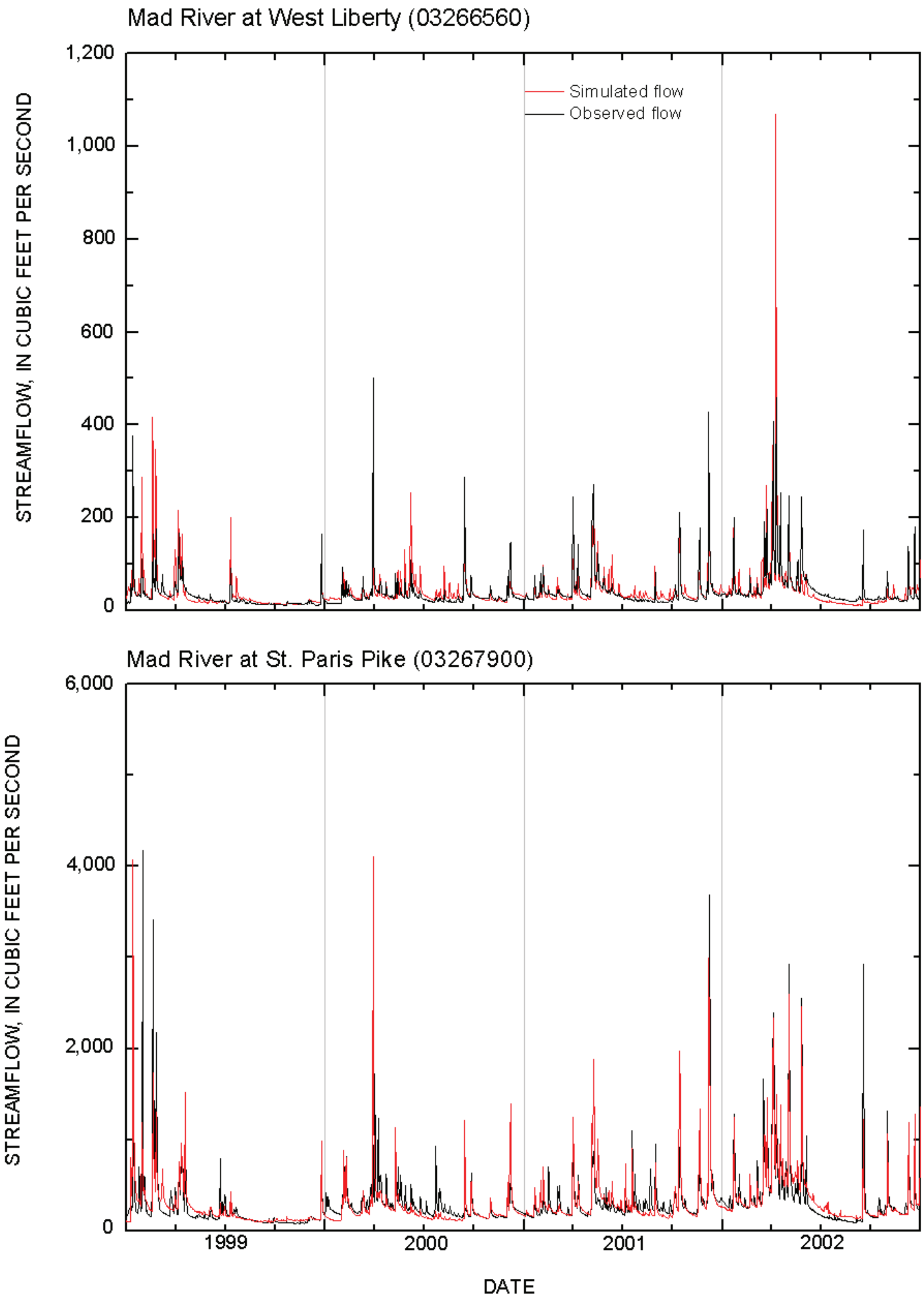

Figure 8a. Relation of simulated daily mean streamflow to observed daily streamflow for Mad River at West Liberty (03266560) and Mad River at St. Paris Pike (03267900), January 1, 1999, through December 31, 2003.

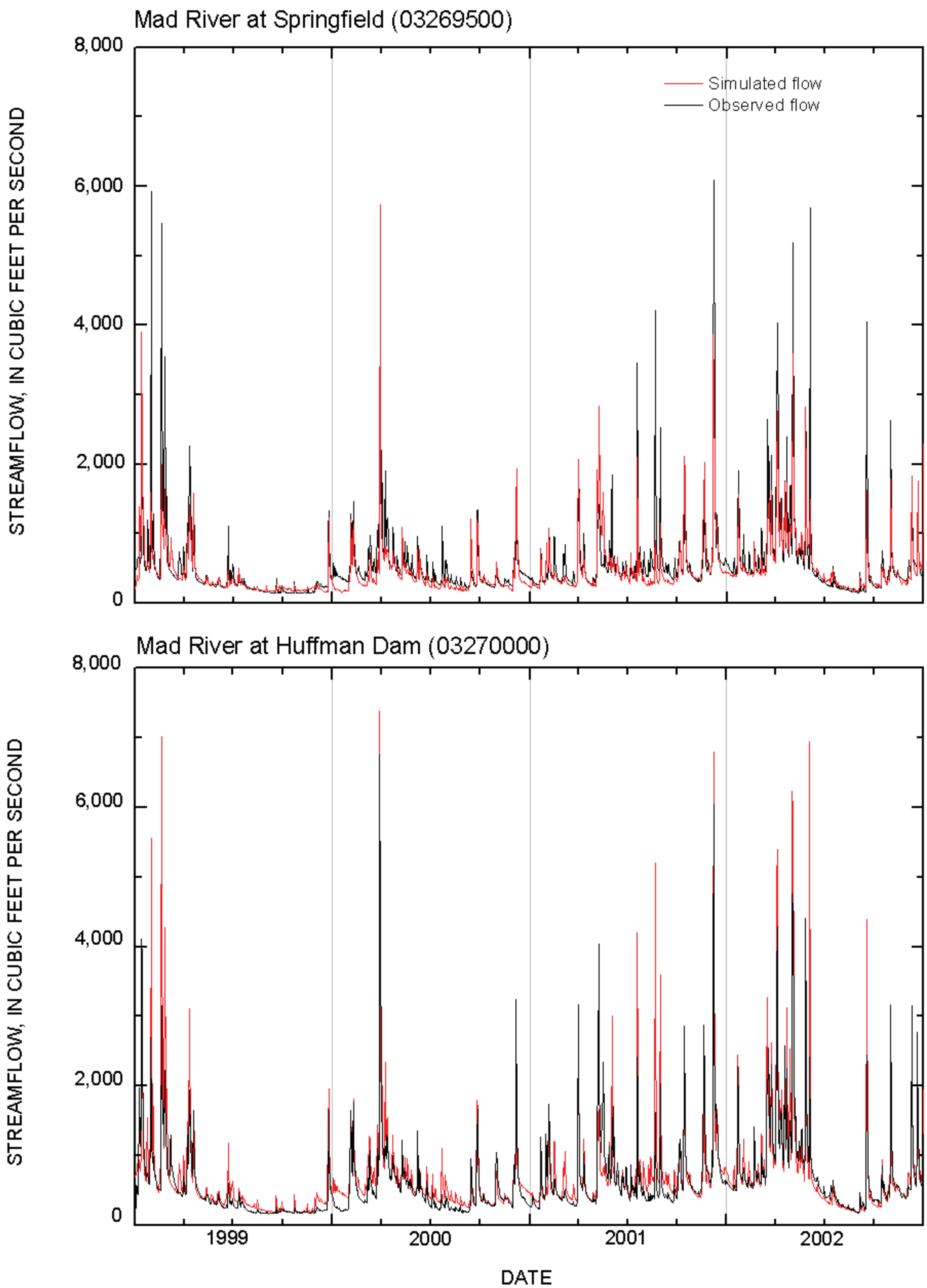

Figure 8b. Relation of simulated daily mean streamflow to observed daily streamflow for Mad River at Springfield (03269500) and Mad River at Huffman Dam (03270000), January 1, 1999, through December 31, 2003.

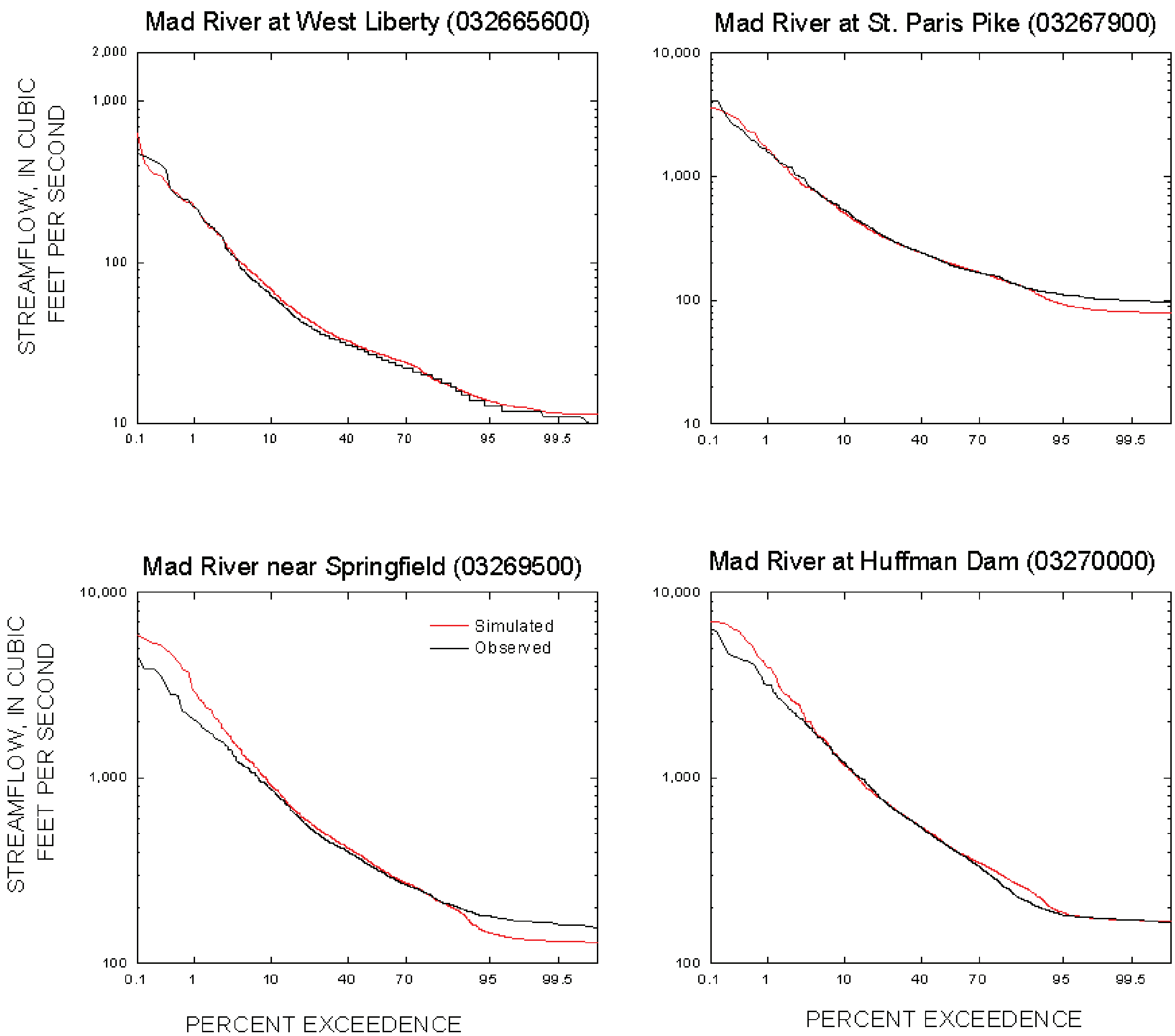

Figure 9. Flow-duration curves of simulated and observed streamflows for Mad River at West Liberty (03266560), Mad River at St. Paris Pike (03267900), Mad River near Springfield (03269500), and Mad River at Huffman Dam (03270000), 1999–2003.

simulation that included 2003. First, the validation period error should fit within the minimum and maximum annual error of the calibration period. Second, the absolute error in the validation period and the aggregate period, 1999–2003, should meet the 1999–2002 calibration criteria. Results for streamflow gage 03266560 show minor exceedance of these criteria for storm volumes and peak streamflow; however, of the four streamflow gages used for the model, this station has the smallest contributing drainage area (36.6 mi^2), making it potentially more sensitive to precipitation input and prone to greater simulation error. Comparison of the simulated and observed streamflow results for these periods indicated that simulation errors were generally within the calibration criteria chosen for the model.

In conclusion, model parameters calibrated on data for the period 1999 through 2002 appear to result in acceptable simulations of other adjacent time periods. The HSPF model is mostly controlled by land-cover characteristics and the parameter values for each land-cover class within a meteorologic zone. Furthermore, it is expected that model-simulation results would be similar for times near the calibration period and (or) land cover that is not significantly different from that represented by the NLCD dataset. Values of the principal parameters used to calibrate the model for streamflow simulation are listed in Appendix 2.

Table 5. Calibration criteria, simulation error, and validation results at four streamflow gages in the Mad River Basin.

[mi², square miles; positive error means the simulated value is greater than the observed value]

		Error in total volume (%)	Seasonal volume error (%)	Error in 50% lowest flows (%)	Error in storm volumes (%)	Summer storm volume error (%)	Average storm peak flow error (%)	Error in 10% highest flows (%)
1999-2002 Calibration criteria		10	10	10	15	20	25	25
03266560 Mad River at West Liberty, subbasin 31 (area, 36.6 mi²)								
Individual-year calibration	1999	22.8	19.4	10.6	27.2	-51.6	0.9	59.9
	2000	12.9	58.5	20.1	-18.7	172.1	-23.6	-1.9
	2001	3.1	30.1	16.1	-18.7	56.3	-27.9	-13.0
	2002	-6.9	50.4	-23.1	-26.1	-37.0	-35.9	2.0
Aggregate results	1999-2002	5.8	0.7	4.5	-10.0	-10.9	-23.7	5.6
Summary statistics for 1999-2002 calibration	Minimum	-6.9	19.4	-23.1	-26.1	-51.6	-35.9	-13.0
	Maximum	22.8	58.5	20.1	27.2	172.1	0.9	59.9
	Median	8.0	40.2	13.3	-18.7	9.6	-25.7	0.0
Validation results	2003	-6.6	25.5	-5.4	-28.6	32.0	-37.1	-5.2
Aggregate validation results	1999-2003	2.1	8.6	3.9	-16.9	6.0	-27.5	0.6
03267900 Mad River at St. Paris Pike, subbasin 33 (area, 310 mi²)								
Individual-year calibration	1999	-6.8	11.8	-9.9	-15.5	-8.3	-15.6	5.3
	2000	9.7	50.2	19.5	-31.9	100.8	-42.4	-9.7
	2001	-5.2	1.3	2.4	-16.0	61.9	-10.8	-14.0
	2002	-2.6	33.2	-14.3	25.7	-23.8	19.3	13.6
Aggregate results	1999-2002	-1.6	1.6	-1.7	-7.9	20.0	-10.1	-1.2
Summary statistics for 1999-2002 calibration	Minimum	-6.8	1.3	-14.3	-31.9	-23.8	-42.4	-14.0
	Maximum	9.7	50.2	19.5	25.7	100.8	19.3	13.6
	Median	-3.9	22.5	-3.8	-15.8	26.8	-13.2	-2.2
Validation results	2003	6.9	5.5	-4.2	10.3	17.5	3.1	28.4
Aggregate validation results	1999-2003	0.8	1.7	-1.3	-1.9	20.0	-7.2	7.3
03269500 Mad River near Springfield, subbasin 34 (area, 490 mi²)								
Individual-year calibration	1999	10.2	12.9	-10.9	12.4	-24.2	27.7	29.9
	2000	12.5	12.8	13.7	0.0	32.1	-12.1	11.0
	2001	6.9	21.9	7.4	0.4	74.1	17.6	9.4
	2002	9.1	17.1	-14.3	33.4	-32.7	36.2	39.6
Aggregate results	1999-2002	9.5	1.6	-0.5	11.4	10.6	17.3	22.5
Summary statistics for 1999-2002 calibration	Minimum	6.9	12.8	-14.3	0.0	-32.7	-12.1	9.4
	Maximum	12.5	21.9	13.7	33.4	74.1	36.2	39.6
	Median	9.7	15.0	-1.7	6.4	4.0	22.7	20.4
Validation results	2003	3.9	2.8	-8.7	7.2	20.9	16.8	36.7
Aggregate validation results	1999-2003	7.9	2.8	0.6	10.0	14.3	17.2	25.0
03270000 Mad River near Dayton, subbasin 30 (area, 635 mi²)								
Individual-year calibration	1999	17.5	4.7	17.4	5.8	-0.2	29.8	20.6
	2000	5.7	17.6	16.1	-10.4	-1.1	-15.0	-0.3
	2001	1.2	17.1	6.1	-5.2	52.1	-4.8	1.2
	2002	-0.7	9.2	-17.4	11.3	-15.4	7.7	16.1
Aggregate results	1999-2002	4.6	4.9	6.0	0.8	8.3	2.4	9.3
Summary statistics for 1999-2002 calibration	Minimum	-0.7	4.7	-17.4	-10.4	-15.4	-15.0	-0.3
	Maximum	17.5	17.6	17.4	11.3	52.1	29.8	20.6
	Median	3.4	13.2	11.1	0.3	-0.6	1.4	8.7
Validation results	2003	-8.1	7.8	-13.8	-5.6	30.4	-4.2	11.2
Aggregate validation results	1999-2003	0.9	5.5	3.6	-1.3	15.4	0.9	8.2

Table 6. Comparison of simulated and estimated median annual base flow, 1999–2002.

[Base-flow estimates from Koltun (1995); negative percent difference means estimated value greater than simulated value]

USGS station number	Median of annual base flow, in inches: Simulated	Median of annual base flow, in inches: Estimated	Percent difference
3266560	8.98	9.05	-0.8
3267900	9.00	10.10	-10.9
3269500	8.88	9.26	-4.1
3270000	8.75	9.07	-3.5

Table 7. Sensitivity of modeled runoff characteristics at gaging station 03270000 to variations in selected hydrologic model parameters for the period 1999–2002.

[Positive error means the simulated value is greater than the observed value. AGWRC, active ground-water recession rate; INFILT, infiltration capacity of the soil; INTERCEP, interception storage capacity; INTFW, interflow coefficient; KVARY, ground-water recession flow parameter; LSUR, length of the overland flow plane; LZETP, lower zone evapotranspiration parameter; LZETPARM, lower zone evapotranspiration; LZSN, lower zone nominal storage; UZSN, upper zone nominal storage]

		Error in total volume (%)	Seasonal volume error (%)	Error in 50% lowest flows (%)	Error in storm volumes (%)	Summer storm volume error (%)	Average storm peak flow error (%)	Error in 10% highest flows (%)
	Calibration criteria	10	10	10	15	20	25	25
	Calibrated model error	4.6	4.9	6.0	0.8	8.3	2.4	9.3
Parameter	**Multiplier**							
AGWRC	0.9	17.4	87.9	-43.9	25.4	-13.8	20.2	77.1
INFILT	2	7.1	14.6	21.0	-14.8	11.9	-22.4	-4.8
INFILT	0.5	4.1	3.8	-6.3	17.3	6.1	31.9	26.1
INTERCEP	2	2.2	0.6	2.1	0.9	6.6	2.9	9.0
INTERCEP	0.5	6.2	8.6	8.7	0.6	9.0	2.0	9.4
INTFW	2	5.3	4.7	5.6	1.0	5.5	-5.4	8.6
INTFW	0.5	4.1	6.2	5.1	4.1	11.5	11.8	12.9
KVARY	2	9.6	3.5	5.2	5.3	4.7	4.6	14.3
KVARY	0.5	-0.9	9.1	2.8	-2.9	9.9	0.4	5.4
LSUR	2	4.3	4.5	6.6	-1.3	6.8	-2.6	6.9
LSUR	0.5	5.0	5.4	5.2	3.6	12.0	8.3	12.6
LZETP	2	4.6	4.9	6.0	0.8	8.3	2.4	9.3
LZETP	0.5	4.6	4.9	6.0	0.8	8.3	2.4	9.3
LZETPARM	2	-3.9	4.9	-3.9	-9.1	7.2	-8.9	1.3
LZETPARM	0.5	19.4	2.1	20.1	22.3	7.0	27.7	28.6
LZSN	2	-5.1	23.4	3.8	-17.0	23.6	-17.7	-8.6
LZSN	0.5	10.4	14.4	2.4	16.3	-10.1	21.3	25.9
UZSN	2	-6.6	21.5	5.0	-24.3	23.2	-28.4	-13.9
UZSN	0.5	15.7	12.6	6.5	32.0	-3.7	42.9	35.4

Sensitivity Analysis

A sensitivity analysis illustrates the response of a model to modifications of input values. The sensitivity analysis was done by varying the principal hydrologic input parameters by fixed percentages from their calibrated values and recording the corresponding change in simulated flow characteristics relative to those determined from the calibrated model. Table 7 (p. 22) lists the relative changes in volumes and flows resulting from adjustment of each parameter. In some cases, changes in the simulation results due to parameter modifications were small because the model is relatively insensitive to changes in the parameter or the model parameter itself was constrained in some way. For example, the parameter value for AGWRC was near or at the maximum allowable model value, so an increased AGWRC had virtually no effect on the simulation results; however, decreasing the AGWRC value had a significant effect on flow, especially the low-flow regime. Adjustment of the INFILT (infiltration capacity of the soil) had a smaller effect on volume and a considerable effect on storm-event peak flow. Simulated high flow, storm volume, and storm peak are sensitive to changes to the parameters LZETPARM (lower zone evapotranspiration), LZSN (lower zone nominal storage), and UZSN (upper zone nominal storage).

Assumptions

Streamflow simulations include the following assumptions:

- Each subbasin within a meteorologic zone has a similar hydrologic response to the input data.
- Daily precipitation disaggregated into an hourly time series are sufficiently accurate.
- Precipitation data are accurate in amount and in spatial and temporal distribution.
- Meteorologic data other than precipitation are representative for all meteorologic zones.
- Differences between land-cover characteristics determined from the NLCD (near 1992) and the actual land-cover characteristics during the calibration period (1999–2002) minimally affect simulation results.
- Parameters for pervious and impervious land areas are representative of the designated meteorologic zone.

Water-Quality Simulation

The HSPF model was used to simulate water quality from 1999 through 2003 for each of the 52 subbasins within the Mad River Basin. The HSPF model is able to account for the movement of fecal coliform and nitrate from the land surface to the streams and through the stream network. The PQUAL module (for the pervious land segments) and the IQUAL module (for the impervious land segments) were used to simulate the transport of the constituents to the streams. The RCHRES module was then used to simulate the transport of fecal coliform and nitrate through the stream network.

The PQUAL module simulates storages and fluxes of fecal coliform and nitrate by means of surface runoff, interflow, and base flow. The deposition of these constituents onto the surface is first defined in the PQUAL module by the monthly accumulation rates (MON-ACCUM). (Nitrate from the atmosphere is another source of deposition used in the model, but it is not a component of the PQUAL module). Fecal coliform and nitrate accumulate on the surface until a monthly storage limit (MON-SQOLIM) has been reached. Fecal coliform is removed from surface storage by either die-off or washoff. The removal rate (REMQOP) of the stored fecal coliform through die-off is defined by the ratio of the monthly accumulation rate (MON-ACCUM) and the monthly storage limit (MON-SQOLIM). Nitrate and the remaining fecal coliform are removed from surface storage by overland flow. The transport of fecal coliform and nitrate by overland flow (SOQUAL) is controlled in the model by the amount of overland flow (SURO) and the susceptibility of these constituents to washoff by overland flow (WSFAC).

The IQUAL module simulates storages and fluxes of fecal coliform and nitrate by means of surface runoff only. The transport processes through washoff are the same in the IQUAL module as those described for the PQUAL module; however, fecal coliform and nitrate stored on an impervious land segment are generally more susceptible to washoff than those stored on pervious land segments. Because of this, the WSFAC for impervious land segments is greater than that for pervious land segments.

A given constituent enters a stream segment from the permeable and impermeable land segments, point sources, and any upstream stream segments. Once the constituent is in the stream segment, the RCHRES module is used in this model to simulate its transport though a stream segment and on to the next downstream stream segment. The RCHRES module also simulates the die-off of fecal coliform within the stream segments with a first-order decay rate (FSTDEC). Additional information on the HSPF model processes used to simulation fecal coliform and nitrate can be found in Bicknell and others (1997).

Source Representations

As specified by Ohio EPA, this study addresses nutrient enrichment (specifically, nitrate) as one of the primary stressors impairing beneficial uses in the Mad River Basin. Also addressed are fecal coliform loads, which have caused some stream segments to be impaired for recreational use. Point sources, such as wastewater-treatment plants (WWTPs) and CSOs, discharge to the Mad River and its tributaries and are likely sources of both nitrate and fecal coliform. However, more diffuse (nonpoint) sources, such as urban and agricultural runoff, ground water contributions, livestock and wildlife, and atmospheric deposition account for the most of the nitrate load to the Mad River (Reutter, 2003). Quantification of sources fecal coliform and nitrate are discussed below.

Point sources included in the model were discharges from WWTPs and CSOs. Failed septic systems, atmospheric deposition (wet and dry sources), and cattle in streams are nonpoint sources that were also included in the model. These constituent sources were stored in the watershed data management (WDM) format, which could be read by the HSPF model. The WDMUtil program was used to create, import, edit, display, and modify these source load files. These sources are then directly input into the targeted stream segment (RCHRES).

Fertilizer and manure applications were not directly input to the HSPF model but were simulated by adjustment of model parameter values such as monthly maximum storage capacities of a constituent, monthly accumulation rates of a constituent, and monthly ground-water and interflow concentrations of a constituent.

Wastewater-Treatment Plants

The USEPA regulates discharges from municipal and industrial wastewater-treatment plants under the National Pollutant Discharge Elimination System (NPDES) permit program. Allowable pollutant loads and maximum allowable concentrations of pollutants in effluent water discharged to a stream are dictated by the NPDES permit (U.S. Environmental Protection Agency, 2003). In Ohio, this program is administered by the Ohio EPA. Table 8 lists NPDES-permitted facilities for which effluent data were provided by the Ohio EPA; these discharges were included in the HSPF model. The median discharge for the period from 1999 through 2004 is also listed along with its receiving stream. Although 2004 was not used to calibrate the HSPF model, this year was included in table 8 to provide a more complete representation of the discharge information. Facility locations are plotted on figure 10. The Springfield WWTP is the largest discharger in the basin, contributing almost 65 percent of the total median discharge (1999 through 2004) from the permitted point sources included in this study (table 8).

Monthly loads of fecal coliform and nitrate were computed from January 1999 through October 2004 for each of the 32 WWTPs listed in table 8. These loads were computed from concentration and discharge data provided by the Ohio EPA for this study. This information is available from the Monthly Operating Reports (MORs) that the permitted facilities are required to submit to the Ohio EPA. In cases where MOR data were incomplete, missing monthly loads were substituted with loads computed from the overall median of the nitrate concentration or the geometric mean of the fecal coliform count computed from the facility's available data. Many smaller discharge facilities were not required by the Ohio EPA to report fecal coliform and (or) nitrate data in their MOR. For nonindustrial facilities, the nitrate median concentration or the fecal coliform geometric mean computed from the other nonindustrial facilities in the study area were used as substitute concentrations of the unrecorded constituent. Loads were then computed using the substituted concentration with the recorded discharge for that facility. Discharges from some industrial plants and Wright-Patterson Air Force Base were excluded from this model because fecal coliform and nitrate data were not required in their MORs. (The MORs from these facilities are typically used to monitor constituents such as dissolved metals and organic compounds in these discharges.) In addition, Ohio EPA does not require discharge facilities to record fecal coliform concentrations in MORs from November through April. However, this study was interested only in the fecal coliform concentrations and loads during the recreational season designated by the Ohio EPA (May 1 through October 15). If known, the discharge design capacity of the WWTP was used in the model rather than the discharge recorded in the MORs. These discharge rates were chosen as part of the margin-of-safety requirements. (See "Margin of Safety" section for more information.)

City of Springfield Combined Sewer Overflows (CSOs)

Combined storm and sanitary sewers within the City of Springfield are another potential source of nitrate and fecal coliform to the Mad River Basin. This system is activated during storm events, when the capacity of the sewers is exceeded and untreated wastewater may overflow into streams. A total of 59 CSOs discharge within the City of Springfield (fig. 10) (Camp Dresser & McKee, 1999). Most of the outfalls discharge to streams in the Buck Creek Subbasin (53 outfalls) (Camp Dresser & McKee, 1998). A total of 340 Mgal of untreated stormwater and sanitary wastewater was discharged into the Buck Creek and Mill Creek Basins in 2003. This amount does not include the WWTP system relief (pipe identification DC01), which discharges directly into the Mad River. This system relief discharges untreated stormwater at rates estimated to be slightly greater than the combined discharge of the CSOs discharging into the Buck Creek and Mill Creek Basins (Camp Dresser & McKee, 1999). Because system-relief point DC01 is known to contribute the largest single total suspended solids and biochemical oxygen demand pollutant load, it is also assumed to contribute significant bacteria loads (Camp Dresser & McKee, 1999).

Daily loads of fecal coliform and nitrate from the 59 active CSOs within the City of Springfield were estimated for this study. These CSOs were grouped by their discharge location in relation to the subbasin defined by the HSPF model. Each group of CSOs was treated as one CSO point source within that subbasin. In all, six subbasins in the HSPF model include a point source representing CSO discharges. No measurements of nitrate or fecal coliform have been taken directly from these CSOs. The model used a fecal coliform count of 215,000 col/100 mL in CSO discharges, which is based upon the median fecal coliform concentration from 603 CSO discharges sampled throughout the Nation (U.S. Environmen-

Table 8. Point-source dischargers included in the Hydrological Simulation Program–Fortran model of the Mad River Basin.

[Flows computed from U.S. Environmental Protection Agency's Permit Compliance System database and Ohio Environmental Protection Agency data; Mgal/d, million gallons per day; MHP, mobile home park; WWTP, wastewater-treatment plant; RM, river mile; na, not available]

Reference number (fig. 10)	Facility name	Receiving stream	Median discharge (1999 –2004) (Mgal/d)	Design capacity (Mgal/d)
1	A & R Sunset Terrace MHP	Moore Run	0.02	na
2	Beaver Valley Resort	Beaver Creek	.009	na
3	Bridgewood MHP	Beaver Creek	.008	na
4	Brookside Village MHP	Sinking Creek	.03	na
5	Catawba WWTP	Tributary to East Fork Buck Creek	.23	na
6	Chateau Estates MHP	East Fork Donnels Creek	.06	na
7	Clark County Southwest Regional WWTP	Mad River (RM 13.33)	1.2	2.0
8	Clark Industrial Park	Moore Run	.004	na
9	Clearview MHP	Tributary to Mad River (RM 24.98)	.01	na
10	Enon Heights MHP	Tributary to Mad River (RM 21.1)	.013	na
11	Fairborn WWTP	Mad River (RM 9.62)	4.0	5.5
12	Graham South Elementary School	Chapman Creek	.002	na
13	Greenon High School	Tributary to Mud Run	.001	na
14	Harmony Estates MHP	Tributary to Beaver Creek	.05	na
15	Harvest Square MHP	Moore Run	.02	na
16	Hustead School	Tributary to Mud Run	.001	na
17	Kamp-a-Lott Campground	Tributary to Mad River (RM 61.41)	.025	na
18	Kirkmont Center	Sugar Creek	.04	na
19	Navistar	Tributary to Moore Run	.16	na
20	Northeastern High School	Sinking Creek	.02	na
21	Northwest Schools	East Fork Donnels Creek	.01	na
22	Rolling Hills MHP	Tributary to Moore Run	.05	na
23	Saint Paris WWTP	Tributary to Nettle Creek	.34	na
24	South Vienna WWTP	Beaver Creek	.06	na
25	Springfield Beckley Airport	Mill Creek	.04	na
26	Springfield WWTP	Mad River (RM 25.34)	16.0	25.0
27	Tecumseh High School	Tributary to Jackson Creek	0.01	na
28	Urbana School District	Dugan Run	.002	na
29	Urbana WWTP	Mad River (RM 39.15)	1.9	3.0
30	Valley View MHP	Bogles Run	.015	na
31	West Liberty Salem School	Macochee Ditch	.004	na
32	West Liberty WWTP	Tributary to Mad River (RM 51.06)	.4	.5

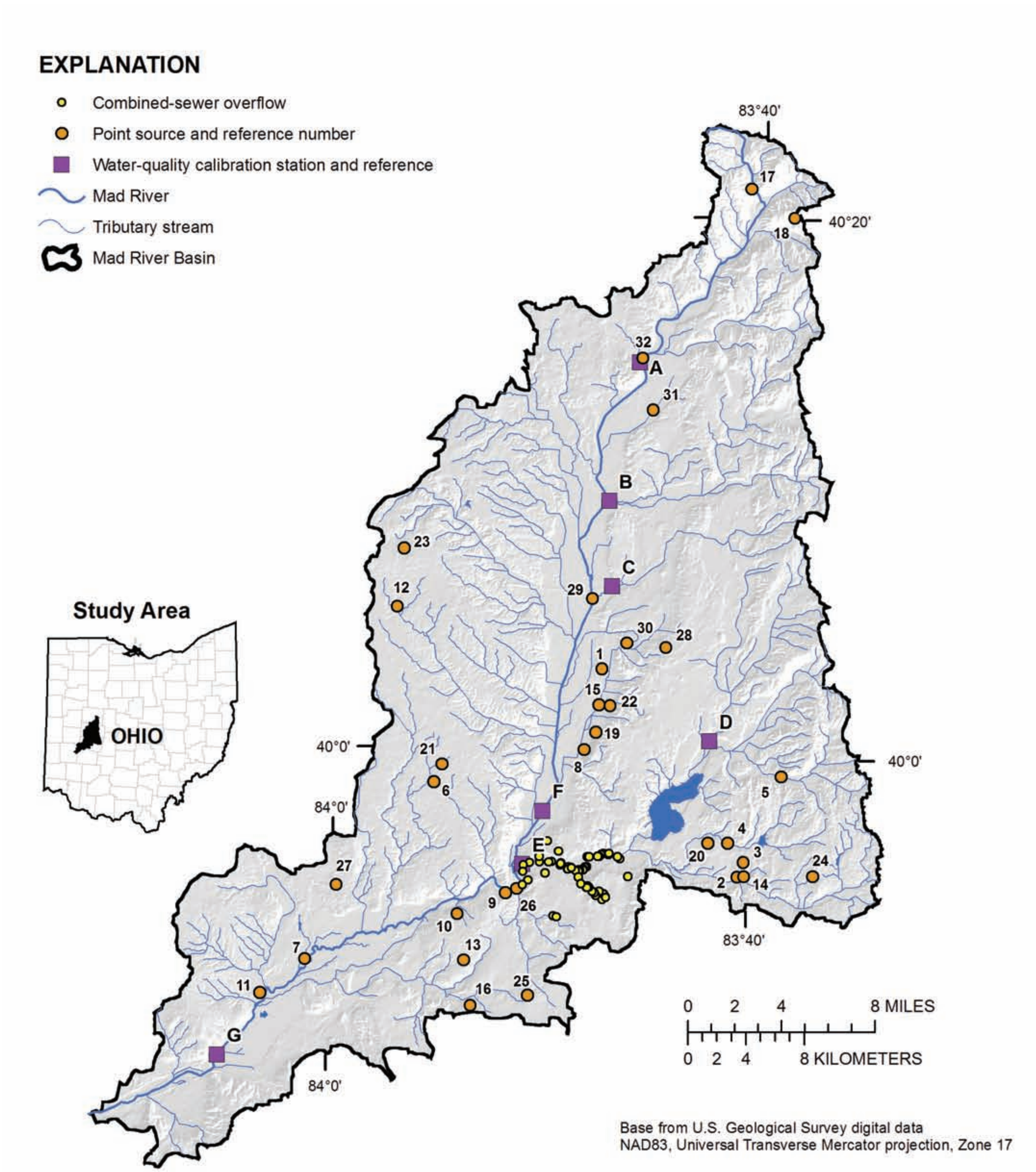

Figure 10. Locations of water-quality stations used for calibration of the water-quality model and locations of wastewater-treatment plants and combined-sewer overflows in the Mad River Basin. (Data from U.S. Environmental Protection Agency, 2003; Camp Dresser and McKee, 1997.)

tal Protection Agency, 2004b). The nitrate concentration in the CSO discharge was estimated to be 1.8 mg/L on the basis of the median nitrate concentration from 13 CSO discharges sampled in Youngstown, Ohio (Stoeckel and Covert, 2002). The CSO discharge volumes also had to be estimated for the calibration period of the model (1999–2003). Camp Dresser & McKee (CDM) was contracted by the City of Springfield to develop a model to simulate the overflow volumes of the CSOs during storm events (Camp Dresser & McKee, 1999). However, CDM was able to simulate discharge volumes only from 1988 through 1994. To estimate the CSO discharge volumes during rain events for the HSPF calibration period (1999–2003), a relation between precipitation and the CSO discharge had to be developed from the CDM model. The model equations of precipitation and streamflow in relation to CSO discharge volume were determined for each of the model subbasins with CSOs during 1988 through 1994 (table 9). These equations were then used to determine CSO discharge volumes for the simulation period for each model subbasin on the basis of 1999–2003 precipitation data and streamflow data from the Mad River at Springfield.

Cattle in Streams

The Bacterial Indicator Tool (BIT) was used to estimate the direct contribution of fecal coliform from cattle in streams. A BIT assumption is that only beef cattle graze on pastures; therefore, only beef cattle have access to streams (U.S. Environmental Protection Agency, 2000b). Dairy cattle are assumed to be kept only in feedlots. These contributions are treated as individual point sources for each subbasin of the HSPF model. The number of cattle in streams was computed for each month by multiplying the number of beef cattle within each subbasin of the model by an assumed fraction of time that grazing cattle were in a stream. The number of beef cattle was estimated for each subbasin from the county-level data provided by the National Agricultural Statistics Service (2004a). In the model, the beef cattle are assumed to be evenly distributed within the pastures. Subbasins within Logan County were the exception to this method. The number of beef cattle had been plotted on county property-ownership plat maps by the Logan County Soil and Water Conservation District; therefore, a more precise estimate was applied to subbasins within this county. Cattle in the study area spend less than 1 percent of their grazing time directly in a stream

Table 9. Equations relating precipitation and next-day daily mean streamflow to combined-sewer-overflow (CSO) discharge volume for each subbasin with a CSO.

[Subbasin locations shown in fig. 7. Volume in million gallons per day; precipitation in inches; streamflow in Mad River at Springfield in cubic feet per second]

Subbasin	Model equation	p-value	r^2 value
19	Volume = -0.22 + (0.087*$\log_{10}$(streamflow)) + (0.26*precipitation) + (0.027*precipitation^2)	<0.0001	0.15
28	Volume = -1.55 + (0.59*$\log_{10}$(streamflow)) + (1.73*precipitation) + (0.21*precipitation^2)	<0.0001	.14
35	Volume = -3.33 + (1.29*$\log_{10}$(streamflow)) + (4.23*precipitation)	<0.0001	.26
47	Volume = -1.76 + (0.67*$\log_{10}$(streamflow)) + (2.19*precipitation) + (0.14*precipitation^2)	<0.0001	.18
48	Volume = -0.064 + (0.025*$\log_{10}$(streamflow)) + (0.056*precipitation) + (0.018*precipitation^2)	<0.0001	.09
49	Volume = -5.46 + (2.12*$\log_{10}$(streamflow)) + (8.63*precipitation) - (1.14*precipitation^2)	<0.0001	.38

(Jennifer Ganson, Ohio State University Agricultural Extension–Champaign County office, oral commun., 2005). Model calibration set the amount of time an individual animal was in a stream at 0.05 percent of the day (less than 1 minute). A percentage much smaller than 1 was selected for the model because of the BIT assumption is that all beef cattle grazing have access to streams. Many properties in the Mad River Basin are fenced in order to limit access to streams, although the proportions of fenced and unfenced properties are unknown. A further HSPF model assumption is that cattle did not graze on the pastures during December through March and grazed only half of the time during April and November.

The fecal coliform load from cattle in streams was computed in the BIT by multiplying the number of beef cattle in the subbasin by the percentage of the day that the cattle are in the streams and the daily production rate of fecal coliform per animal (U.S. Environmental Protection Agency, 2000b). The BIT production rate of 1.04×10^{11} fecal coliform colonies per animal per day is based on a standard established by the American Society of Agricultural Engineers (American Society of Agricultural Engineers, 1998).

For the HSPF model, it is assumed that one beef cattle produces 124 lb of total nitrogen per year from solids and 120 lb of total nitrogen per year from urine on the basis of a study by The Ohio State University (Ohio State University Extension, 1992). Although most nitrogen in manure is in the form of ammonium and organic nitrogen, these nitrogen species are eventually converted to nitrate. For this model, nitrogen from cattle waste was assumed to be nitrate. The nitrate load from cattle in streams was computed by multiplying the number of beef cattle in streams (same number computed in the BIT) by the daily production rate of nitrate per animal.

Failed Septic Systems

The Ohio State University Extension determined that approximately 76 percent of the soils in the Mad River Basin are suitable for septic systems. However, when comparing treatment systems, their study found that less than 5 percent of the soils were suitable for the traditional leach-line treatment systems, approximately 45 percent of the soils were suitable only for mound treatment systems, and approximately 30 percent of the soils were suitable for onsite treatment with irrigation (Mancl and Slater, 2002). Suitable soils are necessary to properly treat wastewater from a septic system. Unsaturated zones should be deep enough to remove pollutants from wastewater before the wastewater enters the water table. Other limiting conditions include soils that are insufficiently permeable, such as some soils derived from glacial till. Glacial till is present in many areas of the Mad River Basin (fig. 2).

Data obtained from the health departments for Clark, Champaign, and Logan Counties indicated that approximately 28,000 septic systems are in use within the Mad River Basin. Although the approximate number of septic systems was available, none of the counties had information regarding the locations of the septic systems. However, the number of households within each township was available from the Ohio State University Extension Data Center (2004). In addition, 250 households within the City of Springfield (about 1 percent of the total) are known to be on a septic system (Robin Berry, Clark County Health Dept., oral commun., 2005). The assumption was made that all households in a rural township were on a septic system but that only 1 percent of the households in the urban areas were on a septic system. The septic systems were assumed to be distributed evenly within the townships and cities. From this information, the number of septic systems was estimated for each subbasin of the model.

The BIT was used to compute the contribution of fecal coliform to streams from failed septic systems. These contributions are treated as individual point sources for each subbasin of the HSPF model. Concentration and overflow-rate assumptions for the BIT simulation of failed septic systems are 10,000 col/100 ml and 70 gal per person per day, respectively (U. S. Environmental Protection Agency, 2000b). On the basis of estimates of the number of people served by septic systems and the number of septic systems for the Mad River Basin, the BIT determined that an average of 2.76 people are served per septic system in the Mad River Basin. A 90-percent failure rate of septic systems was used in the model for the Mad River Basin on account of the small percentage of suitable soils and the prevalence of traditional leach-line systems in the study area. The BIT was able to compute the flow from failed septic systems and the fecal coliform load for each subbasin of the HSPF model.

The flow rates computed from the BIT and a nitrate concentration of 1.1 mg/L were used to determine the nitrate loads from the failed septic systems for each reach in the HSPF model. The selected nitrate concentration is based on the average nitrate concentration from septic-system drainage fields in Medina County, Ohio (Shindel and others, 2005, p. 248). Nitrogen in conventional septic tanks is usually in the form of ammonium (75 percent) and organic nitrogen (25 percent). As the effluent leaves the septic tank and moves through the soils, ammonium nitrogen is converted to nitrite and then to nitrate. Ammonium nitrogen can also be removed by adsorption, volatilization, or plant uptake (Kristiansen, 1981), although this model does not consider the effects of plant uptake of nitrogen in the simulation. The model assumption is that all nitrogen from the septic tank that reaches the streams has converted to nitrate.

Commercial-Fertilizer and Manure Applications

Soybeans, corn, and, to a lesser extent, winter wheat make up the majority of crops planted in the Mad River Basin. Corn and soybeans are typically planted from April through May, whereas winter wheat is typically planted in October. Approximately 50 percent of cropland in the Mad River Basin is used for soybean production and 40 percent is used for corn production (National Agricultural Statistics Service, 2004b). Most of the commercial nitrogen fertilizer used in the study area, however, is for corn. In Ohio, nitrogen fertilizer is applied to nearly 100 percent of the corn acreage but only 21 percent of the soybean acreage (Ohio Department of Agriculture, 2000). Fertilizers generally are applied in spring during corn planting. Nitrogen fertilizer is generally reapplied to corn fields 6 to 10 weeks after planting (table 10). In western Ohio, the application rate of nitrogen is in the range of 150 to 200 lb/acre for corn. For wheat, fertilizers are applied in late summer through early autumn. If not enough nitrogen is available from the previous soybean crop, then starter nitrogen is applied to the wheat fields at a rate less than 20 lb/acre (Ohio State University Extension, 2001).

Manure is applied not only to supply nutrients but also to improve the water-holding capacity of soil, improve aeration of soil, and promote beneficial microorganisms (Ohio State University Extension, 1992). Unfortunately, manure is not only a source of nitrogen but also a source of fecal coliform and other types of bacteria. Manure is generally applied to corn fields in March and April and to winter wheat fields from August through November (table 11). An estimated 17 percent of the corn acreage, 8 percent of the soybean acreage, and 5 percent of the wheat acreage in Ohio receive applications of manure (Ohio State University Extension, 1995). Contributions to the storage limits and accumulation rates of fecal coliform from manure applications are determined by the BIT. The fecal coliform contributions from manure applications are based on the amount of waste produced by the animals in the subbasin, the fraction of manure applied each month, the fraction of manure incorporated in the soil, and the fraction available for runoff.

This study did not use the commercial fertilizer and manure application information directly in the model. However, this information was used to assign accumulation rates and storage capacities to the agricultural lands during application periods.

Table 10. Fraction of commercial fertilizer applied by month, by crop type.

[Source: Mike Haubner, Ohio State University Extension, Clark Co., written commun., 2005]

Crop type	March	April	May	June	October	November
Corn and soybeans	0.20	0.30	0.30	0.15	--	0.05
Winter wheat	0.75	--	--	--	0.25	--

Table 11. Fraction of manure applied by month, by crop type.

[Source: Mike Haubner, Ohio State University Extension, Clark Co., written commun., 2005]

Crop type	March	April	August	September	October	November
Corn and soybeans	0.5	0.5	--	--	--	--
Winter wheat	--	--	0.25	0.25	0.25	0.25

Table 12. Wet and dry atmospheric deposition of nitrate, by season, at three National Atmospheric Deposition Program/National Trends Network stations in Ohio, 1999–2003.

[National Atmospheric Deposition Program (2005); na, not available]

1999–2003	Wet and dry deposition, in pounds per acre, by station					
	OH17 Delaware		OH54 Deer Creek		OH09 Oxford	
	Wet	Dry	Wet	Dry	Wet	Dry
Annual mean	14.1	na	12.7	0.57	12.7	0.58
Winter mean	2.5	na	2.2	.24	2.3	.23
Spring mean	5.0	na	4.5	.13	3.8	.13
Summer mean	4.4	na	4.0	.05	4.2	.06
Fall mean	2.2	na	2.0	.16	2.3	.16

Atmospheric Deposition

Nitrogen entering the hydrologic system by atmospheric deposition is primarily derived from burning of coal for electricity generation (Debrewer and others, 2000). The source of the airborne nitrogen may be hundreds of miles outside the study area (U.S. Environmental Protection Agency, 2004a). “Wet deposition” refers to contaminants (in this case, nitrate) that are dissolved in or adsorbed onto particles in precipitation, whereas “dry deposition” refers to contaminants that are adsorbed onto dust particles. Nitrate concentrations in wet deposition (rain or snow) have been monitored since 1978 by the National Atmospheric Deposition Program/National Trends Network (NADP/NTN) (2005), which includes six stations in Ohio. No NADP/NTN stations are in the Mad River Basin; however, three stations (City of Oxford in northwestern Butler County, Deer Creek State Park in Pickaway County, and City of Delaware in Delaware County) are in the surrounding area. Annual mean wet deposition of nitrate ranged from 12.7 to 14.1 lb/acre at the three stations for calendar years 1999 through 2003. Deposition was greatest in the spring and summer and least in the fall and winter (table 12, p. 29).

Dry deposition in the United States has been monitored by the Clean Air Status and Trends Network (CASTNET) since 1987 (U.S. Environmental Protection Agency, 2004a). CASTNET measures nitric acid (HNO_3) vapor and particulate nitrate nitrogen fluxes in dry deposition. The Mad River Basin lies between two CASTNET monitoring stations, one in northwestern Butler County (Oxford station) and the other in Pickaway County (Deer Creek station). Of the average nitrogen deposition at these two stations from 1999 through 2003, approximately 35 percent was wet deposition of nitrate, whereas less than 2 percent was dry deposition of nitrate (U.S. Environmental Protection Agency, 2004a).

Atmospheric deposition of nitrate was included in the HSPF model as dry deposition in the form of a flux (mass per area per time) and as wet deposition in the form of a concentration in rainfall. The monthly dry and wet deposition of nitrate was computed and entered into the model as a time series from the WDM file. The HSPF model combines the rainfall concentration with the precipitation time series to compute a monthly nitrate flux.

Observed Water-Quality Data

Water-quality data used to calibrate the HSPF model for fecal coliform and nitrate concentrations were available from sampling activities of the Ohio EPA, the USGS, the Upper Mad River Steering Committee, and the MCD at seven sites in the basin (table 13; fig. 10). Mad River at St. Paris Pike near Eagle City, Ohio, had the largest water-quality database, which permitted calibration of the model from January 1, 1999, through September 30, 2003. However, data from only 166 nitrate and 28 fecal coliform samples had been collected at this site over the 5-year period. Other sites had even less water-quality data and could be calibrated only for 2003 (table 13 and figure 10). Calibration of the model was limited by availability of water-quality data. This, unfortunately, leads to a greater uncertainty in the results produced by the model.

The City of Springfield collected stream samples for fecal coliform analysis from sites within Buck Creek Subbasin and on the Mad River immediately upstream from the Buck Creek confluence and immediately downstream from the Mill Creek confluence during six rain events in summer 2002. CSOs did not contribute to the Mad River upstream site, whereas all of the CSOs were contributing to the Mad River downstream site. The fecal coliform concentrations from the upstream site ranged from 320 to 4,700 col/100 mL, with a mean of 1,500 col/100 mL. The fecal coliform concentrations from the downstream site ranged from 130 to 380,000 col/100 mL, with a mean of 100,000 col/100 mL. Some samples collected from Buck Creek had fecal coliform concentrations that were greater than 1,000,000 col /100 mL.

The USGS and MCD also measured nitrate in samples collected from selected shallow water wells (depths of 50 ft or less) in the Mad River Basin. The USGS collected samples in 1999 from 5 wells and the MCD collected samples in 2003 from 13 wells. The nitrate concentrations from the USGS-sampled wells ranged from less than 0.05 to 15 mg/L, whereas the nitrate concentrations from the MCD-sampled wells ranged from less than 0.02 to 17.8 mg/L. The nitrate concentrations in these samples were used to determine an acceptable range of nitrate concentrations that could be used for the ground-water contributions from the model subsurface zones.

Water-Quality Calibration

The HSPF model was calibrated by comparing the modeled concentrations to observed concentrations of fecal coliform and nitrate. Initial model water-quality parameters were assigned as a function of meteorologic zone (described earlier in report; fig. 7) and the land-cover types in the study area. Parameters that could be adjusted in this model included the interflow and ground-water concentrations of fecal coliform and nitrate, monthly accumulation rates of fecal coliform and nitrate on the land surface, and the monthly maximum storage of fecal coliform and nitrate on the land surface. The HSPFParm program (Donigian and others, 2000) was used to identify reasonable initial values for many of the water-quality parameters needed for the fecal coliform and nitrate model. HSPFParm is a model-parameter database that contains parameter values used in calibrated models developed elsewhere. The HSPFParm program entries that were most similar to conditions in the Mad River were from models for agricultural watersheds with corn and soybean crops.

The subbasin in which C.J. Brown Reservoir is located required special calibration considerations because the reservoir acts as a sink for fecal coliform and nitrate. The observed fecal coliform and nitrate concentrations were significantly lower in the stream immediately downstream from the reservoir than immediately upstream. The low fecal coliform counts are likely due to die-off and predation during

Table 13. Water-quality data from surface-water sites used to calibrate the model of the Mad River Basin.

[OEPA, Ohio Environmental Protection Agency; UMSC, Upper Mad River Steering Committee; USGS, U. S. Geological Survey; MCD, Miami Conservancy District; S.R., State Route]

Reference letter (fig. 10)	Sample site	Source of data	Number of nitrate samples collected	Number of fecal coliform samples collected	Year(s) of sampling activity used for model calibration
A	Mad River at Pimtown Road near West Liberty	OEPA UMSC	6 12	5 5	2003 2003
B	Kings Creek at S.R. 290	OEPA UMSC	6 12	5 5	2003 2003
C	Dugan Run at Muzzy Road	OEPA UMSC	6 12	4 5	2003 2003
D	Buck Creek at S.R. 4	OEPA	6	0	2003
E	Buck Creek at Synder Park	OEPA	6	0	2003
F	Mad River at St. Paris Pike near Eagle City	OEPA USGS	60 106	28 0	1999–2003 1999–2003
G	Mad River at Huffman Dam	OEPA MCD	6 137	5 0	2003 2003

the retention time in the reservoir, whereas the low nitrate concentrations are likely due to plant uptake and denitrification. In order to accurately simulate fecal coliform loss in the reservoir, the decay rate for the subbasin that includes C.J. Brown Reservoir had to be set at a high level (10,000 per day). A biodegradation rate was set in the HSPF model to reproduce the decrease in nitrate concentrations below the reservoir (Paul Hummel, Aqua Terra Consultants, oral commun., 2005).

Fecal coliform concentrations initially assigned to monthly interflow (MON-IFLW-CONC) were adjusted during calibration. For the calibrated model, fecal coliform concentrations in interflow water ranged from 10 col/100 mL in forests and water to 60,000 col/100 mL in some agricultural lands. In this model, fecal coliforms were assumed to be absent in ground water. Sand and gravel aquifer systems, such as those found in the study area, tend to act as a filtering mechanism that prevents pathogens, such as fecal coliform, from reaching the ground water. Although ground-water samples collected in the study area were not analyzed for fecal coliform, ground-water samples have been analyzed for *E. coli*. This particular bacteria species has rarely been detected in the samples (Richard Bendula, Ohio Environmental Protection Agency, oral commun., 2006).

The BIT was also used to estimate the monthly accumulation rate of fecal coliform on the land surface and the accumulation limit of fecal coliform should no washoff occur (U.S. Environmental Protection Agency, 2000b). User-defined values supplied to the BIT for each meteorologic zone were land-cover distribution, number of agricultural animals and their monthly grazing patterns, wildlife densities, and the patterns of monthly manure applications to cropland and pasture. Agricultural animals included in the BIT were beef cattle, dairy cattle, swine, poultry, horses, and sheep. Assumptions in the BIT are that manure from swine and poultry is applied only to agricultural lands and that manure from horses and sheep is applied only to pastures. Cattle are assumed to contribute manure to both land covers. Wildlife animals included in the BIT were deer, geese, ducks, beaver, and raccoons. The wildlife densities are computed only for forest, pasture, and agricultural lands and are considered constant for each of these land covers. The fraction of each manure type incorporated into the soils ranged from 0.75 (for cattle) to 0.96 (for poultry). These were the default settings supplied by the BIT. Animal waste production rates and fecal coliform content values used in the model were from American Society of Agricultural Engineers (1998). Model calibration resulted in a 20-percent increase to the accumulation rate initially estimated with the BIT for meteorologic zone 4 and a 40-percent decrease to the storage limit computed by the BIT for meteorologic zones 2, 4, and 7 (fig. 7). Values for these meteorologic zones were adjusted to better match the simulated fecal coliform concentrations to the observed concentrations. Values of the principal parameters used to calibrate the fecal coliform model are listed in Appendix 3.

Nitrate concentrations in the interflow water and ground water within the Mad River Basin were initially assigned to each land-cover type for each meteorologic zone on the basis of available ground-water data and data from the HSPFParm database. The lowest interflow and ground-water nitrate concentrations were initially set at 0.5 mg/L for forest and water areas, whereas the highest nitrate concentrations were initially set at 5 mg/L for agricultural lands. Nitrate concentrations were eventually adjusted for the monthly interflow (MON-IFLW-CONC) and ground-water (MON-GRND-CONC) parameters for most agricultural and pasture lands during model calibration. In the calibrated model, nitrate concentrations in ground water ranged from 0.3 mg/L in forest and waterbodies to 9 mg/L in agricultural areas within the Kings Creek meteorologic zone (no. 7), and nitrate concentrations in the interflow ranged from 0.25 mg/L in forest and waterbodies to 15 mg/L in agricultural areas within the Kings Creek meteorologic zone. High nitrate concentrations have been observed in Kings Creek and are thought to result from the link between the agricultural practices and the shallow aquifer in this meteorologic zone (Ohio Environmental Protection Agency, 2005a).

No program similar to the BIT is available to estimate the accumulation rate or the storage limit of nitrate on the land surface for the various land covers in the individual zones. The HSPFParm database was again used to estimate some initial values on the basis of previous HSPF modeling of nitrate from other watersheds within the corn-soybean region of the Nation (Donigian and others, 2000). Information regarding the application periods and application rates of commercial fertilizer and manure was useful for determining the range of these parameter values to use in the HSPF model and for determining in which months to increase or decrease these values. Months when fertilizer and manure applications are common were typically assigned higher accumulation rates and accumulation-limit values than months when applications are uncommon. Values of the principal parameters used to calibrate the nitrate model are listed in Appendix 4.

Daily mean concentrations of fecal coliform and nitrate simulated by the HSPF model are shown in figures 11 and 12, along with simulated daily mean streamflow. Data shown in figures 11 and 12 are from the Mad River at St. Paris Pike and the Mad River at Huffman Dam, respectively. These sites had the largest number of observed values available for the calibration period. Great fluctuations in fecal coliform counts are seen in the observed and simulated values. Of the 27 fecal coliform values observed at the St. Paris Pike site for the calibration period, the highest count was 29,000 col/100 mL, whereas the lowest count observed was 10 col/100 mL. With only five observed values at the Huffman Dam site, the fecal coliform count ranged from 140 to 24,000 col/100 mL. Samples collected at Mad River at St. Paris Pike show little difference in nitrate concentrations from season to season, mainly because of the high contribution of base flow from ground water throughout the year. This provides a constant supply of nitrate to the streams. Samples collected by the Miami Conservancy District indicate that nitrate concentrations are lower during high-flow events at the Huffman Dam site than during normal flow conditions. This pattern suggests that nitrate concentration from runoff is higher than the nitrate concentration in the base flow and shows the effect of dilution on storm-water samples. This pattern was not observed in the nitrate concentrations at Mad River at St. Paris Pike, which is in an agriculture-dominated watershed and not affected by the CSO discharges originating from Springfield.

Simulated nitrate and fecal coliform values from the calibrated model were compared to observed values from seven sites within the study area (table 14). For this comparison, simulated mean nitrate or geometric mean fecal coliform concentrations were computed only for days with observed values. However, the simulated values are daily mean values, whereas the observed values are instantaneous. This distinction is especially important to remember when comparing the fecal coliform concentrations. Fecal coliform concentrations in a stream can change by orders of magnitude within a day if a runoff event has occurred. For fecal coliform, the ratios of geometric mean values of simulated concentrations to observed concentrations ranged from 0.15 to 1.18. For nitrate, the ratios of mean values of simulated concentration to observed concentration ranged 0.85 to 1.17. These results, especially for fecal coliform, reflect the uncertainty in the model output due to the scarcity of data available for model calibration. Values of the principal parameters used to calibrate the model for simulation of fecal coliform and nitrate concentrations are listed in Appendixes 3 and 4, respectively.

Sensitivity Analysis

A sensitivity analysis was done for the water-quality model. As noted previously, a sensitivity analysis indicates the response of a model to modifications of input values. The principal water-quality parameters used for model calibration were selected for sensitivity analysis. For most parameters, values were changed by 50 and 200 percent of their calibrated values (table 15). The model run was terminated before completion, however, when the monthly accumulation rates (MON-ACCUM) of fecal coliform were doubled and when the monthly limiting storage (MON-SQOLIM) of fecal coliform was halved. In these cases, smaller percentage changes in parameters were used (table 15). Changes in monthly accumulation rates and interflow concentrations (MON-IFLW-CONC) had little effect on the fecal coliform loads. Changes in the decay rates (FSTDEC), however, had a major effect on the fecal coliform loads (table 15); this is likely because of the minor contribution that nonpoint sources have to the fecal coliform loads. Changes to monthly ground-water concentrations (MON-GRND-CONC) of nitrate had a large effect on simulated nitrate loads, whereas changes to the monthly accumulation rates had the smallest effect (table 15).

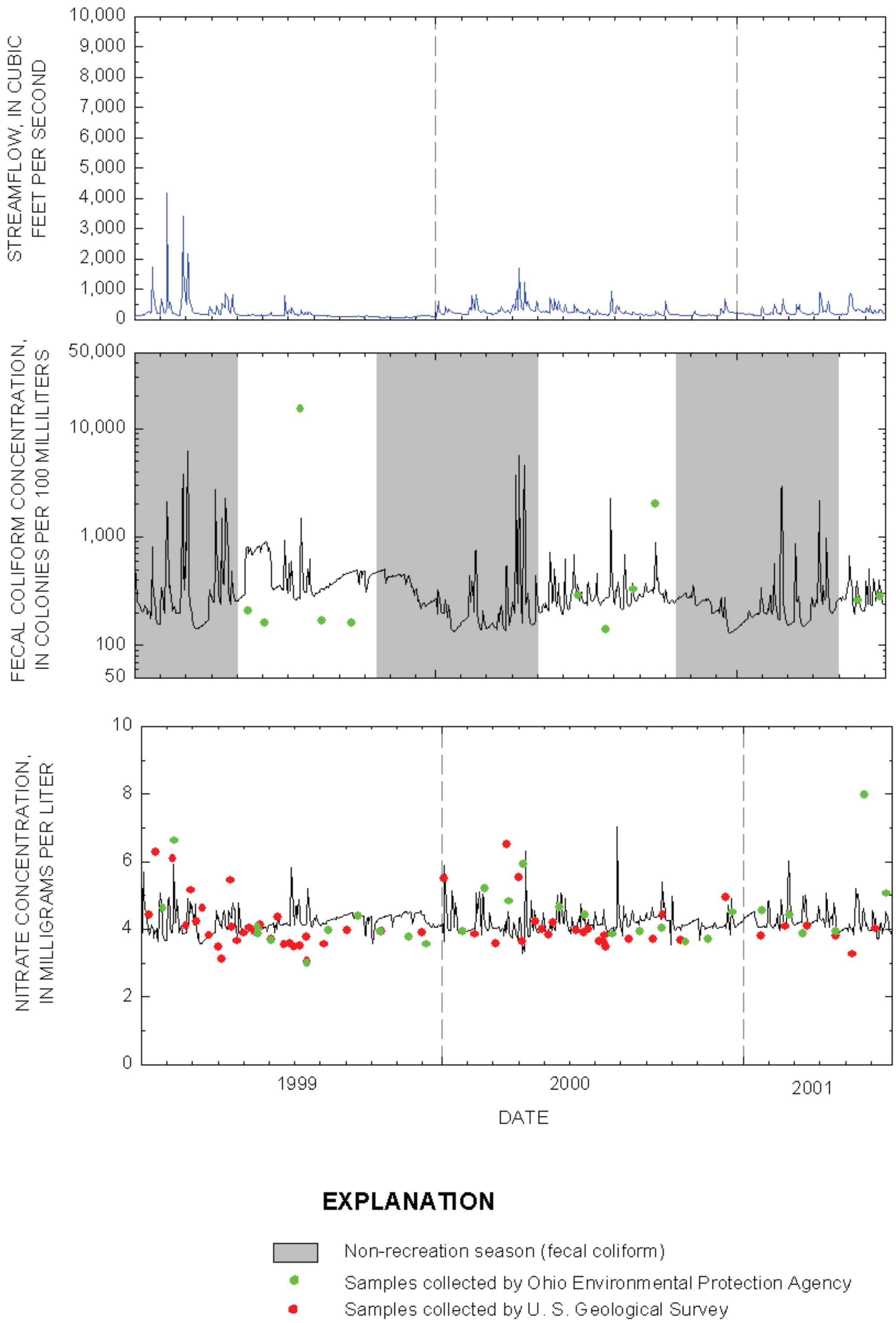

Figure 11a. Simulated daily mean streamflow, simulated daily mean concentrations of nitrate and fecal coliform, and observed instantaneous concentrations, Mad River at St. Paris Pike (03267900), January 1, 1999, through June 30, 2001.

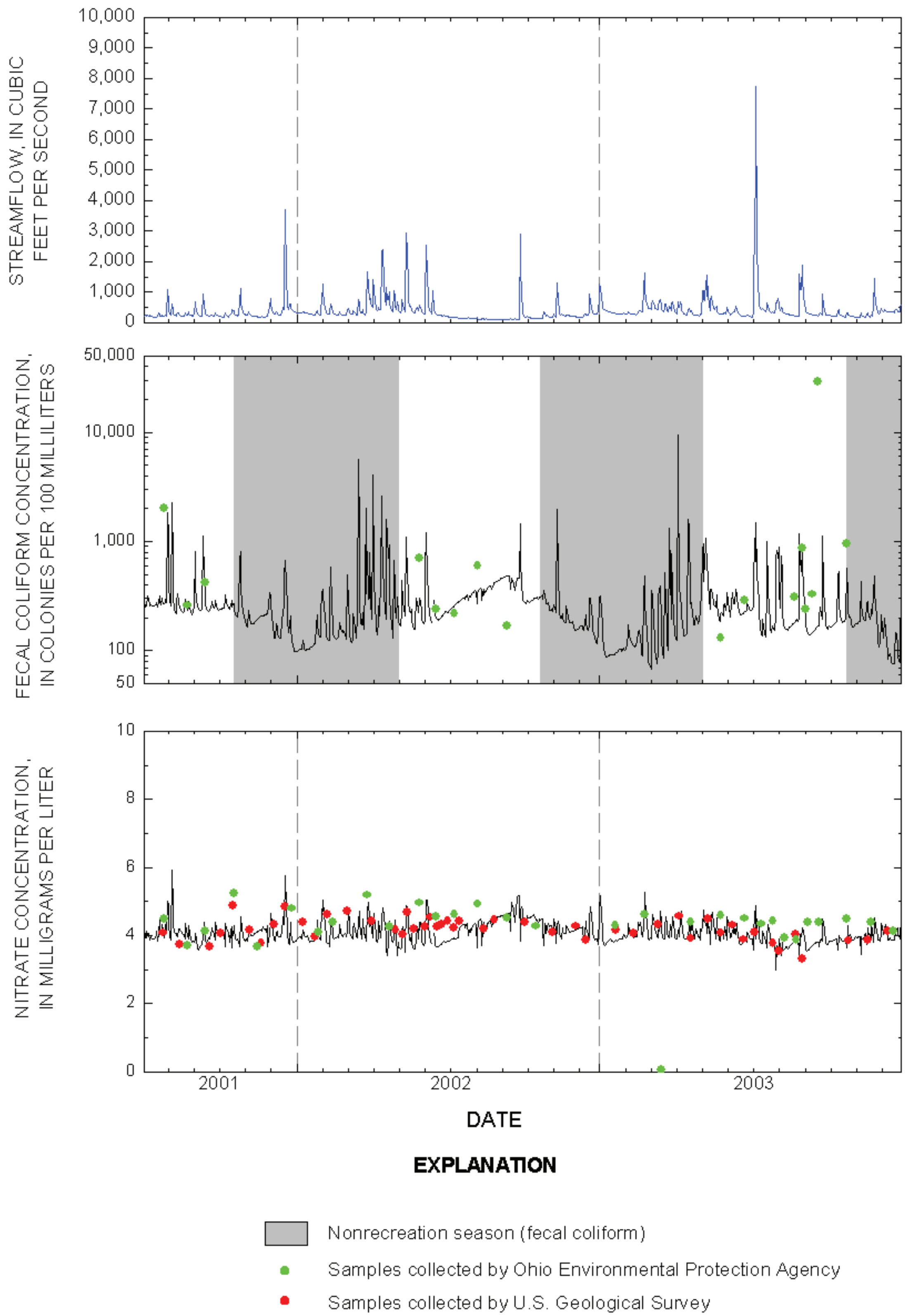

Figure 11b. Simulated daily mean streamflow, simulated daily mean concentrations of nitrate and fecal coliform, and observed instantaneous concentrations, Mad River at St. Paris Pike (03267900), July 1, 2001, through December 31, 2003.

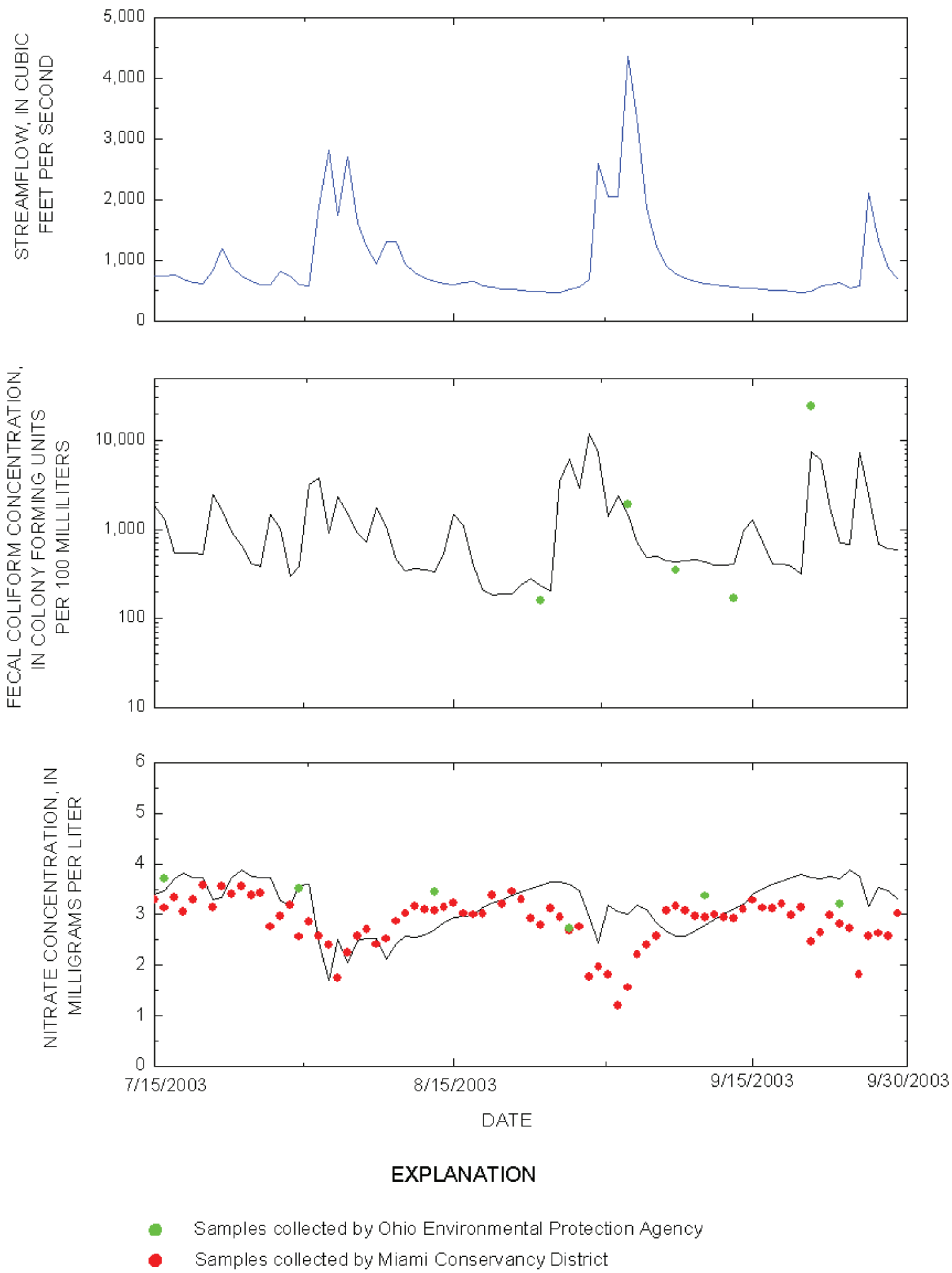

Figure 12. Simulated daily mean streamflow, simulated daily mean concentrations of nitrate and fecal coliform, and observed instantaneous concentrations, Mad River at Huffman Dam (03270000), July 15 through September 30, 2003.

Table 14. Comparison of observed and simulated nitrate and fecal coliform concentrations at sites in the Mad River Basin, 1999–2003.

[USGS, U.S. Geological Survey; OEPA, Ohio Environmental Protection Agency; UMSC, Upper Mad River Steering Committee; MCD, Miami Conservancy District; S.R., State Route; Ratio is the simulated concentration divided by the observed concentration]

Site	Mean nitrate concentration, in milligrams per liter			Sample size
	Observed (instantaneous)	Simulated (daily mean)	Ratio	
Mad River at St. Paris Pike	4.12 – USGS	4.13	1.00	106
	4.35 – OEPA	4.30	0.99	60
Mad River at Pimtown Road	3.43 – OEPA	3.24	.94	6
	3.52 – UMSC	3.58	1.01	12
Kings Creek at S.R. 29	7.15 – OEPA	7.10	.99	6
	7.36 – UMSC	7.60	1.03	12
Buck Creek at S.R. 4	7.97 – OEPA	8.35	1.05	6
Buck Creek at Snyder Park	1.75 – OEPA	1.48	.85	6
Dugan Run at Muzzy Road	6.01 – OEPA	5.95	0.98	6
	5.97 – UMSC	6.15	1.03	12
Mad R. at Huffman Dam	3.00 – MCD	3.49	1.16	137
	3.33 – OEPA	3.31	.99	6

Site	Geometric mean fecal coliform concentration, in colonies per 100 milliliters			Sample size
	Observed (instantaneous)	Simulated (daily mean)	Ratio	
Mad River at St. Paris Pike	365 – OEPA	330	0.90	28
Mad River at Pimtown Road	235 – UMSC	220	.94	5
	961 – OEPA	220	.23	5
Kings Creek at S.R. 29	137 – UMSC	180	1.17	5
Buck Creek at Snyder Park	2,350 – OEPA	1,600	0.68	5
Dugan Run at Muzzy Road	1,860 – OEPA	280	.15	4
	206 – UMSC	245	1.18	5
Mad R. at Huffman Dam	824 – OEPA	810	0.98	5

Simulation Results

The calibrated model was used to simulate loads and concentrations of fecal coliform and nitrate from sources within the basin. The simulated daily mean concentrations were compared to the target concentrations to identify the current water-quality conditions and to determine the percentage reduction in input loads needed to achieve the target concentrations. A load-reduction scenario was then modeled, and the results were assessed to determine whether target concentrations could be achieved.

Table 15. Sensitivity analyses of modeled water-quality characteristics to variations in selected water-quality model parameters for the mouth of the Mad River (hydrologic unit 05080001-190-040) during calibration period 1999–2003.

[Recreational season is May 1 through October 15. FSTDEC, first order decay rate for fecal coliform; MON-GRND-CONC, monthly concentration of a quality constituent in active ground water; MON-IFLW-CONC, monthly concentration of a quality constituent in interflow; MON-ACCUM, monthly accumulation rates of a quality constituent; MON-SQOLIM, monthly limiting storage of a quality constituent; WSFAC, susceptibility of a quality constituent to washoff; na, not applicable.]

Water-quality parameter modified	Multiplier	Fecal coliform load per recreational season at mouth of Mad River, in 10^{15} colonies	Percent of fecal coliform load from calibrated model	Multiplier	Annual nitrate load at mouth of Mad River, in thousands of pounds	Percent of nitrate load from calibrated model
No changes (Calibrated model)	na	3.0	100	na	5,300	100
FSTDEC	2	1.8	60	na	na	na
	0.5	3.9	130	na	na	na
MON-GRND-CONC	na	na	na	2	7,100	134
	na	na	na	0.5	4,400	83
MON-IFLW-CONC	2	3.1	103	2	6,600	123
	0.5	2.9	97	0.5	4,700	87
MON-ACCUM	1.25	3.0	100	2	5,400	102
	0.5	3.1	103	0.5	5,900	111
MON-SQOLIM	2	3.5	117	2	6,600	122
	0.8	2.9	97	0.5	5,200	98
WSFAC	2	2.8	93	2	5,100	96
	0.5	3.3	110	0.5	5,600	106

Simulated Loads and Concentrations

The calibrated HSPF model was able to simulate the loads of fecal coliform and nitrate from nonpoint sources such as failed septic systems, cattle in streams, fertilizer and manure applications, and atmospheric deposition, as well as point sources such as WWTP discharges and CSOs. The mean recreation-season loads of fecal coliform and annual nitrate from point and nonpoint sources combined were computed for each HU using the results of the HSPF model simulation.

Fecal Coliform

Nonpoint sources of fecal coliform include manure applications and wildlife and livestock wastes from grazing. On the basis of the results of model simulation, the greatest fecal coliform load from nonpoint sources came from pasture and agricultural lands (table 16). Agriculture and pasture lands contributed approximately 4.3 billion colonies per acre, whereas forests contributed approximately 25 million colonies per acre.

An analysis of simulation results indicated that CSOs were the largest point source of fecal coliform (table 17). HU 05080001-170-060 (Buck Creek) contributed the highest load of fecal coliform to the Mad River Basin from point sources; CSOs contributed 1,900 trillion fecal coliform colonies per recreation season, more than 99 percent of the fecal coliform load to this hydrologic unit (HU).

Table 18 lists the loads exiting each HU (which include all contributions upstream from the HUs) and the difference between the loads entering the individual HUs and the loads exiting the individual HUs. The HSPF model computed a

Table 16. Mean fecal coliform loads per recreation season from nonpoint sources simulated from calibrated model (Existing loads) and source-reduction model, 1999–2003.

Hydrologic unit (05080001-)		Fecal coliform loads, in million colonies, from indicated land cover								
		Water	Low-intensity residential	High-intensity residential	Com-mercial/industrial	Urban or built-up land	Forest	Pasture	Agricultural land	Total nonpoint source
150-010	Existing load	630	280	0	110	0	12,000	3,400,000	11,000,000	15,000,000
	Percent reduction	0	0	0	0	0	0	0	0	0
	Source-reduction load	630	280	0	110	0	12,000	3,400,000	11,000,000	15,000,000
150-020	Existing load	190	12,000	890	420	7,900	38,000	13,000,000	56,000,000	68,000,000
	Percent reduction	0	0	0	0	0	0	0	0	0
	Source-reduction load	190	12,000	890	420	7,900	38,000	13,000,000	56,000,000	68,000,000
150-030	Existing load	180	160	140	0	1,300	29,000	8,600,000	17,000,000	26,000,000
	Percent reduction	0	0	0	0	0	0	0	0	0
	Source-reduction load	180	160	140	0	1,300	29,000	8,600,000	17,000,000	26,000,000
150-040	Existing load	80	12,000	2,800	1,500	19,000	10,000	7,900,000	27,000,000	35,000,000
	Percent reduction	0	0	0	0	0	0	0	0	0
	Source-reduction load	80	12,000	2,800	1,500	19,000	10,000	7,900,000	27,000,000	35,000,000
150-050	Existing load	450	62	100	0	0	3,700	14,000,000	21,000,000	35,000,000
	Percent reduction	0	0	0	0	0	0	0	0	0
	Source-reduction load	450	62	100	0	0	3,700	14,000,000	21,000,000	35,000,000
150-060	Existing load	340	3,900	130	1,100	0	47,000	65,000,000	55,000,000	120,000,000
	Percent reduction	0	0	0	0	0	0	0	0	0
	Source-reduction load	340	3,900	130	1,100	0	47,000	65,000,000	55,000,000	120,000,000
160-010	Existing load	3,500	1,400	760	780	180	4,700	2,200,000	10,000,000	12,000,000
	Percent reduction	0	0	0	0	0	0	0	0	0
	Source-reduction load	3,500	1,400	760	780	180	4,700	2,200,000	10,000,000	12,000,000
160-020	Existing load	220	80	0	0	0	13,000	4,800,000	30,000,000	35,000,000
	Percent reduction	0	0	0	0	0	0	0	0	0
	Source-reduction load	220	80	0	0	0	13,000	4,800,000	30,000,000	35,000,000
160-030	Existing load	1,600	94,000	28,000	14,000	89,000	12,000	7,900,000	22,000,000	30,000,000
	Percent reduction	0	0	0	0	0	0	0	0	0
	Source-reduction load	1,600	94,000	28,000	14,000	89,000	12,000	7,900,000	22,000,000	30,000,000
160-040	Existing load	620	18,000	4,700	850	3,200	34,000	12,000,000	28,000,000	40,000,000
	Percent reduction	0	0	0	0	0	0	0	0	0
	Source-reduction load	620	18,000	4,700	850	3,200	34,000	12,000,000	28,000,000	40,000,000

Table 16. Mean fecal coliform loads per recreation season from nonpoint sources simulated from calibrated model (existing loads) and source-reduction model, 1999–2003.—Continued

Hydrologic unit (05080001-)		Fecal coliform loads, in million colonies, from indicated land cover								
		Water	Low-intensity residential	High-intensity residential	Com-mercial/ industrial	Urban or built-up land	Forest	Pasture	Agricultural land	Total nonpoint source
	Existing load	160	1,200	490	480	0	7,600	4,700,000	23,000,000	28,000,000
160-050	Percent reduction	0	0	0	0	0	0	0	0	0
	Source-reduction load	160	1,200	490	480	0	7,600	4,700,000	23,000,000	28,000,000
	Existing load	540	6,400	1,700	1,300	940	13,000	8,400,000	21,000,000	30,000,000
160-060	Percent reduction	0	0	0	0	0	0	0	0	0
	Source-reduction load	540	6,400	1,700	1,300	940	13,000	8,400,000	21,000,000	30,000,000
	Existing load	60	2,300	140	1,000	0	8,700	4,300,000	9,300,000	14,000,000
160-070	Percent reduction	0	0	0	0	0	0	0	0	0
	Source-reduction load	60	2,300	140	1,000	0	8,700	4,300,000	9,300,000	14,000,000
	Existing load	160	5,400	600	920	0	9,500	27,000,000	31,000,000	58,000,000
160-080	Percent reduction	0	0	0	0	0	0	0	0	0
	Source-reduction load	160	5,400	600	920	0	9,500	27,000,000	31,000,000	58,000,000
	Existing load	270	4,400	940	1,100	6,100	28,000	92,000,000	75,000,000	170,000,000
170-010	Percent reduction	0	0	0	0	0	0	0	0	0
	Source-reduction load	270	4,400	940	1,100	6,100	28,000	92,000,000	75,000,000	170,000,000
	Existing load	580	4,000	790	970	0	66,000	110,000,000	58,000,000	170,000,000
170-020	Percent reduction	0	0	0	0	0	0	0	0	0
	Source-reduction load	580	4,000	790	970	0	66,000	110,000,000	58,000,000	170,000,000
	Existing load	25,000	24,000	1,200	2,600	10,000	89,000	55,000,000	19,000,000	75,000,000
170-030	Percent reduction	0	0	0	0	0	0	0	0	0
	Source-reduction load	25,000	24,000	1,200	2,600	10,000	89,000	55,000,000	19,000,000	75,000,000
	Existing load	1,000	22,000	3,900	4,600	20,000	120,000	30,000,000	15,000,000	45,000,000
170-040	Percent reduction	0	0	0	0	0	0	0	0	0
	Source-reduction load	1,000	22,000	3,900	4,600	20,000	120,000	30,000,000	15,000,000	45,000,000
	Existing load	1,400	3,500	830	1,200	0	52,000	20,000,000	7,900,000	28,000,000
170-050	Percent reduction	0	0	0	0	0	0	0	0	0
	Source-reduction load	1,400	3,500	830	1,200	0	52,000	20,000,000	7,900,000	28,000,000
	Existing load	510	390,000	120,000	67,000	170,000	95,000	3,300,000	1,600,000	5,700,000
170-060	Percent reduction	0	0	0	0	0	0	0	0	0
	Source-reduction load	510	390,000	120,000	67,000	170,000	95,000	3,300,000	1,600,000	5,700,000

Table 16. Mean fecal coliform loads per recreation season from nonpoint sources simulated from calibrated model (existing loads) and source-reduction model, 1999–2003.—Continued

Hydrologic unit (05080001-)		Fecal coliform loads, in million colonies, from indicated land cover								
		Water	Low-intensity residential	High-ntensity residential	Com-mercial/ industrial	Urban or built-up land	Forest	Pasture	Agricultural land	Total nonpoint source
	Existing load	1,700	100,000	9,400	19,000	52,000	180,000	16,000,000	5,600,000	22,000,000
180-010	Percent reduction	0	0	0	0	0	0	0	0	0
	Source-reduction load	1,700	100,000	9,400	19,000	52,000	180,000	16,000,000	5,600,000	22,000,000
	Existing load	240	92,000	7,300	14,000	28,000	150,000	20,000,000	7,700,000	28,000,000
180-020	Percent reduction	0	0	0	0	0	0	0	0	0
	Source-reduction load	240	92,000	7,300	14,000	28,000	150,000	20,000,000	7,700,000	28,000,000
	Existing load	2,600	42,000	5,700	8,800	7,900	96,000	15,000,000	4,900,000	20,000,000
180-030	Percent reduction	0	0	0	0	0	0	0	0	0
	Source-reduction load	2,600	42,000	5,700	8,800	7,900	96,000	15,000,000	4,900,000	20,000,000
	Existing load	100	140,000	27,000	21,000	25,000	72,000	13,000,000	6,500,000	20,000,000
180-040	Percent reduction	0	0	0	0	0	0	0	0	0
	Source-reduction load	100	140,000	27,000	21,000	25,000	72,000	13,000,000	6,500,000	20,000,000
	Existing load	77	36,000	6,500	3,200	14,000	37,000	11,000,000	4,600,000	15,000,000
180-050	Percent reduction	0	0	0	0	0	0	0	0	0
	Source-reduction load	77	36,000	6,500	3,200	14,000	37,000	11,000,000	4,600,000	15,000,000
	Existing load	77	17,000	1,400	610	2,700	67,000	15,000,000	11,000,000	26,000,000
180-060	Percent reduction	0	0	0	0	0	0	0	0	0
	Source-reduction load	77	17,000	1,400	610	2,700	67,000	15,000,000	11,000,000	26,000,000
	Existing load	13	3,100	2,100	610	0	24,000	9,800,000	5,900,000	16,000,000
180-070	Percent reduction	0	0	0	0	0	0	0	0	0
	Source-reduction load	13	3,100	2,100	610	0	24,000	9,800,000	5,900,000	16,000,000
	Existing load	4,200	18,000	4,200	4,200	11,000	5,700	17,000,000	7,000,000	24,000,000
180-080	Percent reduction	0	0	0	0	0	0	0	0	0
	Source-reduction load	4,200	19,000	4,200	4,200	11,000	5,700	17,000,000	7,000,000	24,000,000
	Existing load	38	2,700	450	1,100	0	32,000	11,000,000	5,900,000	17,000,000
180-090	Percent reduction	0	0	0	0	0	0	0	0	0
	Source-reduction load	38	2,700	450	1,100	0	32,000	11,000,000	5,900,000	17,000,000
	Existing load	1,200	46,000	19,000	9,700	17,000	6,300	30,000,000	10,000,000	41,000,000
190-010	Percent reduction	0	0	0	0	0	0	0	0	0
	Source-reduction load	1,200	46,000	19,000	9,700	17,000	6,300	30,000,000	10,000,000	41,000,000
	Existing load	4,500	110,000	58,000	64,000	140,000	10,000	24,000,000	6,900,000	32,000,000
190-020	Percent reduction	0	0	0	0	0	0	0	0	0
	Source-reduction load	4,500	110,000	58,000	64,000	140,000	10,000	24,000,000	6,900,000	32,000,000
	Existing load	1,900	51,000	9,500	13,000	26,000	10,000	46,000,000	15,000,000	61,000,000
190-030	Percent reduction	0	0	0	0	0	0	0	0	0
	Source-reduction load	1,900	51,000	9,500	13,000	26,000	10,000	46,000,000	15,000,000	61,000,000
	Existing load	7,100	200,000	100,000	80,000	65,000	6,800	8,700,000	1,800,000	11,000,000
190-040	Percent reduction	0	0	0	0	0	0	0	0	0
	Source-reduction load	7,100	200,000	100,000	80,000	65,000	6,800	8,700,000	1,800,000	11,000,000

Table 17. Mean fecal coliform load per recreation season from selected sources and totals from nonpoint sources simulated from calibrated model (existing loads) and source-reduction model, 1999–2003.

[Recreation season is May 1 through October 15. WWTPs, wastewater-treatment plants; CSOs, combined-sewer overflows; data may not sum to totals because of independent rounding]

Hydrologic unit (05080001-)		Fecal coliform loads, in million colonies						
		WWTPs (1)	Failed septic systems (2)	Cattle in streams (3)	CSOs (4)	Total of columns 1 through 4	Total nonpoint sources (see table 16)	Total
150-010	Existing load	37,000	3,300,000	1,500,000	0	4,800,000	15,000,000	20,000,000
	Percent reduction	0	100	100	0	99	0	24
	Source-reduction load	37,000	0	0	0	37,000	15,000,000	15,000,000
150-020	Existing load	99,000	14,000,000	6,300,000	0	20,000,000	68,000,000	88,000,000
	Percent reduction	61	100	100	0	100	0	23
	Source-reduction load	39,000	0	0	0	39,000	68,000,000	68,000,000
150-030	Existing load	0	9,000,000	2,600,000	0	12,000,000	26,000,000	38,000,000
	Percent reduction	0	100	100	0	100	0	31
	Source-reduction load	0	0	0	0	0	26,000,000	26,000,000
150-040	Existing load	540,000	10,000,000	5,600,000	0	16,000,000	35,000,000	51,000,000
	Percent reduction	9	100	100	0	97	0	31
	Source-reduction load	490,000	0	0	0	490,000	35,000,000	35,000,000
150-050	Existing load	0	590,000	3,300,000	0	3,900,000	35,000,000	39,000,000
	Percent reduction	0	100	100	0	100	0	10
	Source-reduction load	0	0	0	0	0	35,000,000	27,000,000
150-060	Existing load	0	20,000,000	6,900,000	0	27,000,000	120,000,000	150,000,000
	Percent reduction	0	100	100	0	100	0	18
	Source-reduction load	0	0	0	0	0	120,000,000	95,000,000
160-010	Existing load	19,000,000	3,600,000	2,200,000	0	25,000,000	12,000,000	37,000,000
	Percent reduction	65	100	100	0	73	0	49
	Source-reduction load	6,600,000	0	0	0	6,600,000	12,000,000	19,000,000
160-020	Existing load	0	11,000,000	5,800,000	0	17,000,000	35,000,000	52,000,000
	Percent reduction	0	100	100	0	100	0	32
	Source-reduction load	0	0	0	0	0	35,000,000	35,000,000
160-030	Existing load	0	11,000,000	6,100,000	0	17,000,000	30,000,000	47,000,000
	Percent reduction	0	100	100	0	100	0	36
	Source-reduction load	0	0	0	0	0	30,000,000	30,000,000

Table 17. Mean fecal coliform load per recreation season from selected sources and totals from nonpoint sources simulated from calibrated model (existing loads) and source-reduction model, 1999–2003.—Continued

Hydrologic unit (05080001-)		Fecal coliform loads, in million colonies						
		WWTPs (1)	Failed septic systems (2)	Cattle in streams (3)	CSOs (4)	Total of columns 1 through 4	Total nonpoint sources (see table 16)	Total
160-040	Existing load	1,200,000	13,000,000	6,400,000	0	21,000,000	40,000,000	61,000,000
	Percent reduction	22	100	100	0	95	0	32
	Source-reduction load	940,000	0	0	0	940,000	40,000,000	41,000,000
160-050	Existing load	0	8,200,000	2,900,000	0	11,000,000	28,000,000	39,000,000
	Percent reduction	0	100	100	0	100	0	28
	Source-reduction load	0	0	0	0	0	28,000,000	28,000,000
160-060	Existing load	0	9,000,000	4,500,000	0	14,000,000	30,000,000	44,000,000
	Percent reduction	0	100	100	0	100	0	31
	Source-reduction load	0	0	0	0	0	30,000,000	30,000,000
160-070	Existing load	0	4,300,000	2,600,000	0	6,900,000	14,000,000	21,000,000
	Percent reduction	0	100	100	0	100	0	33
	Source-reduction load	0	0	0	0	0	14,000,000	14,000,000
160-080	Existing load	0	11,000,000	7,700,000	0	19,000,000	58,000,000	77,000,000
	Percent reduction	0	100	100	0	100	0	24
	Source-reduction load	0	0	0	0	0	58,000,000	58,000,000
170-010	Existing load	0	14,000,000	9,800,000	0	24,000,000	170,000,000	190,000,000
	Percent reduction	0	100	100	0	100	0	12
	Source-reduction load	0	0	0	0	0	170,000,000	170,000,000
170-020	Existing load	22,000	13,000,000	8,800,000	0	22,000,000	170,000,000	190,000,000
	Percent reduction	0	100	100	0	100	0	11
	Source-reduction load	22,000	0	0	0	22,000	170,000,000	170,000,000
170-030	Existing load	0	9,600,000	6,200,000	0	16,000,000	75,000,000	90,000,000
	Percent reduction	0	100	100	0	100	0	17
	Source-reduction load	0	0	0	0	0	75,000,000	75,000,000
170-040	Existing load	26,000,000	12,000,000	7,600,000	0	46,000,000	45,000,000	91,000,000
	Percent reduction	99	100	100	0	100	0	50
	Source-reduction load	180,000	0	0	0	180,000	45,000,000	45,000,000

Table 17. Mean fecal coliform load per recreation season from selected sources and totals from nonpoint sources simulated from calibrated model (existing loads) and source-reduction model, 1999–2003.—Continued

Hydrologic unit (05080001-)		Fecal coliform loads, in million colonies						
		WWTPs (1)	Failed septic systems (2)	Cattle in streams (3)	CSOs (4)	Total of columns 1 through 4	Total nonpoint sources (see table 16)	Total
170-050	Existing load	140,000	6,400,000	4,200,000	0	10,700,000	28,000,000	39,000,000
	Percent reduction	76	100	100	0	100	0	28
	Source-reduction load	34,000	0	0	0	34,000	28,000,000	28,000,000
170-060	Existing load	7,000	8,500,000	1,200,000	1,900,000,000	1,900,000,000	5,700,000	1,900,000,000
	Percent reduction	0	100	100	95	95	0	95
	Source-reduction load	7,000	0	0	95,000,000	95,000,000	5,700,000	100,000,000
180-010	Existing load	0	7,700,000	3,600,000	0	11,300,000	22,000,000	33,000,000
	Percent reduction	0	100	100	0	100	0	34
	Source-reduction load	0	0	0	0	0	22,000,000	22,000,000
180-020	Existing load	2,100,000	8,600,000	4,500,000	0	15,200,000	28,000,000	43,000,000
	Percent reduction	79	100	100	0	97	0	34
	Source-reduction load	440,000	0	0	0	440,000	28,000,000	28,000,000
180-030	Existing load	76,000,000	5,300,000	2,600,000	1,700,000,000	1,780,000,000	20,000,000	1,800,000,000
	Percent reduction	18	100	100	95	93	0	92
	Source-reduction load	62,000,000	0	0	62,000,000	124,000,000	20,000,000	140,000,000
180-040	Existing load	200,000	7,200,000	3,200,000	63,000,000	73,600,000	20,000,000	94,000,000
	Percent reduction	0	100	100	95	93	0	73
	Source-reduction load	200,000	0	0	4,800,000	5,000,000	20,000,000	25,000,000
180-050	Existing load	0	4,200,000	2,300,000	0	6,500,000	15,000,000	22,000,000
	Percent reduction	0	100	100	0	100	0	30
	Source-reduction load	0	0	0	0	0	15,000,000	15,000,000
180-060	Existing load	0	8,100,000	5,200,000	0	13,300,000	26,000,000	39,000,000
	Percent reduction	0	100	100	0	100	0	34
	Source-reduction load	0	0	0	0	0	26,000,000	26,000,000
180-070	Existing load	350,000	4,200,000	2,700,000	0	7,250,000	16,000,000	23,000,000
	Percent reduction	63	100	100	0	98	0	31
	Source-reduction load	130,000	0	0	0	130,000	16,000,000	16,000,000
180-080	Existing load	1,700,000	6,600,000	3,700,000	0	12,000,000	24,000,000	36,000,000
	Percent reduction	6	100	100	0	87	0	29
	Source-reduction load	1,600,000	0	0	0	1,600,000	24,000,000	26,000,000
180-090	Existing load	0	4,400,000	2,800,000	0	7,200,000	17,000,000	24,000,000
	Percent reduction	0	100	100	0	100	0	30
	Source-reduction load	0	0	0	0	0	17,000,000	17,000,000

Table 17. Mean fecal coliform load per recreation season from selected sources and totals from nonpoint sources simulated from calibrated model (existing loads) and source-reduction model, 1999–2003.—Continued

Hydrologic unit (0508001-)		Fecal coliform loads, in million colonies						
		WWTPs (1)	Failed septic systems (2)	Cattle in streams (3)	CSOs (4)	Total of columns 1 through 4	Total nonpoint sources (see table 16)	Total
190-010	Existing load	0	11,000,000	6,500,000	0	17,500,000	41,000,000	58,000,000
	Percent reduction	0	100	100	0	100	0	30
	Source-reduction load	0	0	0	0	0	41,000,000	41,000,000
190-020	Existing load	3,800,000	13,000,000	4,000,000	0	20,800,000	32,000,000	53,000,000
	Percent reduction	66	100	100	0	94	0	37
	Source-reduction load	1,300,000	0	0	0	1,300,000	32,000,000	33,000,000
190-030	Existing load	3,000	15,000,000	8,500,000	0	23,500,000	61,000,000	84,000,000
	Percent reduction	0	100	100	0	100	0	28
	Source-reduction load	3,000	0	0	0	3,000	61,000,000	61,000,000
190-040	Existing load	0	9,800,000	1,400,000	0	11,200,000	11,000,000	22,000,000
	Percent reduction	0	100	100	0	100	0	50
	Source-reduction load	0	0	0	0	0	11,000,000	11,000,000

loss in fecal coliform load within HU 0508001-170-030 (the segment of Buck Creek in which C.J. Brown Reservoir is located). Losses in fecal coliform also were observed in the Mad River HUs downstream from the Donnels Creek confluence (0508001-180-080, -190-020, and -190-040). The loss of fecal coliform in these HUs is presumably due to die-off (decay). The Mad River HU (050880-180-030) immediately upstream from these HUs receives fecal coliform contributions from the Springfield CSOs and the Springfield WWTP—the largest combined loads of fecal coliform in the basin. The mean recreational-season load of fecal coliform exiting the Mad River Basin during the study period was approximately 3,000 trillion colonies (table 18). Of this load, the model indicated that point sources (WWTPs and CSOs) contributed 67 percent of the fecal coliform load in Mad River Basin streams.

Thirty-day geometric mean concentrations of fecal coliform were computed for each HU (table 19). The maximum fecal coliform concentrations were compared to numeric target of 1,000 col/100 mL. Simulated geometric mean counts that were greater than or equal to 1,000 col/100mL are highlighted in bold in table 19. Concentrations exceeded the target in the HUs of Mad River below Kings Creek (05080001-160-010), Beaver Creek (05080001-170-040), Buck Creek (05080001-170-060), Mill Creek (05080001-180-040), East Fork Donnels Creek (05080001-180-070) and the Mad River from Springfield to the mouth (05080001-180-030, -080, -190-020, -190-040) (fig. 13). The greatest exceedance was in Beaver Creek, where simulated concentrations were approaching 5 times the target concentration and an 79 percent reduction would be needed to achieve the target of 1,000 col/100 mL. However, Buck Creek below C.J. Brown Reservoir (05080001-170-060) had the most exceedances of the target (37 percent of the simulation period) (table 19).

In general, HUs with geometric mean concentrations of fecal coliform exceeding the Ohio EPA target received discharges from CSOs and (or) major WWTPs (greater than 0.5 Mgal/d). The exceptions to this are the Beaver Creek HU (05080001-170-040) and the Mad River HU that includes the city of Urbana (05080001-160-010). Both HUs had WWTPs (less than 0.5 Mgal/d) with high fecal coliform concentrations recorded in their monthly operating report (MOR) during certain months within the simulation period.

Nitrate

Nonpoint sources of nitrate include fertilizer and manure applications, atmospheric deposition, wildlife, and agricultural livestock. The greatest total nitrate loads from nonpoint sources came from pasture and agricultural lands (table 20), which make up 75 percent of the Mad River Basin. On the basis of model simulation results, the highest nitrate loads per acre came from agricultural lands and residential areas. Agricultural and residential areas contributed approximately 13 lb/acre of nitrate, and forests contributed approximately 1.6 lb/acre.

Table 18. Fecal coliform and nitrate loads at outlet of each 14-digit hydrologic unit (includes all contributions upstream from hydrologic unit) and loads contributed by each hydrologic unit, 1999–2003 (simulated from calibrated model).

[Recreation season is May 1 through October 15. A negative load difference indicates losses due to chemical transformation, plant uptake, or die-off. HU, Hydrologic Unit; E.F., East Fork]

Stream	Hydrologic unit code (0508001-)	Mean fecal coliform load per recreation season, in billion colonies		Mean nitrate load per year, in 1,000 pounds	
		Load discharged from HU	Load outflow-inflow difference within HU	Load discharged from HU	Load outflow-inflow difference within HU
Mad River	150-010	19,000	19,000	62	62
Mad River	150-020	110,000	87,000	340	280
Machochee Creek	150-030	37,000	37,000	120	120
Mad River	150-040	220,000	37,000	760	210
Glady Creek	150-050	39,000	39,000	83	83
Kings Creek	150-060	120,000	120,000	680	680
Mad River	160-010	460,000	-5,000	2,100	150
Muddy Creek	160-020	51,000	51,000	170	170
Dugan Run	160-030	74,000	74,000	330	330
Nettle Creek	160-040	87,000	87,000	340	340
Anderson Creek	160-050	38,000	38,000	140	140
Mad River	160-060	600,000	19,000	2,600	140
Storms Creek	160-070	20,000	20,000	64	64
Chapman Creek	160-080	76,000	76,000	180	180
Buck Creek	170-010	180,000	180,000	620	620
E. F. Buck Creek	170-020	180,000	180,000	540	540
Buck Creek	170-030	51,000	-300,000	430	-730
Beaver Creek	170-040	93,000	56,000	91	61
Sinking Creek	170-050	37,000	37,000	30	30
Buck Creek	170-060	1,800,000	1,600,000	630	110
Mad River	180-010	730,000	4,000	2,800	67
Moore Run	180-020	43,000	43,000	53	53
Mad River	180-030	4,100,000	1,500,000	4,300	760
Mill Creek	180-040	86,000	86,000	54	54
Rock Run	180-050	19,000	19,000	22	22
Donnels Creek	180-060	52,000	32,000	58	58
E. F. Donnels Creek	180-070	20,000	20,000	22	22
Mad River	180-080	3,700,000	-520,000	4,600	190
Jackson Creek	180-090	24,000	24,000	20	20
Mud Creek	190-010	53,000	53,000	41	41
Mad River	190-020	3,700,000	-70,000	5,200	560
Mud Run	190-030	60,000	60,000	49	49
Mad River	190-040	3,000,000	-700,000	5,300	100

Table 19. Fecal coliform concentrations simulated from calibrated model, 1999–2003.

[Numbers in bold indicate mean fecal coliform concentration exceeded Ohio Environmental Protection Agency water-quality standard of 1,000 colonies per 100 milliliters for fecal coliform (based on a 30-day geometric mean); E. F., East Fork; C., Creek; col/100 mL, colonies per 100 milliliters; na, not applicable]

Stream	Hydrologic unit code [05080001-]	Maximum 30-day geometric mean fecal coliform count (col/100 mL)	Percent of 30-day geometric mean fecal coliform concentrations above 1,000 col/100 mL	Percent reduction needed to meet target of 1,000 col/100 mL for maximum
Mad River	150-010	480	0	na
Mad River	150-020	500	0	na
Machochee Creek	150-030	520	0	na
Mad River	150-040	440	0	na
Glady Creek	150-050	380	0	na
Kings Creek	150-060	370	0	na
Mad River	160-010	**1,100**	0.7	9
Muddy Creek	160-020	650	0	na
Dugan Run	160-030	580	0	na
Nettle Creek	160-040	440	0	na
Anderson Creek	160-050	540	0	na
Mad River	160-060	860	0	na
Storms Creek	160-070	660	0	na
Chapman Creek	160-080	670	0	na
Buck Creek	170-010	880	0	na
E. F. Buck Creek	170-020	840	0	na
Buck Creek	170-030	10	0	na
Beaver Creek	170-040	**4,700**	8	79
Sinking Creek	170-050	1,000	0	na
Buck Creek	170-060	**3,700**	37	73
Mad River	180-010	720	0	na
Moore Run	180-020	1,000	0.1	na
Mad River	180-030	**2,100**	31	52
Mill Creek	180-040	**1,700**	33	41
Rock Run	180-050	940	0	na
Donnels Creek	180-060	1,000	0	na
E. F. Donnels C.	180-070	**1,200**	3	17
Mad River	180-080	**1,800**	16	44
Jackson Creek	180-090	1,000	0	na
Mud Creek	190-010	700	0	na
Mad River	190-020	**1,500**	6	33
Mud Run	190-030	750	0	na
Mad River	190-040	**1,200**	1.6	17

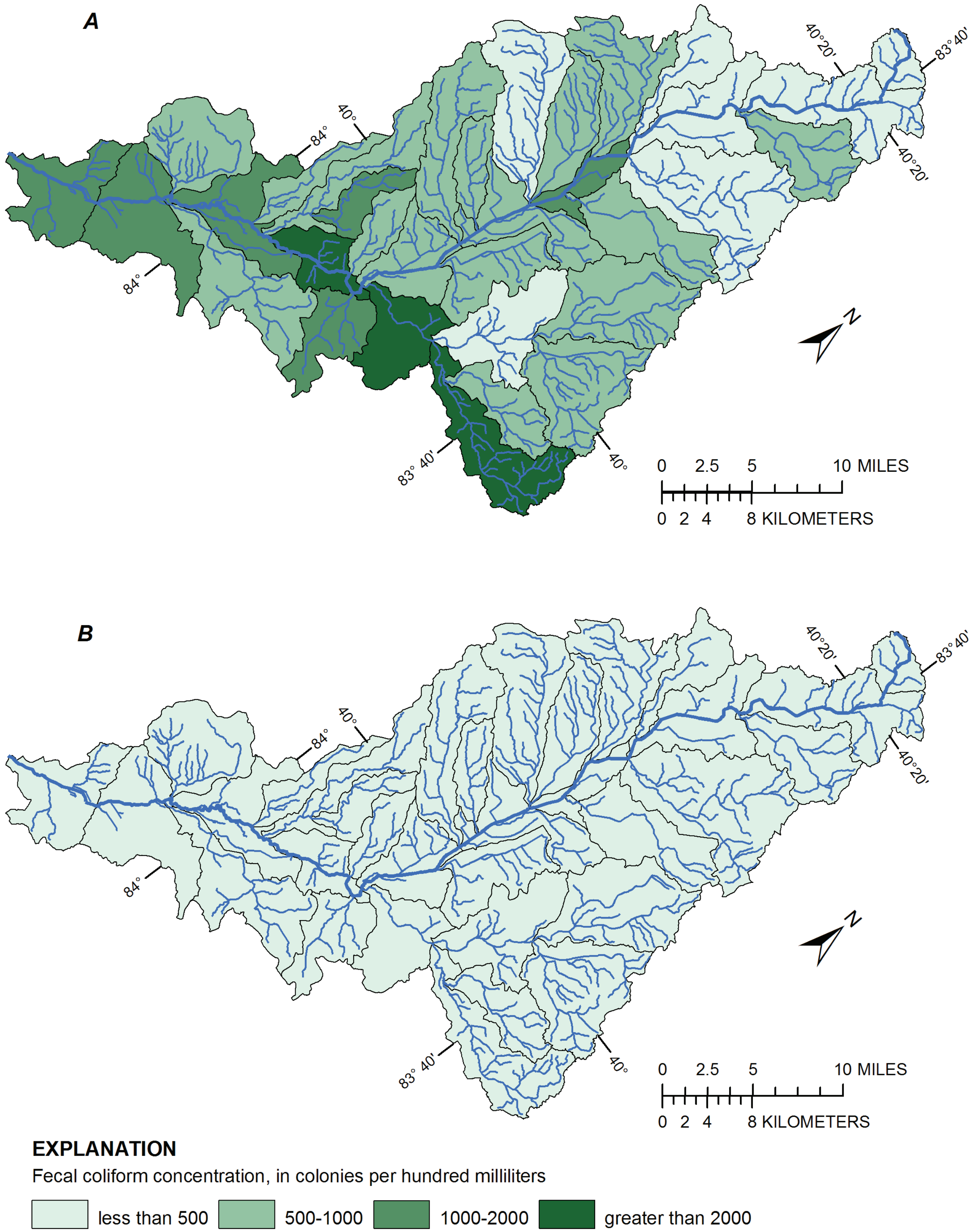

Figure 13. Simulated maximum 30-day geometric mean concentrations of fecal coliform from (*A*) calibrated model and (*B*) source-reduction model, Mad River Basin, 1999–2003.

Table 20. Mean annual nitrate loads from nonpoint sources simulated from calibrated model (existing loads) and source-reduction model, 1999-2003.

[Data may not sum to totals because of independent rounding]

Hydrologic unit (05080001-)		Nitrate loads, in pounds, from indicated land cover								
		Water	Low-intensity residential	High-intensity residential	Com-mercial/industrial	Urban or built-up land	Forest	Pasture	Agricultural Land	Total nonpoint source
150-010	Existing load	280	100	0	73	0	2,200	19,000	38,000	59,000
	Percent reduction	5	28		31		9	35	34	33
	Source-reduction load	260	71	0	51	0	2,000	12,000	25,000	40,000
150-020	Existing load	83	4,200	180	270	2,500	7,200	70,000	190,000	270,000
	Percent reduction	5	26	25	31	31	9	35	34	33
	Source-reduction load	79	3,100	130	190	1,700	6,500	46,000	130,000	180,000
150-030	Existing load	62	34	16	0	300	3,200	25,000	88,000	120,000
	Percent reduction	4	30	32		32	8	35	34	34
	Source-reduction load	60	24	11	0	210	2,900	16,000	58,000	77,000
150-040	Existing load	27	2,600	370	780	4,200	1,100	23,000	140,000	170,000
	Percent reduction	4	28	27	30	33	8	35	34	34
	Source-reduction load	26	1,900	270	540	2,800	1,000	15,000	91,000	110,000
150-050	Existing load	190	21	21	0	0	710	9,600	70,000	80,000
	Percent reduction	3	33	34			9	34	33	33
	Source-reduction load	190	14	14	0	0	640	6,300	47,000	54,000
150-060	Existing load	150	1,200	23	700	0	3,400	160,000	500,000	670,000
	Percent reduction	4	28	30	31		7	34	34	34
	Source-reduction load	140	860	16	490	0	3,100	100,000	330,000	440,000
160-010	Existing load	1,200	320	100	420	37	510	6,400	51,000	60,000
	Percent reduction	4	28	25	30	38	8	34	35	34
	Source-reduction load	1,100	230	76	290	23	470	4,200	33,000	40,000
160-020	Existing load	76	17	0	0	0	1,500	14,000	150,000	170,000
	Percent reduction	4	30				8	35	35	34
	Source-reduction load	73	12	0	0	0	1,300	9,100	100,000	110,000
160-030	Existing load	580	27,000	4,600	7,800	22,000	1,200	56,000	210,000	330,000
	Percent reduction	5	31	29	31	35	8	35	34	34
	Source-reduction load	550	18,000	3,300	5,400	14,000	1,200	37,000	140,000	220,000
160-040	Existing load	210	4,000	630	440	700	3,700	34,000	140,000	190,000
	Percent reduction	4	28	26	30	33	8	35	35	34
	Source-reduction load	210	2,900	470	310	470	3,400	22,000	94,000	120,000

Table 20. Mean annual nitrate loads from nonpoint sources simulated from calibrated model (existing loads) and source-reduction model, 1999-2003.—Continued

Hydrologic unit (05080001-)		Nitrate loads, in pounds, from indicated land cover								
		Water	Low-intensity residential	High-intensity residential	Com-mercial/ industrial	Urban or built-up land	Forest	Pasture	Agricultural Land	Total nonpoint source
160-050	Existing load	55	260	70	250	0	830	14,000	120,000	130,000
	Percent reduction	4	28	22	30		8	35	35	34
	Source-reduction load	53	190	55	180	0	760	8,800	78,000	88,000
160-060	Existing load	190	1,400	220	670	210	1,500	24,000	110,000	140,000
	Percent reduction	4	28	26	30	34	8	34	35	34
	Source-reduction load	180	1,000	160	470	140	1,300	16,000	71,000	90,000
160-070	Existing load	21	500	16	550	0	960	12,000	47,000	62,000
	Percent reduction	4	29	32	30		8	35	35	34
	Source-reduction load	20	360	11	380	0	880	8,100	31,000	41,000
160-080	Existing load	69	1,900	120	560	0	1,500	36,000	140,000	180,000
	Percent reduction	4	31	28	30		8	34	33	33
	Source-reduction load	66	1,300	88	390	0	1,300	23,000	92,000	120,000
170-010	Existing load	110	2,100	260	690	1,700	3,500	100,000	500,000	610,000
	Percent reduction	3	32	31	31	32	8	34	34	34
	Source-reduction load	110	1,400	180	480	1,100	3,200	66,000	330,000	410,000
170-020	Existing load	240	1,900	220	620	0	8,200	120,000	390,000	520,000
	Percent reduction	3	32	30	31		8	34	34	33
	Source-reduction load	230	1,300	150	430	0	7,500	81,000	260,000	350,000
170-030	Existing load	11,000	4,500	110	1,300	820	3,900	42,000	97,000	160,000
	Percent reduction	4	30	25	32	24	18	35	34	31
	Source-reduction load	11,000	3,200	82	880	620	3,200	28,000	65,000	110,000
170-040	Existing load	450	1,700	280	2,200	1,600	4,700	10,000	31,000	52,000
	Percent reduction	4	23	18	32	24	20	35	33	31
	Source-reduction load	440	1,300	230	1,500	1,200	3,800	6,700	21,000	36,000
170-050	Existing load	660	240	54	560	0	1,900	6,300	16,000	25,000
	Percent reduction	6	16	12	30		16	30	29	27
	Source-reduction load	620	200	48	390	0	1,600	4,400	11,000	18,000
170-060	Existing load	230	26,000	7,700	31,000	13,000	3,500	1,000	3,100	86,000
	Percent reduction	6	16	12	30	18	17	30	29	22
	Source-reduction load	220	22,000	6,800	22,000	11,000	2,900	740	2,200	67,000

Table 20. Mean annual nitrate loads from nonpoint sources simulated from calibrated model (existing loads) and source-reduction model, 1999-2003.—Continued

Hydrologic unit (05080001-)		Nitrate loads, in pounds, from indicated land cover								
		Water	Low-intensity residential	High-intensity residential	Com-mercial/industrial	Urban or built-up land	Forest	Pasture	Agricultural Land	Total nonpoint source
180-010	Existing load	750	6,800	630	9,100	3,800	6,500	5,000	11,000	44,000
	Percent reduction	5	17	12	31	18	15	30	29	25
	Source-reduction load	710	5,700	560	6,300	3,100	5,500	3,500	7,900	33,000
180-020	Existing load	110	6,300	480	6,600	2,000	5,600	6,400	15,000	43,000
	Percent reduction	10	16	13	30	15	17	31	27	26
	Source-reduction load	100	5,300	420	4,600	1,700	4,700	4,500	11,000	32,000
180-030	Existing load	1,200	2,800	400	4,200	600	3,500	4,900	9,600	27,000
	Percent reduction	6	16	11	30	18	16	30	29	25
	Source-reduction load	1,100	2,400	350	2,900	490	2,700	3,400	6,800	20,000
180-040	Existing load	47	9,800	1,800	10,000	1,800	2,700	4,200	13,000	43,000
	Percent reduction	6	16	12	30	18	16	30	29	24
	Source-reduction load	44	8,300	1,600	7,000	1,500	2,200	3,000	9,200	33,000
180-050	Existing load	35	2,400	430	1,500	1,000	1,400	3,400	9,200	19,000
	Percent reduction	6	16	12	30	18	16	30	29	26
	Source-reduction load	33	2,000	380	1,100	850	1,200	2,400	6,600	14,000
180-060	Existing load	35	1,200	98	300	210	2,500	4,700	23,000	32,000
	Percent reduction	4	16	11	30	18	16	30	29	27
	Source-reduction load	33	1,000	87	200	170	2,100	3,300	16,000	23,000
180-070	Existing load	6	220	150	290	0	890	3,100	12,000	16,000
	Percent reduction	6	15	11	30		16	30	29	28
	Source-reduction load	6	190	130	200	0	750	2,200	8,300	12,000
180-080	Existing load	1,600	1,400	280	1,900	970	820	3,900	11,000	22,000
	Percent reduction	12	15	14	33	16	18	25	27	24
	Source-reduction load	1,400	1,200	240	1,300	810	680	2,900	8,000	17,000
180-090	Existing load	18	170	38	540	0	1,200	3,600	12,000	17,000
	Percent reduction	6	17	9	30		16	30	29	28
	Source-reduction load	17	150	35	370	0	1,000	2,500	8,300	12,000
190-010	Existing load	460	3,500	1,200	4,400	1,500	910	7,000	16,000	35,000
	Percent reduction	7	16	15	33	16	18	25	27	25
	Source-reduction load	410	2,900	1,100	2,900	1,200	750	5,300	12,000	27,000
190-020	Existing load	1,500	8,500	4,000	29,000	12,000	1,600	6,400	12,000	75,000
	Percent reduction	4	20	17	33	19	26	34	34	28
	Source-reduction load	1,500	6,800	3,300	19,000	9,800	1,200	4,300	7,800	54,000
190-030	Existing load	1,300	3,800	3,100	3,400	2,000	1,700	12,000	30,000	57,000
	Percent reduction	2	22	34	29	22	26	34	33	31
	Source-reduction load	1,300	2,900	2,000	2,400	1,500	1,200	8,000	20,000	40,000
190-040	Existing load	2,600	15,000	6,900	36,000	5,600	1,000	2,000	2,900	72,000
	Percent reduction	10	16	15	33	16	18	25	27	25
	Source-reduction load	2,400	13,000	5,900	24,000	4,700	810	1,500	2,100	54,000

The simulation results indicated that WWTPs were the largest point source of nitrate (table 21). Mad River between Buck Creek confluence and Donnels Creek confluence (05080001-180-030) contributed the highest load of nitrate to the Mad River Basin from point sources. Wastewater treatment discharges (mainly the Springfield WWTP set to the design capacity) contributed 730,000 lb annually, about 96 percent of the nitrate load to this HU.

The nitrate loads exiting the Mad River Basin during the study period were approximately 5.3 million pounds annually (table 18). The model indicates that nonpoint sources contributed 74 percent of the nitrate load.

Daily mean concentrations of nitrate were computed at the outlet of each HU for the model simulation period 1999–2003 (table 22). The daily mean nitrate concentration ranged from 8.7 mg/L for Buck Creek above C.J. Brown Reservoir (05080001-170-010) to 1.0 mg/L for Sinking Creek (05080001-170-050), Jackson Creek (05080001-180-090), and Mud Creek (05080001-190-010). Mean nitrate concentrations exceeded the target of 5 mg/L in the subbasins of Kings Creek, Dugan Run, Buck Creek, and East Fork Buck Creek (05080001-150-060, -160-030, -170-010, -170-020) (fig. 14). Reductions needed to meet the target are specified in table 22, with the largest percent reduction (42 percent) needed in Buck Creek above C.J. Brown Reservoir (05080001-170-010). This HU, along with Kings Creek (05080001-150-060) and East Fork Buck Creek (05080001-170-020) exceeded the target concentration through the entire simulation period (table 22).

All HUs with mean nitrate concentrations greater than 5.0 mg/L were in predominantly agricultural areas. The maximum daily mean nitrate concentrations simulated at these HUs were on days with streamflows greater than the 90th percentile for all HUs except Dugan Run (05080001-160-030). The maximum daily mean nitrate concentration simulated was 21 mg/L (February 9, 1999) for Anderson Creek (05080001-160-050) and Nettle Creek (05080001-160-040).

Result of Load-Reduction Simulations

The Ohio EPA developed source-reduction scenarios for fecal coliform and nitrate in order to improve the water-quality conditions of streams in the Mad River Basin. HSPF models were revised to reflect changes associated with the source-reduction scenarios to assess the probable effect of the reductions on instream loads.

Fecal Coliform

The source-reduction scenario for fecal coliform included the elimination of failing septic systems from the Mad River Basin, the elimination of direct access of cattle to streams, the reduction of fecal coliform loads from CSOs by 95 percent, and an improvement to WWTPs that would eliminate all 30-day geometric mean exceedances of 1,000 col/100 mL in their effluent. The CSO loads were recomputed to adjust for a 95-percent reduction and stored in the WDM file. MORs from the WWTPs were reviewed, and all fecal coliform concentrations above 1,000 col/100 mL were lowered to 1,000 col/100 mL. The fecal coliform loads from these facilities were then recomputed on the basis of the lowered concentrations and entered as new time series in the WDM file.

Fecal coliform loads were computed for each HU from the revised model (table 23). The source-reduction model estimated that 810 trillion colonies would exit the Mad River Basin (HU 05080001-190-040), a 73-percent decrease in fecal coliform loads. The fecal-coliform-load reductions were not evenly distributed among the HUs. The elimination of failing septic systems and cattle in streams resulted in some reduction in the fecal coliform loads throughout the study area; however, the greatest load reductions of fecal coliform came from the 95-percent decrease in CSO loads, which had been identified as the largest source of fecal coliform by the calibrated model. The HUs affected by the CSO source reductions were only those in the vicinity of Springfield and the Mad River below Springfield.

As in the calibrated model, 30-day geometric mean fecal coliform concentrations for the source-reduction-scenario model were computed for each HU in the Mad River Basin (table 24). Target fecal coliform concentrations were not exceeded in any HUs in the source-reduction-scenario model. The maximum 30-day geometric mean fecal coliform concentration of 490 col/100 mL was simulated at Mad River below Springfield (HUC 05080001-180-030). This source-reduction scenario successfully lowered all stream concentrations below the target concentration for fecal coliform (fig. 13).

Nitrate

The source-reduction scenario for nitrate included the elimination of failing septic systems from the Mad River Basin, the elimination of direct access of cattle to streams, and a 30 percent reduction in nitrate runoff. This reduction scenario was selected by the Ohio EPA as part of a strategy established in the Mississippi River/Gulf of Mexico Watershed Nutrient Task Force Action Plan (2001) to reduce the hypoxia in the Gulf of Mexico. Because cattle in streams and failing septic systems were treated as point sources in the model, they could be removed by individual HU from the model. The reduction in nitrate runoff, however, required that a number of model parameters be altered for each model zone. These parameters included monthly interflow concentrations, monthly ground-water concentrations, maximum surface storage available for runoff, the accumulation rate of surface storage, and the susceptibility to washoff.

Nitrate loads were computed for each HU from the source-reduction model (table 23). The source-reduction model estimated that 2.6 million pounds of nitrate would exit the Mad River Basin (05080001-190-040), a 48-percent decrease in nitrate loads. Because most of the nitrate sources were evenly distributed across the study area, the percentage

Table 21. Mean annual nitrate load from selected sources and totals from nonpoint sources simulated from calibrated model (existing loads) and source-reduction model, 1999–2003.

[WWTPs, wastewater-treatment plants; CSOs, combined-sewer overflows; data may not sum to totals because of independent rounding]

Hydrologic unit (05080001-)		Nitrate loads, in pounds						
		WWTPs (1)	Failed septic systems (2)	Cattle in streams (3)	CSOs (4)	Total of columns 1 through 4	Total nonpoint sources (see table 20)	Total
150-010	Existing load	760	1,600	13	0	2,400	59,000	61,000
	Percent reduction	0	100	100	0	68	33	35
	Source-reduction load	760	0	0	0	760	40,000	40,000
150-020	Existing load	1,300	6,500	54	0	7,900	270,000	280,000
	Percent reduction	0	100	100	0	83	33	35
	Source-reduction load	1,300	0	0	0	1,300	180,000	180,000
150-030	Existing load	0	4,300	43	0	4,300	120,000	120,000
	Percent reduction	0	100	100	0	100	34	38
	Source-reduction load	0	0	0	0	0	77,000	77,000
150-040	Existing load	26,000	5,300	56	0	31,000	170,000	200,000
	Percent reduction	0	100	100	0	17	34	32
	Source-reduction load	26,000	0	0	0	26,000	110,000	140,000
150-050	Existing load	0	3,000	34	0	3,000	80,000	83,000
	Percent reduction	0	100	100	0	100	33	35
	Source-reduction load	0	0	0	0	0	54,000	54,000
150-060	Existing load	0	9,700	110	0	9,800	670,000	680,000
	Percent reduction	0	100	100	0	100	34	35
	Source-reduction load	0	0	0	0	0	440,000	440,000
160-010	Existing load	74,000	1,700	18	0	76,000	60,000	136,000
	Percent reduction	0	100	100	0	2	34	16
	Source-reduction load	74,000	0	0	0	74,000	40,000	114,000
160-020	Existing load	0	5,100	59	0	5,200	170,000	175,000
	Percent reduction	0	100	100	0	100	34	37
	Source-reduction load	0	0	0	0	0	110,000	110,000
160-030	Existing load	0	5,200	50	0	5,200	330,000	340,000
	Percent reduction	0	100	100	0	100	34	34
	Source-reduction load	0	0	0	0	0	220,000	220,000

Table 21. Mean annual nitrate load from selected sources and totals from nonpoint sources simulated from calibrated model (existing loads) and source-reduction model, 1999–2003.—Continued

Hydrologic unit (05080001-)		Nitrate loads, in pounds						
		WWTPs (1)	Failed septic systems (2)	Cattle in streams (3)	CSOs (4)	Total of columns 1 through 4	Total nonpoint sources (see table 20)	Total
	Existing load	4,400	6,300	67	0	11,000	190,000	200,000
160-040	Percent reduction	0	100	100	0	59	34	38
	Source-reduction load	4,400	0	0	0	4,400	120,000	120,000
	Existing load	0	3,900	47	0	3,900	130,000	130,000
160-050	Percent reduction	0	100	100	0	100	34	34
	Source-reduction load	0	0	0	0	0	88,000	88,000
	Existing load	0	4,300	48	0	4,300	140,000	140,000
160-060	Percent reduction	0	100	100	0	100	34	38
	Source-reduction load	0	0	0	0	0	90,000	90,000
	Existing load	0	2,000	22	0	2,000	62,000	64,000
160-070	Percent reduction	0	100	100	0	100	34	36
	Source-reduction load	0	0	0	0	0	41,000	41,000
	Existing load	0	5,400	63	0	5,500	180,000	190,000
160-080	Percent reduction	0	100	100	0	100	33	35
	Source-reduction load	0	0	0	0	0	120,000	120,000
	Existing load	0	6,800	80	0	6,900	610,000	620,000
170-010	Percent reduction	0	100	100	0	100	34	34
	Source-reduction load	0	0	0	0	0	410,000	410,000
	Existing load	6,700	6,400	72	0	13,200	520,000	530,000
170-020	Percent reduction	0	100	100	0	49	33	33
	Source-reduction load	6,700	0	0	0	6,700	350,000	360,000
	Existing load	0	4,600	51	0	4,700	160,000	160,000
170-030	Percent reduction	0	100	100	0	100	31	33
	Source-reduction load	0	0	0	0	0	110,000	110,000
	Existing load	4,400	5,700	63	0	10,000	52,000	62,000
170-040	Percent reduction	0	100	100	0	57	31	33
	Source-reduction load	4,400	0	0	0	4,400	36,000	41,000

Table 21. Mean annual nitrate load from selected sources and totals from nonpoint sources simulated from calibrated model (existing loads) and source-reduction model, 1999–2003.—Continued

Hydrologic unit (05080001-)		Nitrate loads, in pounds						
		WWTPs (1)	Failed septic systems (2)	Cattle in streams (3)	CSOs (4)	Total of columns 1 through 4	Total nonpoint sources (see table 20)	Total
170-050	Existing load	440	3,000	34	0	3,500	25,000	30,000
	Percent reduction	0	100	100	0	87	27	36
	Source-reduction load	440	0	0	0	440	18,000	19,000
170-060	Existing load	350	4,000	10	750	5,100	86,000	96,000
	Percent reduction	0	100	100	0	78	22	28
	Source-reduction load	350	0	0	750	1,100	67,000	69,000
180-010	Existing load	0	3,600	30	0	3,600	44,000	50,000
	Percent reduction	0	100	100	0	100	25	33
	Source-reduction load	0	0	0	0	0	33,000	33,000
180-020	Existing load	4,800	4,100	36	0	8,900	45,000	54,000
	Percent reduction	0	100	100	0	46	29	32
	Source-reduction load	4,800	0	0	0	4,800	32,000	37,000
180-030	Existing load	730,000	2,500	21	540	730,000	27,000	760,000
	Percent reduction	0	100	100	0	0	25	1
	Source-reduction load	730,000	0	0	540	730,000	20,000	750,000
180-040	Existing load	880	3,400	26	29	4,300	43,000	47,000
	Percent reduction	0	100	100	0	79	24	28
	Source-reduction load	880	0	0	29	900	33,000	34,000
180-050	Existing load	0	2,000	19	0	2,000	19,000	21,000
	Percent reduction	0	100	100	0	100	26	33
	Source-reduction load	0	0	0	0	0	14,000	14,000
180-060	Existing load	0	3,900	42	0	3,900	32,000	36,000
	Percent reduction	0	100	100	0	100	27	36
	Source-reduction load	0	0	0	0	0	23,000	23,000
180-070	Existing load	1,800	2,000	22	0	3,800	16,000	20,000
	Percent reduction	0	100	100	0	53	28	30
	Source-reduction load	1,800	0	0	0	1,800	12,000	14,000
180-080	Existing load	140,000	3,100	30	0	143,000	22,000	170,000
	Percent reduction	0	100	100	0	2	24	5
	Source-reduction load	140,000	0	0	0	140,000	17,000	160,000
180-090	Existing load	0	2,100	22	0	2,100	17,000	19,000
	Percent reduction	0	100	100	0	100	28	37
	Source-reduction load	0	0	0	0	0	12,000	12,000

Table 21. Mean annual nitrate load from selected sources and totals from nonpoint sources simulated from calibrated model (existing loads) and source-reduction model, 1999–2003.—Continued

Hydrologic unit (05080001-)		Nitrate loads, in pounds						
		WWTPs (1)	Failed septic systems (2)	Cattle in streams (3)	CSOs (4)	Total of columns 1 through 4	Total nonpoint sources (see table 20)	Total
190-010	Existing load	0	5,100	53	0	5,200	35,000	40,000
	Percent reduction	0	100	100	0	100	25	33
	Source-reduction load	0	0	0	0	0	27,000	27,000
190-020	Existing load	440,000	6,300	33	0	446,000	75,000	520,000
	Percent reduction	0	100	100	0	1	28	5
	Source-reduction load	440,000	0	0	0	440,000	54,000	490,000
190-030	Existing load	58	7,200	69	0	7,300	57,000	64,000
	Percent reduction	0	100	100	0	99	31	38
	Source-reduction load	58	0	0	0	58	40,000	40,000
190-040	Existing load	0	4,600	11	0	4,600	72,000	77,000
	Percent reduction	0	100	100	0	100	25	30
	Source-reduction load	0	0	0	0	0	54,000	54,000

Table 22. Nitrate concentrations simulated from calibrated model, 1999–2003.

[Numbers in bold indicate mean nitrate concentration exceeded Ohio Environmental Protection Agency water-quality standard of 5 mg/L for nitrate; E. Fk., East Fork; Crk, Creek; mg/L, milligrams per liter; na, not applicable]

Stream	Hydrologic unit [05080001-]	Maximum nitrate concentration (mg/L)	Percent of daily mean nitrate concentrations greater than 5 mg/L	Mean nitrate concentration (mg/L)	Percent reduction needed to meet target of 5 mg/L for mean
Mad River	150-010	5.3	0.6	3.4	na
Mad River	150-020	5.8	3.3	3.7	na
Machochee Creek	150-030	5.6	0.1	2.8	na
Mad River	150-040	11.4	0.3	3.6	na
Glady Creek	150-050	11.9	0.1	2.9	na
Kings Creek	150-060	10.8	100	**7.6**	34
Mad River	160-010	10.3	32	4.9	na
Muddy Creek	160-020	6.2	0.2	3.5	na
Dugan Run	160-030	10.7	99	**6.1**	18
Nettle Creek	160-040	21.3	0.6	3.3	na
Anderson Creek	160-050	21.4	0.7	3.6	na
Mad River	160-060	17	4.4	4.5	na
Storms Creek	160-070	10.8	0.1	3.1	na
Chapman Creek	160-080	6.1	2.2	3.1	na
Buck Creek	170-010	13.2	100	**8.7**	42
E. Fk. Buck Creek	170-020	12.2	100	**8.0**	38
Buck Creek	170-030	3.4	0	2.0	na
Beaver Creek	170-040	4.0	0	1.2	na
Sinking Creek	170-050	2.8	0	1.0	na
Buck Creek	170-060	7.9	0.1	1.8	na
Mad River	180-010	14.4	1.4	4.1	na
Moore Run	180-020	7.2	0.1	1.4	na
Mad River	180-030	7.9	11	4.2	na
Mill Creek	180-040	9.2	0.1	1.4	na
Rock Run	180-050	5.2	0.1	1.1	na
Donnels Creek	180-060	3.2	0	1.1	na
E. Fk. Donnels Crk	180-070	3.1	0	1.2	na
Mad River	180-080	8.2	11	4.1	na
Jackson Creek	180-090	2.8	0	1.0	na
Mud Creek	190-010	7.1	0.1	1.0	na
Mad River	190-020	9.0	20	4.3	na
Mud Run	190-030	4.7	0	1.1	na
Mad River	190-040	9.0	17	4.1	na

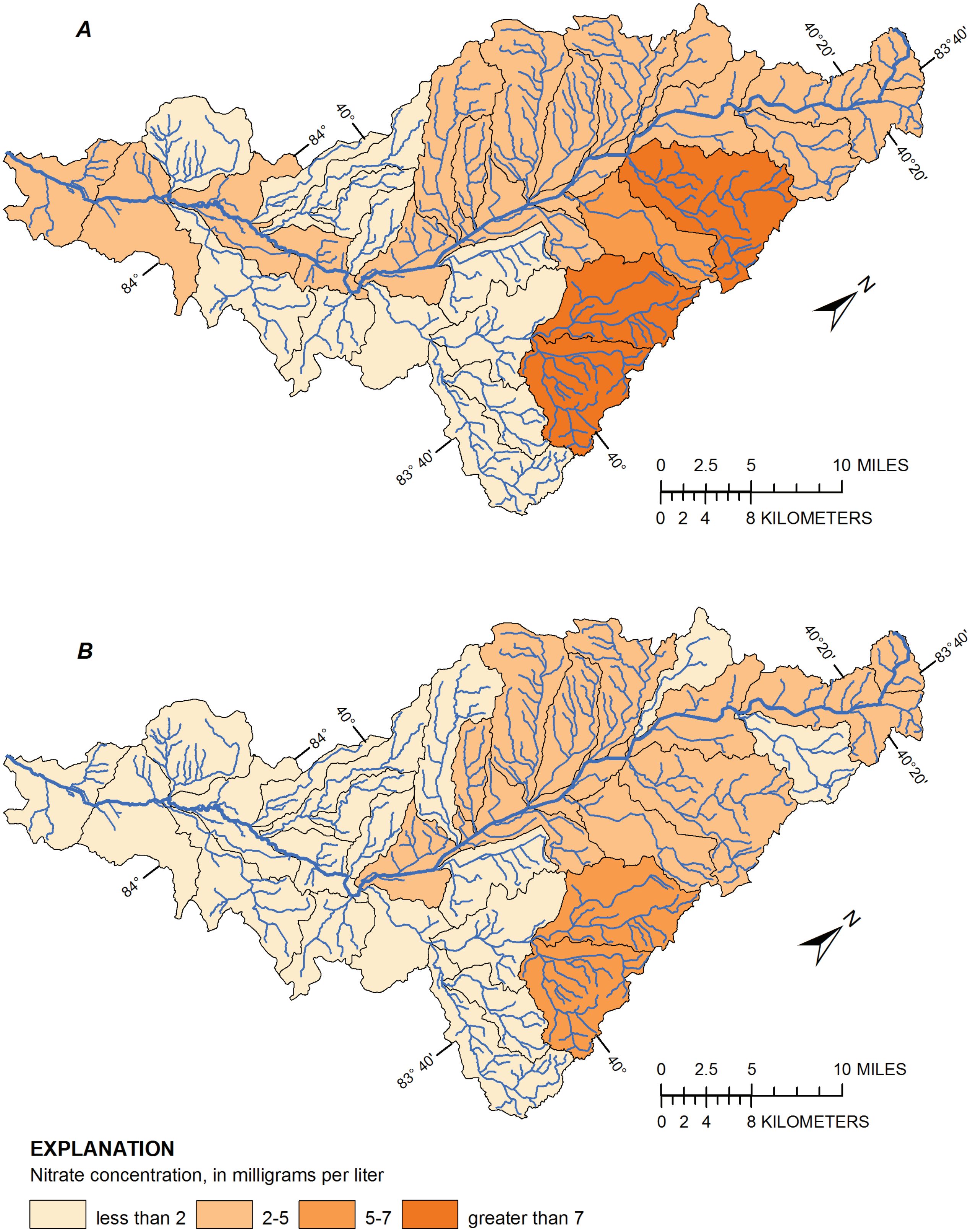

Figure 14. Simulated mean concentrations of nitrate from (*A*) calibrated model and (*B*) source-reduction model, Mad River Basin, 1999–2003.

Table 23. Nitrate and fecal coliform loads at outlet of each 14-digit hydrologic unit (includes all contributions upstream from hydrologic unit) simulated from source-reduction model, 1999–2003.

[Recreation season is May 1 through October 15. A negative load difference indicates losses due to chemical transformation, plant uptake, or die-off. HU, Hydrologic unit]

Stream	Hydrologic unit Code (05080001-)	Mean fecal coliform load per recreation season, in billion colonies		Mean nitrate load per year, in 1,000 pounds	
		Load discharged from HU	Load outflow - inflow difference within HU	Load discharged from HU	Load outflow - inflow difference within HU
Mad River	150-010	14,000	14,000	40	40
Mad River	150-020	82,000	67,000	220	180
Machochee Creek	150-030	33,000	33,000	77	77
Mad River	150-040	220,000	69,000	470	110
Glady Creek	150-050	42,000	42,000	54	54
Kings Creek	150-060	100,000	100,000	440	440
Mad River	160-010	350,000	-68,000	1,300	44
Muddy Creek	160-020	35,000	35,000	110	110
Dugan Run	160-030	58,000	58,000	220	220
Nettle Creek	160-040	61,000	61,000	220	220
Anderson Creek	160-050	26,000	26,000	90	90
Mad River	160-060	450,000	12,000	1,600	41
Storms Creek	160-070	13,000	13,000	41	41
Chapman Creek	160-080	57,000	57,000	120	120
Buck Creek	170-010	160,000	160,000	410	410
East Fork Buck Creek	170-020	160,000	160,000	350	350
Buck Creek	170-030	51,000	-260,000	290	-470
Beaver Creek	170-040	55,000	28,000	57	38
Sinking Creek	170-050	27,000	27,000	19	19
Buck Creek	170-060	180,000	76,000	420	72
Mad River	180-010	540,000	5,000	1,800	34
Moore Run	180-020	29,000	29,000	33	33
Mad River	180-030	900,000	140,000	2,300	22
Mill Creek	180-040	20,000	20,000	39	39
Rock Run	180-050	14,000	14,000	15	15
Donnels Creek	180-060	36,000	22,000	37	24
East Fork Donnels Creek	180-070	14,000	14,000	13	13
Mad River	180-080	890,000	-61,000	2,400	27
Jackson Creek	180-090	17,000	17,000	13	13
Mud Creek	190-010	38,000	38,000	27	27
Mad River	190-020	950,000	-19,000	2,500	58
Mud Run	190-030	41,000	41,000	32	32
Mad River	190-040	810,000	-140,000	2,600	58

Table 24. Fecal coliform and nitrate concentrations by 14-digit hydrologic unit simulated from source-reduction model, 1999–2003.

[See text for explanation of reduced-source scenario; numbers in bold indicate mean nitrate concentration exceeded Ohio EPA water-quality standard; E. Fk., East Fork; Crk, Creek; col, colonies; mL, milliliter; mg/L, milligrams per liter; na, not applicable]

Stream	Hydrologic unit code (05080001-)	Maximum 30-day geometric mean fecal coliform concentration, in col/100 mL	Mean 30-day geometric mean fecal coliform concentration, in col/100 mL	Maximum nitrate concentration, in mg/L	Mean nitrate concentration, in mg/L	Percent reduction needed to meet target of 5 mg/L for mean concentration
Mad River	150-010	230	44	3.4	2.1	na
Mad River	150-020	260	49	3.8	2.4	na
Machochee Creek	150-030	100	12	4.1	1.9	na
Mad River	150-040	220	50	5.3	2.2	na
Glady Creek	150-050	290	33	9.7	1.8	na
Kings Creek	150-060	140	19	7.1	5.0	na
Mad River	160-010	210	57	5.3	3.0	na
Muddy Creek	160-020	140	17	4.4	2.3	na
Dugan Run	160-030	270	19	7.6	3.9	na
Nettle Creek	160-040	180	43	5.7	2.2	na
Anderson Creek	160-050	190	25	5.6	2.4	na
Mad River	160-060	200	52	6.1	2.8	na
Storms Creek	160-070	140	14	8.5	2.1	na
Chapman Creek	160-080	170	18	4.4	1.9	na
Buck Creek	170-010	370	58	8.6	5.7	12
E. Fk. Buck Creek	170-020	310	49	8.0	5.1	2
Buck Creek	170-030	10	10	2.3	1.3	na
Beaver Creek	170-040	190	57	3.7	0.6	na
Sinking Creek	170-050	230	80	2.4	0.5	na
Buck Creek	170-060	230	65	5.5	1.1	na
Mad River	180-010	190	55	5.1	2.5	na
Moore Run	180-020	190	80	6.6	0.6	na
Mad River	180-030	490	150	4.3	1.9	na
Mill Creek	180-040	220	100	6.6	0.8	na
Rock Run	180-050	200	61	3.9	0.6	na
Donnels Creek	180-060	210	68	2.9	0.6	na
E. Fk. Donnels Crk	180-070	210	80	2.7	0.6	na
Mad River	180-080	400	140	4.1	1.8	na
Jackson Creek	180-090	230	77	2.0	0.5	na
Mud Creek	190-010	20	3	5.1	0.6	na
Mad River	190-020	350	120	4.2	1.6	na
Mud Run	190-030	35	7	3.3	0.6	na
Mad River	190-040	260	89	4.7	1.7	na

of nitrate reductions within each HU was relatively consistent (table 20; table 23).

Daily mean nitrate concentrations were computed for each HU for 1999–2003 on the basis of the source-reduction scenario. The mean nitrate concentrations ranged from 5.7 mg/L for Buck Creek above C.J. Brown Reservoir (HU 05080001-170-010) to 0.5 mg/L for Jackson Creek (HU 05080001-180-090) and Sinking Creek (HU 05080001-170-050). The maximum daily mean nitrate concentration simulated was 9.7 mg/L (August 3, 2001) for Glady Creek (HU 05080001-150-050); however, the mean daily concentration in Glady Creek (1.8 m/L) was below the target concentration. Additional load reductions are necessary to decrease mean nitrate concentrations to meet the nitrate target in the subbasins of Buck Creek and East Fork Buck Creek (HUs 05080001-170-010 and -170-020) (fig 14). To meet the nitrate target, further reductions of 12 and 2 percent, respectively, are needed in these subbasins (table 24).

TMDL Requirements

The calibrated water-quality model will be used by Ohio EPA to establish the TMDL for the Mad River Basin. The model must adequately simulate streamflow conditions during which the highest nitrate concentrations and fecal coliform counts occur. To calculate the TMDL, loads from all point sources, nonpoint sources, and natural background sources are summed. (See “Simulated Loads and Concentrations” section of this report.) The TMDL must include a margin of safety (MOS) that accounts for uncertainties inherent in the model and calibration data. The summed loads, with the incorporated MOS, are then converted to concentrations and are compared to target concentrations for fecal coliform bacteria and nitrate (based on Ohio WQS, where applicable) to determine whether the loads from the various sources in the basin can be sufficiently assimilated to allow all stream segments to meet their designated uses. If simulated concentrations of fecal coliform and nitrate exceed target concentrations, load-reduction scenarios must be considered that, if implemented, would result in meeting target concentrations. A load-reduction scenario that results in meeting target concentrations may then be selected by Ohio EPA and designated as the TMDL for the Mad River Basin.

Seasonal and Streamflow Variability

Seasonal variability in nitrate concentrations was neither indicated by the model nor evident from the observed data from the Mad River at St. Paris Pike streamflow gage. The absence of variability is likely due to the large ground-water component of streamflow, which delivers a relatively constant load of nitrate to the streams in the Mad River Basin. Seasonal variability in fecal coliform concentrations was not addressed in this study because the model was calibrated for the recreation season only (May 1st through October 15th). Further, linear regression of fecal coliform or nitrate concentrations on daily streamflow for each HU produced coefficients of determination (R^2) values of less than 0.3 for fecal coliform (during recreation season) and 0.4 for nitrate (during entire year), indicating a weak association of fecal coliform and nitrate concentrations with streamflow. However, when fecal coliform counts and nitrate concentrations were grouped as to whether or not the streamflows were at the highest 10-percent flows, the Wilcoxon-rank statistical test showed that the fecal coliform and nitrate concentrations were significantly higher during high streamflows at the Mad River at St. Paris Pike streamflow gage (results not presented herein).

Margin of Safety

A margin of safety was incorporated implicitly into the model from two model inputs. The failure rate of septic systems was set high (90 percent), given the predominant soil conditions in the Mad River Basin that are unfavorable for conventional leach-line septic systems. In addition, the discharge volumes of the five largest WWTP dischargers (with design capacity discharges of 0.5 Mgal/d or greater) were set at their design capacities, which were 25 to 67 percent greater than their present discharge volumes (table 8).

Target Concentrations

Target concentrations for the TMDLs were selected by Ohio EPA. The targets for fecal coliform concentrations for the protection of recreational water quality are stated in the Ohio WQS (Ohio Environmental Protection Agency, 2002). For primary contact waters, fecal coliform bacteria cannot exceed 2,000 col/100 mL in more than 10 percent of the samples collected during a 30-day period. Also, the geometric mean of the fecal coliform concentrations cannot exceed 1,000 col/100 mL (from at least five samples collected within a 30-day period) (Ohio Environmental Protection Agency, 2002). On the basis of changes to recreational use designations that were recently recommended by Ohio EPA (2005a), almost all waters in the Mad River Basin are currently considered primary contact waters. The exception is the West Liberty tributary. Although this tributary has a designated recreational use of secondary contact, it was aggregated with other streams in HU 005080001-150-040 in the model that have primary contact use designation. Therefore, the more stringent target specified for primary contact waters was applied to this HU as well as to all other HUs in the basin.

The target concentration for nitrate modeling was more difficult to determine. The Ohio WQS does not list a statewide numeric criterion for nitrate for the protection of aquatic life. Therefore, Ohio EPA established, for purposes of this study, a target mean nitrate concentration of 5 mg/L in the Mad River Basin that corresponds to a public-water-supply “action alert” that is equal to 50 percent of the Maximum Contaminant Level for drinking water (Ohio Environmental Protection Agency, 2005b).

Summary and Conclusions

The U.S. Geological Survey (USGS), in cooperation with the Ohio Environmental Protection Agency (Ohio EPA), developed a Hydrological Simulation Program–FORTRAN (HSPF) model to aid in total maximum daily load (TMDL) determinations for fecal coliform and nitrate in the Mad River Basin. The HSPF model simulated fecal coliform and nitrate loads at the outlet of each 14-digit Hydrologic Unit within the Mad River Basin.

The HSPF model included inputs from 32 WWTPs (5 of which had design capacities of 0.5 Mgal/d or greater), CSOs within the City of Springfield, failing septic systems, and cattle with direct access to streams. The inputs from the CSOs, failing septic systems, and cattle with direct access to streams were computed for each subbasin and treated as point sources from each subbasin to the main stream flowing through the subbasin. Atmospheric deposition and contributions from interflow and ground water were treated as nonpoint sources in the model. Parameter values for monthly maximum storage capacities for runoff, monthly accumulation rates for runoff, interflow concentrations, and ground-water concentrations to simulate these nonpoint sources were adjusted for each meteorologic zone that was defined in the model.

The calibrated model demonstrated fecal coliform counts (based on the maximum 30-day geometric average) in numerous HUs were greater than the chronic water-quality standard of 1,000 col/100 mL during the study period, 1999–2003. These exceedences were observed in HUs downstream of the Springfield CSOs and at outlets immediately downstream from wastewater-treatment facilities that reported the discharge of excessive fecal coliform concentrations during selected months within the study period. The model also demonstrated that daily mean nitrate concentrations in some HUs exceeded the target concentration of 5 mg/L. Although this concentration is not a water-quality standard, the Ohio EPA considers it to be a concentration above which is a reason for concern (Dale White, Ohio Environmental Protection Agency, written comm., 2005). HUs with mean nitrate concentrations greater than 5 mg/L were in predominately agricultural areas.

The calibrated model was revised to create scenarios that simulated reductions in the loads of fecal coliform and nitrate and provided a means to assess the effects of source reductions on instream fecal coliform and nitrate concentrations. The source-reduction scenarios used in the revised models were determined by the Ohio EPA. For the fecal coliform model, failing septic systems were eliminated, direct access of cattle to streams was eliminated, CSO loads were reduced by 95 percent, and monthly fecal coliform counts reported above 1,000 col/100 mL were reduced to 1,000 col/100 mL at all wastewater-treatment facilities. For the nitrate analysis, nonpoint sources were reduced throughout the Mad River Basin by 30 percent, failing septic systems were eliminated, and direct access of cattle to streams was eliminated. These source-reduction models produced major decreases in the fecal coliform and nitrate loads to the Mad River Basin. A comparison of the fecal coliform and nitrate loads exiting the outlet of the Mad River Basin showed a 73-percent reduction of fecal coliform and a 52-percent reduction of nitrate. Some HUs with mean nitrate concentrations above 5 mg/L were still indicated with the source-reduction model, although the number of HUs and the concentrations were greatly decreased. Ohio EPA may use this calibrated model to run further load-reduction scenarios before a TMDL for nitrate will be established. There were no HUs with maximum 30-day geometric means above 1,000 col/100 mL observed with the source-reduction scenario for fecal coliform.

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Appendixes

Explanation of the PERLAND codes used in Appendixes 2 through 4

The term “PERLAND” is used in the following tables to describe the permeable land segments used in the models. The PERLAND consists of a three-digit code. The first digit of the PERLAND code represents the model-segmentation number, and the last two digits represent the land-use classification. The following numbers are used for land-use classification:

01 Water
02 Low-intensity residential
03 High-intensity residential
04 Commercial/Industrial
05 Urban or built-up land
06 Forest
07 Pasture
08 Agricultural land

Appendix 1. Percentage of each 14-digit hydrologic unit with a given land-cover classification.

[Land-cover data obtained from U.S. Geological Survey, 1992. Some categories were reclassified for the model, as indicated in table 3. Model subbasins are shown on figure 7. HU, hydrologic unit]

14-digit HU, (05080001-)	Model subbasin(s)	Model land-cover classification							
		Water	Low-intensity residential	High-intensity residential	Commercial/ industrial	Forest	Pasture	Agricultural land	Urban or built-up land
150-010	26	0.70	0.08	0.01	0.07	42.44	20.72	35.97	0.00
150-020	31	0.05	0.98	0.05	0.06	33.77	19.20	45.30	0.59
150-030	27	0.08	0.02	0.01	0.00	25.24	20.13	54.38	0.15
150-040	2, 40	0.03	0.93	0.16	0.25	7.48	15.87	73.79	1.49
150-050	1	0.34	0.01	0.01	0.01	6.79	13.69	79.16	0.00
150-060	3	0.07	0.19	0.01	0.09	10.47	22.58	66.59	0.00
160-010	8, 32, 42	3.31	0.32	0.10	0.39	9.57	11.96	74.30	0.05
160-020	4	0.08	0.00	0.00	0.00	9.67	9.49	80.76	0.00
160-030	5, 51	0.52	7.99	1.46	2.41	8.17	15.06	57.49	6.89
160-040	7, 41	0.17	1.26	0.20	0.11	19.64	18.38	60.04	0.20
160-050	6	0.07	0.13	0.03	0.10	7.10	11.77	80.81	0.00
160-060	11	0.21	0.69	0.10	0.27	11.45	19.50	67.67	0.11
160-070	9	0.06	0.51	0.03	0.45	15.88	21.04	62.04	0.00
160-080	10	0.06	0.58	0.04	0.16	9.02	21.07	69.06	0.00
170-010	39	0.08	0.29	0.03	0.15	6.29	16.88	75.91	0.36
170-020	38	0.18	0.27	0.03	0.15	15.49	21.78	62.11	0.00
170-030	13, 37	13.03	1.76	0.07	0.51	8.98	26.38	48.55	0.72
170-040	14, 36	0.49	1.40	0.20	0.82	10.04	21.60	64.19	1.25
170-050	15	1.27	0.43	0.08	0.40	8.06	26.34	63.42	0.00
170-060	28, 35, 47, 48	0.31	35.06	8.44	16.78	11.09	3.26	9.73	15.35
180-010	17, 33	1.25	9.54	0.75	5.21	22.45	17.31	37.99	5.49
180-020	12	0.16	8.17	0.53	3.46	17.72	20.39	47.12	2.46
180-030	29, 34, 49	2.67	5.79	0.67	3.37	16.94	23.64	45.80	1.12
180-040	19, 52	0.08	15.44	2.34	6.37	10.01	15.87	47.21	2.68
180-050	18	0.11	6.39	0.93	1.62	8.75	21.84	57.80	2.55
180-060	20	0.06	1.63	0.11	0.16	8.22	15.80	73.76	0.26
180-070	15	0.01	0.57	0.29	0.31	5.67	19.85	73.29	0.00
180-080	23, 44	2.35	6.53	0.88	2.84	12.56	20.31	52.42	2.11
180-090	21	0.05	0.46	0.06	0.55	7.32	21.86	69.70	0.00
190-010	22	0.52	6.93	1.60	2.22	9.66	22.23	54.55	2.28
190-020	30, 45, 50	1.67	12.82	3.98	11.96	12.42	14.37	28.43	14.36
190-030	24, 43	0.22	3.96	0.32	1.55	11.27	23.79	56.63	2.26
190-040	25, 46	3.12	31.33	9.27	19.18	11.01	6.75	10.08	9.26

Appendix 2. Values of selected parameters used in calibrated model to simulate streamflow.

Table 2-1. Monthly lower zone evapotranspiration (MON-LZETPARM) [PERLAND, permeable land segment]

PERLAND	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
101-105	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.2
106	0.2	0.2	0.3	0.3	0.5	0.7	0.7	0.7	0.5	0.3	0.2	0.2
107	0.2	0.2	0.3	0.3	0.4	0.5	0.5	0.5	0.4	0.3	0.2	0.2
108	0.2	0.2	0.2	0.2	0.3	0.5	0.7	0.7	0.6	0.4	0.2	0.2
201-205	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.2
206	0.2	0.2	0.3	0.3	0.5	0.7	0.7	0.7	0.5	0.3	0.2	0.2
207	0.2	0.2	0.3	0.3	0.4	0.5	0.5	0.5	0.4	0.3	0.2	0.2
208	0.2	0.2	0.2	0.2	0.3	0.5	0.7	0.7	0.6	0.4	0.2	0.2
301-305	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.2
306	0.2	0.2	0.3	0.3	0.5	0.7	0.7	0.7	0.5	0.3	0.2	0.2
307	0.2	0.2	0.3	0.3	0.4	0.5	0.5	0.5	0.4	0.3	0.2	0.2
308	0.2	0.2	0.2	0.2	0.3	0.5	0.7	0.7	0.6	0.4	0.2	0.2
401-405	0.4	0.4	0.4	0.4	0.4	0.4	0.4	0.4	0.4	0.4	0.4	0.4
406	0.4	0.4	0.6	0.6	1	1.4	1.4	1.4	1	0.6	0.4	0.4
407	0.4	0.4	0.6	0.6	0.8	1	1	1	0.8	0.6	0.4	0.4
408	0.4	0.4	0.4	0.4	0.6	1	1.4	1.4	1.2	0.8	0.4	0.4
501-505	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.2
506	0.2	0.2	0.3	0.3	0.5	0.7	0.7	0.7	0.5	0.3	0.2	0.2
507	0.2	0.2	0.3	0.3	0.4	0.5	0.5	0.5	0.4	0.3	0.2	0.2
508	0.2	0.2	0.2	0.2	0.3	0.5	0.7	0.7	0.6	0.4	0.2	0.2
601-605	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.2
606	0.2	0.2	0.3	0.3	0.5	0.7	0.7	0.7	0.5	0.3	0.2	0.2
607	0.2	0.2	0.3	0.3	0.4	0.5	0.5	0.5	0.4	0.3	0.2	0.2
608	0.2	0.2	0.2	0.2	0.3	0.5	0.7	0.7	0.6	0.4	0.2	0.2
701-704	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.2
706	0.2	0.2	0.3	0.3	0.5	0.7	0.7	0.7	0.5	0.3	0.2	0.2
707	0.2	0.2	0.3	0.3	0.4	0.5	0.5	0.5	0.4	0.3	0.2	0.2
708	0.2	0.2	0.2	0.2	0.3	0.5	0.7	0.7	0.6	0.4	0.2	0.2
801-804	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.2
806	0.2	0.2	0.3	0.3	0.5	0.7	0.7	0.7	0.5	0.3	0.2	0.2
807	0.2	0.2	0.3	0.3	0.4	0.5	0.5	0.5	0.4	0.3	0.2	0.2
808	0.2	0.2	0.2	0.2	0.3	0.5	0.7	0.7	0.6	0.4	0.2	0.2
901-903	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.2
906	0.2	0.2	0.3	0.3	0.5	0.7	0.7	0.7	0.5	0.3	0.2	0.2
907	0.2	0.2	0.3	0.3	0.4	0.5	0.5	0.5	0.4	0.3	0.2	0.2
908	0.2	0.2	0.2	0.2	0.3	0.5	0.7	0.7	0.6	0.4	0.2	0.2

Appendix 2. Values of selected parameters used in calibrated model to simulate streamflow. —Continued

Table 2-2. Monthly interception storage capacity (MON-INTERCEP), in inches

PERLAND	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
101	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02
102	0.092	0.092	0.092	0.093	0.095	0.096	0.096	0.096	0.096	0.094	0.092	0.092
103	0.092	0.092	0.092	0.093	0.094	0.095	0.094	0.094	0.094	0.094	0.092	0.092
104	0.092	0.092	0.092	0.093	0.093	0.094	0.094	0.094	0.094	0.094	0.092	0.092
105	0.092	0.092	0.092	0.093	0.095	0.096	0.096	0.096	0.096	0.094	0.092	0.092
106	0.06	0.06	0.06	0.08	0.12	0.16	0.16	0.16	0.16	0.16	0.07	0.06
107	0.06	0.06	0.06	0.068	0.078	0.088	0.098	0.098	0.098	0.078	0.06	0.06
108	0.02	0.02	0.02	0.04	0.08	0.1	0.143	0.143	0.143	0.08	0.02	0.02
201	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02
202	0.092	0.092	0.092	0.093	0.095	0.096	0.096	0.096	0.096	0.094	0.092	0.092
203	0.092	0.092	0.092	0.093	0.094	0.095	0.094	0.094	0.094	0.094	0.092	0.092
204	0.092	0.092	0.092	0.093	0.093	0.094	0.094	0.094	0.094	0.094	0.092	0.092
205	0.092	0.092	0.092	0.093	0.095	0.096	0.096	0.096	0.096	0.094	0.092	0.092
206	0.06	0.06	0.06	0.08	0.12	0.16	0.16	0.16	0.16	0.1	0.07	0.06
207	0.06	0.06	0.06	0.068	0.078	0.088	0.098	0.098	0.098	0.078	0.06	0.06
208	0.02	0.02	0.02	0.04	0.08	0.1	0.143	0.143	0.143	0.08	0.02	0.02
301	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02
302	0.092	0.092	0.092	0.093	0.095	0.096	0.096	0.096	0.096	0.094	0.092	0.092
303	0.092	0.092	0.092	0.093	0.094	0.095	0.094	0.094	0.094	0.094	0.092	0.092
304	0.092	0.092	0.092	0.093	0.093	0.094	0.094	0.094	0.094	0.094	0.092	0.092
305	0.092	0.092	0.092	0.093	0.095	0.096	0.096	0.096	0.096	0.094	0.092	0.092
306	0.06	0.06	0.06	0.08	0.12	0.16	0.16	0.16	0.16	0.1	0.07	0.06
307	0.06	0.06	0.06	0.068	0.078	0.088	0.098	0.098	0.098	0.078	0.06	0.06
308	0.02	0.02	0.02	0.04	0.08	0.1	0.143	0.143	0.143	0.08	0.02	0.02

Appendix 2. Values of selected parameters used in calibrated model to simulate streamflow. —Continued

Table 2-2. Monthly interception storage capacity (MON-INTERCEP), in inches.—Continued

PERLAND	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
401	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02
402	0.092	0.092	0.092	0.093	0.095	0.096	0.096	0.096	0.096	0.094	0.092	0.092
403	0.092	0.092	0.092	0.093	0.094	0.095	0.094	0.094	0.094	0.094	0.092	0.092
404	0.092	0.092	0.092	0.093	0.093	0.094	0.094	0.094	0.094	0.094	0.092	0.092
405	0.092	0.092	0.092	0.093	0.095	0.096	0.096	0.096	0.096	0.094	0.092	0.092
406	0.06	0.06	0.06	0.08	0.12	0.16	0.16	0.16	0.16	0.1	0.07	0.06
407	0.06	0.06	0.06	0.068	0.078	0.088	0.098	0.098	0.098	0.078	0.06	0.06
408	0.02	0.02	0.02	0.04	0.08	0.1	0.143	0.143	0.143	0.08	0.02	0.02
501	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02
502	0.092	0.092	0.092	0.093	0.095	0.096	0.096	0.096	0.096	0.094	0.092	0.092
503	0.092	0.092	0.092	0.093	0.094	0.095	0.094	0.094	0.094	0.094	0.092	0.092
504	0.092	0.092	0.092	0.093	0.093	0.094	0.094	0.094	0.094	0.094	0.092	0.092
505	0.092	0.092	0.092	0.093	0.095	0.096	0.096	0.096	0.096	0.094	0.092	0.092
506	0.06	0.06	0.06	0.08	0.12	0.16	0.16	0.16	0.16	0.1	0.07	0.06
507	0.06	0.06	0.06	0.068	0.078	0.088	0.098	0.098	0.098	0.078	0.06	0.06
508	0.02	0.02	0.02	0.04	0.08	0.1	0.143	0.143	0.143	0.08	0.02	0.02
601	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02
602	0.092	0.092	0.092	0.093	0.095	0.096	0.096	0.096	0.096	0.094	0.092	0.092
603	0.092	0.092	0.092	0.093	0.094	0.095	0.094	0.094	0.094	0.094	0.092	0.092
604	0.092	0.092	0.092	0.093	0.093	0.094	0.094	0.094	0.094	0.094	0.092	0.092
605	0.092	0.092	0.092	0.093	0.095	0.096	0.096	0.096	0.096	0.094	0.092	0.092
606	0.06	0.06	0.06	0.08	0.12	0.16	0.16	0.16	0.16	0.1	0.07	0.06
607	0.06	0.06	0.06	0.068	0.078	0.088	0.098	0.098	0.098	0.078	0.06	0.06
608	0.02	0.02	0.02	0.04	0.08	0.1	0.143	0.143	0.143	0.08	0.02	0.02

Appendix 2. Values of selected parameters used in calibrated model to simulate streamflow. —Continued

Table 2-2. Monthly interception storage capacity (MON-INTERCEP), in inches.—Continued

PERLAND	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
701	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02
702	0.092	0.092	0.092	0.093	0.095	0.096	0.096	0.096	0.096	0.094	0.092	0.092
703	0.092	0.092	0.092	0.093	0.094	0.095	0.094	0.094	0.094	0.094	0.092	0.092
704	0.092	0.092	0.092	0.093	0.093	0.094	0.094	0.094	0.094	0.094	0.092	0.092
706	0.06	0.06	0.06	0.08	0.12	0.16	0.16	0.16	0.16	0.1	0.07	0.06
707	0.06	0.06	0.06	0.068	0.078	0.088	0.098	0.098	0.098	0.078	0.06	0.06
708	0.02	0.02	0.02	0.04	0.08	0.1	0.143	0.143	0.143	0.08	0.02	0.02
801	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02
802	0.092	0.092	0.092	0.093	0.095	0.096	0.096	0.096	0.096	0.094	0.092	0.092
803	0.092	0.092	0.092	0.093	0.094	0.095	0.094	0.094	0.094	0.094	0.092	0.092
804	0.092	0.092	0.092	0.093	0.093	0.094	0.094	0.094	0.094	0.094	0.092	0.092
806	0.06	0.06	0.06	0.08	0.12	0.16	0.16	0.16	0.16	0.1	0.07	0.06
807	0.06	0.06	0.06	0.068	0.078	0.088	0.098	0.098	0.098	0.078	0.06	0.06
808	0.02	0.02	0.02	0.04	0.08	0.1	0.143	0.143	0.143	0.08	0.02	0.02
901	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02
902	0.092	0.092	0.092	0.093	0.095	0.096	0.096	0.096	0.096	0.094	0.092	0.092
903	0.092	0.092	0.092	0.093	0.094	0.095	0.094	0.094	0.094	0.094	0.092	0.092
906	0.06	0.06	0.06	0.08	0.12	0.16	0.16	0.16	0.16	0.1	0.07	0.06
907	0.06	0.06	0.06	0.068	0.078	0.088	0.098	0.098	0.098	0.078	0.06	0.06
908	0.02	0.02	0.02	0.04	0.08	0.1	0.143	0.143	0.143	0.08	0.02	0.02

Appendix 2. Values of selected parameters used in calibrated model to simulate streamflow. —Continued

Table 2-3. Additional parameter values used to simulate streamflow.

[INFILT, infiltration capacity of the soil (inches per hour); INTFW, interflow coefficient; KVARY, ground-water recession flow (per inches); LSUR, length of the overland flow plane (feet); LZETP, lower zone evapotranspiration parameter (inches); LZSN, lower zone nominal storage (inches); UZSN, upper zone nominal storage (inches)]

PERLAND	AGWRC	INFILT	INTFW	KVARY	LSUR	LZETP	LZSN	UZSN
101	0.999	0.006	3	4	350	0.1	3.6	0.281
102	0.999	0.024	1.5	4	350	0.3	3.9	0.844
103	0.999	0.024	2	4	350	0.25	3.9	0.703
104	0.999	0.015	2	4	350	0.2	3.9	0.563
105	0.999	0.018	2	4	350	0.3	3.6	0.844
106	0.999	0.06	1.5	4	350	0.7	3.9	1.969
107	0.999	0.06	2	4	350	0.5	3.6	1.406
108	0.999	0.024	2.2	4	350	0.6	3.6	1.688
201	0.999	0.01	3	2	350	0.1	3	0.281
202	0.999	0.04	1.5	2	350	0.3	3.25	0.844
203	0.999	0.04	2	2	350	0.25	3.25	0.703
204	0.999	0.025	2	2	350	0.2	3.25	0.563
205	0.999	0.03	2	2	350	0.3	3	0.844
206	0.999	0.1	1.5	2	350	0.7	3.25	1.969
207	0.999	0.1	2	2	350	0.5	3	1.406
208	0.999	0.04	2.2	2	350	0.6	3	1.688
301	0.999	0.01	3	2	350	0.1	3	0.281
302	0.999	0.04	1.5	2	350	0.3	3.25	0.844
303	0.999	0.04	2	2	350	0.25	3.25	0.703
304	0.999	0.025	2	2	350	0.2	3.25	0.563
305	0.999	0.03	2	2	350	0.3	3	0.844
306	0.999	0.1	1.5	2	350	0.7	3.25	1.969
307	0.999	0.1	2	2	350	0.5	3	1.8
308	0.999	0.04	2.2	2	350	0.6	3	1.8
401	0.999	0.004	6	5	350	0.1	5.6	0.281
402	0.999	0.002	5	5	350	0.3	5.9	0.844
403	0.999	0.008	5.5	5	350	0.25	5.9	0.703
404	0.999	0.008	5.5	5	350	0.2	5.9	0.563
405	0.999	0.005	3	5	350	0.3	5.6	0.844
406	0.999	0.007	2.5	5	350	0.7	3.9	1.969
407	0.999	0.022	6.8	5	350	0.5	5.6	1.8
408	0.999	0.022	6.9	5	350	0.6	5.6	1.8

Appendix 2. Values of selected parameters used in calibrated model to simulate streamflow. —Continued

PERLAND	AGWRC	INFILT	INTFW	KVARY	LSUR	LZETP	LZSN	UZSN
501	0.999	0.008	3	2	350	0.1	3	0.2813
502	0.999	0.04	1.5	2	350	0.3	3.25	0.8438
503	0.999	0.04	2	2	350	0.25	3.25	0.7031
504	0.999	0.025	2	2	350	0.2	3.25	0.5625
505	0.999	0.03	2	2	350	0.3	3	0.8438
506	0.999	0.1	1.5	2	350	0.7	3.25	1.9688
507	0.999	0.1	2	2	350	0.5	3	1.4063
508	0.999	0.04	2.2	2	350	0.6	3	1.6875
601	0.999	0.006	3	2	350	0.1	3.6	0.281
602	0.999	0.024	1.5	2	350	0.3	3.9	0.844
603	0.999	0.024	2	2	350	0.25	3.9	0.703
604	0.999	0.015	2	2	350	0.2	3.9	0.563
605	0.999	0.018	2	2	350	0.3	3.6	0.844
606	0.999	0.06	1.5	2	350	0.7	3.9	1.969
607	0.999	0.06	2	2	350	0.5	3.6	1.406
608	0.999	0.024	2.2	2	350	0.6	3.6	1.688
701	0.999	0.01	3	2	350	0.1	3	0.2813
702	0.999	0.04	1.5	2	350	0.3	3.25	0.8438
703	0.999	0.04	2	2	350	0.25	3.25	0.7031
704	0.999	0.025	2	2	350	0.2	3.25	0.5625
706	0.999	0.1	1.5	2	350	0.7	3.25	1.9688
707	0.999	0.1	2	2	350	0.5	3	1.4063
708	0.999	0.04	2.2	2	350	0.6	3	1.6875
801	0.999	0.01	3	2	350	0.1	3	0.2813
802	0.999	0.04	1.5	2	350	0.3	3.25	0.8438
803	0.999	0.04	2	2	350	0.25	3.25	0.7031
804	0.999	0.025	2	4	350	0.2	3.25	0.5625
806	0.999	0.1	1.5	2	350	0.7	3.25	1.9688
807	0.999	0.1	2	2	350	0.5	3	1.4063
808	0.999	0.04	2.2	2	350	0.6	3	1.6875
901	0.999	0.006	3	4	350	0.1	3.6	0.281
902	0.999	0.024	1.5	4	350	0.3	3.9	0.844
903	0.999	0.024	2	4	350	0.25	3.9	0.703
906	0.999	0.06	1.5	4	350	0.7	3.9	1.969
907	0.999	0.06	2	4	350	0.5	3.6	1.406
908	0.999	0.024	2.2	4	350	0.6	3.6	1.688

Appendix 3. Parameter values used in calibrated model to simulate fecal coliform concentrations.

Table 3-1. Monthly accumulation rate (million colonies per acre per day).

[PERLAND, permeable land segment]

PERLAND	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
101	0.78	0.78	0.78	0.78	0.78	0.78	0.78	0.78	0.78	0.78	0.78	0.78
102	10.3	10.3	10.3	10.3	10.3	10.3	10.3	10.3	10.3	10.3	10.3	10.3
103	20	20	20	20	20	20	20	20	20	20	20	20
104	6.2	6.2	6.2	6.2	6.2	6.2	6.2	6.2	6.2	6.2	6.2	6.2
105	11.3	11.3	11.3	11.3	11.3	11.3	11.3	11.3	11.3	11.3	11.3	11.3
106	13.5	13.5	13.5	13.5	13.5	13.5	13.5	13.5	13.5	13.5	13.5	13.5
107	5.35	5.35	191.1	4682	14682	11109	11109	11109	14682	146821	18256	376
108	679	750	8244	8526	765	708	679	2756	790	779	2787	679
201	0.78	0.78	0.78	0.78	0.78	0.78	0.78	0.78	0.78	0.78	0.78	0.78
202	10.3	10.3	10.3	10.3	10.3	10.3	10.3	10.3	10.3	10.3	10.3	10.3
203	20	20	20	20	20	20	20	20	20	20	20	20
204	6.2	6.2	6.2	6.2	6.2	6.2	6.2	6.2	6.2	6.2	6.2	6.2
205	11.3	11.3	11.3	11.3	11.3	11.3	11.3	11.3	11.3	11.3	11.3	11.3
206	13.5	13.5	13.5	13.5	13.5	13.5	13.5	13.5	13.5	13.5	13.5	13.5
207	5	5	203	5723	5723	4395	4395	4395	5723	5723	7051	399
208	731	808	9093	9403	889	763	731	3039	919	904	3008	731
301	0.78	0.78	0.78	0.78	0.78	0.78	0.78	0.78	0.78	0.78	0.78	0.78
302	10.3	10.3	10.3	10.3	10.3	10.3	10.3	10.3	10.3	10.3	10.3	10.3
303	20	20	20	20	20	20	20	20	20	20	20	20
304	6.2	6.2	6.2	6.2	6.2	6.2	6.2	6.2	6.2	6.2	6.2	6.2
305	11.3	11.3	11.3	11.3	11.3	11.3	11.3	11.3	11.3	11.3	11.3	11.3
306	13.5	13.5	13.5	13.5	13.5	13.5	13.5	13.5	13.5	13.5	13.5	13.5
307	7	7	317	21800	21800	16513	16513	16513	21800	21800	27000	627
308	928	1026	11313	11700	1050	969	928	3781	1085	1070	3821	928

Appendix 3. Parameter values used in calibrated model to simulate fecal coliform concentrations.—Continued

Table 3-1. Monthly accumulation rate (million colonies per acre per day).—Continued

PERLAND	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
401	0.78	0.78	0.78	0.78	0.78	0.78	0.78	0.78	0.78	0.78	0.78	0.78
402	10.3	10.3	10.3	10.3	10.3	10.3	10.3	10.3	10.3	10.3	10.3	10.3
403	20	20	20	20	20	20	20	20	20	20	20	20
404	6.2	6.2	6.2	6.2	6.2	6.2	6.2	6.2	6.2	6.2	6.2	6.2
405	11.3	11.3	11.3	11.3	11.3	11.3	11.3	11.3	11.3	11.3	11.3	11.3
406	13.5	13.5	13.5	13.5	13.5	13.5	13.5	13.5	13.5	13.5	13.5	13.5
407	3.2	3.2	163.5	7558	7558	5752	5752	5752	7558	7558	9364	324
408	333	368	4043	4181	449	417	400	1622	465	458	1368	333
501	0.78	0.78	0.78	0.78	0.78	0.78	0.78	0.78	0.78	0.78	0.78	0.78
502	10.3	10.3	10.3	10.3	10.3	10.3	10.3	10.3	10.3	10.3	10.3	10.3
503	20	20	20	20	20	20	20	20	20	20	20	20
504	6.2	6.2	6.2	6.2	6.2	6.2	6.2	6.2	6.2	6.2	6.2	6.2
505	11.3	11.3	11.3	11.3	11.3	11.3	11.3	11.3	11.3	11.3	11.3	11.3
506	13.5	13.5	13.5	13.5	13.5	13.5	13.5	13.5	13.5	13.5	13.5	13.5
507	7	7	396	30924	30924	23395	23395	23395	30924	30924	38453	784
508	482	533	5851	6051	555	504	482	1959	573	566	1973	482
601	0.78	0.78	0.78	0.78	0.78	0.78	0.78	0.78	0.78	0.78	0.78	0.78
602	10.3	10.3	10.3	10.3	10.3	10.3	10.3	10.3	10.3	10.3	10.3	10.3
603	20	20	20	20	20	20	20	20	20	20	20	20
604	6.2	6.2	6.2	6.2	6.2	6.2	6.2	6.2	6.2	6.2	6.2	6.2
605	11.3	11.3	11.3	11.3	11.3	11.3	11.3	11.3	11.3	11.3	11.3	11.3
606	13.5	13.5	13.5	13.5	13.5	13.5	13.5	13.5	13.5	13.5	13.5	13.5
607	6	6	234	18079	18079	13679	13679	13679	18079	18079	22480	463
608	749	828	9085	9394	832	781	749	3037	860	846	3079	749
701	0.78	0.78	0.78	0.78	0.78	0.78	0.78	0.78	0.78	0.78	0.78	0.78
702	10.3	10.3	10.3	10.3	10.3	10.3	10.3	10.3	10.3	10.3	10.3	10.3
703	20	20	20	20	20	20	20	20	20	20	20	20
704	6.2	6.2	6.2	6.2	6.2	6.2	6.2	6.2	6.2	6.2	6.2	6.2
706	13.5	13.5	13.5	13.5	13.5	13.5	13.5	13.5	13.5	13.5	13.5	13.5
707	6	6	252	19514	19514	14764	14764	14764	19514	19514	24264	497
708	638	706	7746	8011	719	666	638	2590	742	732	2620	638

Appendix 3. Parameter values used in calibrated model to simulate fecal coliform concentrations.—Continued

Table 3-1. Monthly accumulation rate (million colonies per acre per day).—Continued

PERLAND	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
801	0.78	0.78	0.78	0.78	0.78	0.78	0.78	0.78	0.78	0.78	0.78	0.78
802	10.3	10.3	10.3	10.3	10.3	10.3	10.3	10.3	10.3	10.3	10.3	10.3
803	20	20	20	20	20	20	20	20	20	20	20	20
804	6.2	6.2	6.2	6.2	6.2	6.2	6.2	6.2	6.2	6.2	6.2	6.2
806	13.5	13.5	13.5	13.5	13.5	13.5	13.5	13.5	13.5	13.5	13.5	13.5
807	6	6	289	22346	22346	16907	16907	16907	22346	22364	27785	572
808	588	650	7142	7386	668	614	588	2389	690	681	2412	588
901	0.78	0.78	0.78	0.78	0.78	0.78	0.78	0.78	0.78	0.78	0.78	0.78
902	10.3	10.3	10.3	10.3	10.3	10.3	10.3	10.3	10.3	10.3	10.3	10.3
903	20	20	20	20	20	20	20	20	20	20	20	20
906	13.5	13.5	13.5	13.5	13.5	13.5	13.5	13.5	13.5	13.5	13.5	13.5
907	6	6	260	29838	29838	29838	29838	29838	29838	29838	29838	514
908	775	857	9383	9701	855	807	775	800	883	868	3183	775

Appendix 3. Parameter values used in calibrated model to simulate fecal coliform concentrations.—Continued

Table 3-2. Monthly storage limit (million colonies per acre).

PERLAND	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
101	1.4	1.4	1.4	1.4	1.4	1.4	1.4	1.4	1.4	1.4	1.4	1.4
102	18.6	18.6	18.6	18.6	18.6	18.6	18.6	18.6	18.6	18.6	18.6	18.6
103	35.9	35.9	35.9	35.9	35.9	35.9	35.9	35.9	35.9	35.9	35.9	35.9
104	11.2	11.2	11.2	11.2	11.2	11.2	11.2	11.2	11.2	11.2	11.2	11.2
105	20.4	20.4	20.4	20.4	20.4	20.4	20.4	20.4	20.4	20.4	20.4	20.4
106	24.3	24.3	24.3	24.3	24.3	24.3	24.3	24.3	24.3	24.3	24.3	24.3
107	9.6	9.6	343	44758	44758	44758	44758	44758	44758	39254	39254	677
108	1221	1350	14839	12788	1148	1062	1018	4135	1185	1402	5016	1221
201	1.4	1.4	1.4	1.4	1.4	1.4	1.4	1.4	1.4	1.4	1.4	1.4
202	18.6	18.6	18.6	18.6	18.6	18.6	18.6	18.6	18.6	18.6	18.6	18.6
203	35.9	35.9	35.9	35.9	35.9	35.9	35.9	35.9	35.9	35.9	35.9	35.9
204	11.2	11.2	11.2	11.2	11.2	11.2	11.2	11.2	11.2	11.2	11.2	11.2
205	20.4	20.4	20.4	20.4	20.4	20.4	20.4	20.4	20.4	20.4	20.4	20.4
206	24.3	24.3	24.3	24.3	24.3	24.3	24.3	24.3	24.3	24.3	24.3	24.3
207	10	10	364	8585	8585	6593	6593	6593	8585	10302	12693	719
208	1317	1455	16365	24548	1334	1144	1097	4558	1378	1627	5412	1317
301	1.96	1.96	1.96	1.96	1.96	1.96	1.96	1.96	1.96	1.96	1.96	1.96
302	26.04	26.04	26.042	6.04	26.04	26.04	26.04	26.04	26.04	26.042	6.04	26.04
303	50.26	50.26	50.265	0.26	50.26	50.26	50.26	50.26	50.26	50.265	0.26	50.26
304	15.68	15.68	15.681	5.68	15.68	15.68	15.68	15.68	15.68	15.681	5.68	15.68
305	28.56	28.56	28.562	8.56	28.56	28.56	28.56	28.56	28.56	28.562	8.56	28.56
306	34.02	34.02	34.023	4.02	34.02	34.02	34.02	34.02	34.02	34.023	4.02	34.02
307	5.6	5.6	257.6	14770	14770	11186	11186	11186	14770	17723	22022	510
308	959	1060	11683	17525	904	834	799	3254	933.8	1105	3945	959

Appendix 3. Parameter values used in calibrated model to simulate fecal coliform concentrations.—Continued

Table 3-2. Monthly storage limit (million colonies per acre).—Continued

PERLAND	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
401	1.4	1.4	1.4	1.4	1.4	1.4	1.4	1.4	1.4	1.4	1.4	1.4
402	18.6	18.6	18.6	18.6	18.6	18.6	18.6	18.6	18.6	18.6	18.6	18.6
403	35.9	35.9	35.9	35.9	35.9	35.9	35.9	35.9	35.9	35.9	35.9	35.9
404	11.2	11.2	11.2	11.2	11.2	11.2	11.2	11.2	11.2	11.2	11.2	11.2
405	20.4	20.4	20.4	20.4	20.4	20.4	20.4	20.4	20.4	20.4	20.4	20.4
406	24.3	24.3	24.3	24.3	24.3	24.3	24.3	24.3	24.3	24.3	24.3	24.3
407	5	5	192	11908	11908	9000	9000	9000	11908	14000	17764	380
408	600	757	8345	10917	562	521	499.5	2324	580	789	2818	600
501	1.4	1.4	1.4	1.4	1.4	1.4	1.4	1.4	1.4	1.4	1.4	1.4
502	18.6	18.6	18.6	18.6	18.6	18.6	18.6	18.6	18.6	18.6	18.6	18.6
503	35.9	35.9	35.9	35.9	35.9	35.9	35.9	35.9	35.9	35.9	35.9	35.9
504	11.2	11.2	11.2	11.2	11.2	11.2	11.2	11.2	11.2	11.2	11.2	11.2
505	20.4	20.4	20.4	20.4	20.4	20.4	20.4	20.4	20.4	20.4	20.4	20.4
506	24.3	24.3	24.3	24.3	24.3	24.3	24.3	24.3	24.3	24.3	24.3	24.3
507	13	13	712	46386	46386	35093	35093	35093	46386	55664	69215	1411
508	868	959	10531	15797	832	756	724	2938	859	1019	3551	868
601	1.4	1.4	1.4	1.4	1.4	1.4	1.4	1.4	1.4	1.4	1.4	1.4
602	18.6	18.6	18.6	18.6	18.6	18.6	18.6	18.6	18.6	18.6	18.6	18.6
603	35.9	35.9	35.9	35.9	35.9	35.9	35.9	35.9	35.9	35.9	35.9	35.9
604	11.2	11.2	11.2	11.2	11.2	11.2	11.2	11.2	11.2	11.2	11.2	11.2
605	20.4	20.4	20.4	20.4	20.4	20.4	20.4	20.4	20.4	20.4	20.4	20.4
606	24.3	24.3	24.3	24.3	24.3	24.3	24.3	24.3	24.3	24.3	24.3	24.3
607	5	5	211	13560	13560	10259	10259	10259	13560	16272	20232	417
608	675	746	8176	12265	625	586	562	2278	645	761	2771	675

Appendix 3. Parameter values used in calibrated model to simulate fecal coliform concentrations.—Continued

Table 3-2. Monthly storage limit (million colonies per acre).—Continued

PERLAND	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
701	1.4	1.4	1.4	1.4	1.4	1.4	1.4	1.4	1.4	1.4	1.4	1.4
702	18.6	18.6	18.6	18.6	18.6	18.6	18.6	18.6	18.6	18.6	18.6	18.6
703	35.9	35.9	35.9	35.9	35.9	35.9	35.9	35.9	35.9	35.9	35.9	35.9
704	11.2	11.2	11.2	11.2	11.2	11.2	11.2	11.2	11.2	11.2	11.2	11.2
706	24.3	24.3	24.3	24.3	24.3	24.3	24.3	24.3	24.3	24.3	24.3	24.3
707	10	10	453	29271	29271	22145	22145	22145	29271	35125	43675	895
708	1149	1270	13943	20915	1078	999	958	3886	1114	1317	4716	1149
801	1.4	1.4	1.4	1.4	1.4	1.4	1.4	1.4	1.4	1.4	1.4	1.4
802	18.6	18.6	18.6	18.6	18.6	18.6	18.6	18.6	18.6	18.6	18.6	18.6
803	35.9	35.9	35.9	35.9	35.9	35.9	35.9	35.9	35.9	35.9	35.9	35.9
804	11.2	11.2	11.2	11.2	11.2	11.2	11.2	11.2	11.2	11.2	11.2	11.2
806	24.3	24.3	24.3	24.3	24.3	24.3	24.3	24.3	24.3	24.3	24.3	24.3
807	11	11	520	33519	33519	25360	25360	25360	33519	40223	50013	1030
808	1059	1170	12855	19282	1002	921	882	3583	1035	1225	4341	1059
901	1.4	1.4	1.4	1.4	1.4	1.4	1.4	1.4	1.4	1.4	1.4	1.4
902	18.6	18.6	18.6	18.6	18.6	18.6	18.6	18.6	18.6	18.6	18.6	18.6
903	35.9	35.9	35.9	35.9	35.9	35.9	35.9	35.9	35.9	35.9	35.9	35.9
906	24.3	24.3	24.3	24.3	24.3	24.3	24.3	24.3	24.3	24.3	24.3	24.3
907	11	11	468	30133	30133	22798	22798	22798	30133	53709	53709	925
908	1395	1542	16889	14552	1282	1210	1162	1200	1325	1562	5730	1395

Appendix 3. Parameter values used in calibrated model to simulate fecal coliform concentrations.—Continued

Table 3-3. Monthly interflow concentrations (million colonies per liter).

PERLAND	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
101	1e-6	1e-6	1e-6	1e-6	1e-6	1e-6	1e-6	1e-6	1e-6	1e-6	1e-6	1e-6
102-105	1e-4	1e-4	1e-4	1e-4	1e-4	1e-4	1e-4	1e-4	1e-4	1e-4	1e-4	1e-4
106	1e-5	1e-5	1e-5	1e-5	1e-5	1e-5	1e-5	1e-5	1e-5	1e-5	1e-5	1e-5
107-108	0.015	0.015	0.015	0.015	0.015	0.015	0.015	0.015	0.015	0.015	0.015	0.015
201	1e-6	1e-6	1e-6	1e-6	1e-6	1e-6	1e-6	1e-6	1e-6	1e-6	1e-6	1e-6
202-205	0.001	0.001	0.001	0.001	0.001	0.001	0.001	0.001	0.001	0.001	0.001	0.001
206	1e-5	1e-5	1e-5	1e-5	1e-5	1e-5	1e-5	1e-5	1e-5	1e-5	1e-5	1e-5
207	0.3	0.3	0.3	0.3	0.3	0.3	0.4	0.4	0.5	0.4	0.3	0.3
208	0.4	0.4	0.4	0.4	0.4	0.4	0.5	0.5	0.6	0.5	0.4	0.4
301	1e-6	1e-6	1e-6	1e-6	1e-6	1e-6	1e-6	1e-6	1e-6	1e-6	1e-6	1e-6
302-305	0.001	0.001	0.001	0.001	0.001	0.001	0.001	0.001	0.001	0.001	0.001	0.001
306	1e-5	1e-5	1e-5	1e-5	1e-5	1e-5	1e-5	1e-5	1e-5	1e-5	1e-5	1e-5
307	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05
308	0.15	0.15	0.15	0.15	0.15	0.15	0.15	0.15	0.15	0.15	0.15	0.15
401	1e-6	1e-6	1e-6	1e-6	1e-6	1e-6	1e-6	1e-6	1e-6	1e-6	1e-6	1e-6
402-405	0.001	0.001	0.001	0.001	0.001	0.001	0.001	0.001	0.001	0.001	0.001	0.001
406	1e-5	1e-5	1e-5	1e-5	1e-5	1e-5	1e-5	1e-5	1e-5	1e-5	1e-5	1e-5
407	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1
408	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1

Appendix 3. Parameter values used in calibrated model to simulate fecal coliform concentrations.—Continued

Table 3-3. Monthly interflow concentrations (million colonies per liter).—Continued

PERLAND	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
501	1e-6	1e-6	1e-6	1e-6	1e-6	1e-6	1e-6	1e-6	1e-6	1e-6	1e-6	1e-6
502-505	0.001	0.001	0.001	0.001	0.001	0.001	0.001	0.001	0.001	0.001	0.001	0.001
506	1e-5	1e-5	1e-5	1e-5	1e-5	1e-5	1e-5	1e-5	1e-5	1e-5	1e-5	1e-5
507	0.05	0.05	0.05	0.05	0.01	0.01	0.01	0.01	0.01	0.01	0.05	0.05
508	0.15	0.15	0.15	0.15	0.3	0.3	0.3	0.3	0.3	0.3	0.15	0.15
601	1e-6	1e-6	1e-6	1e-6	1e-6	1e-6	1e-6	1e-6	1e-6	1e-6	1e-6	1e-6
602-605	0.001	0.001	0.001	0.001	0.001	0.001	0.001	0.001	0.001	0.001	0.001	0.001
606	1e-5	1e-5	1e-5	1e-5	1e-5	1e-5	1e-5	1e-5	1e-5	1e-5	1e-5	1e-5
607	0.02	0.05	0.05	0.05	0.05	0.1	0.1	0.05	0.02	0.02	0.02	0.02
608	0.05	0.05	0.05	0.05	0.05	0.2	0.3	0.1	0.05	0.05	0.05	0.05
701	1e-6	1e-6	1e-6	1e-6	1e-6	1e-6	1e-6	1e-6	1e-6	1e-6	1e-6	1e-6
702-704	0.001	0.001	0.001	0.001	0.001	0.001	0.001	0.001	0.001	0.001	0.001	0.001
706	1e-5	1e-5	1e-5	1e-5	1e-5	1e-5	1e-5	1e-5	1e-5	1e-5	1e-5	1e-5
707	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05
708	0.15	0.15	0.15	0.15	0.15	0.15	0.15	0.15	0.15	0.15	0.15	0.15
801	1e-6	1e-6	1e-6	1e-6	1e-6	1e-6	1e-6	1e-6	1e-6	1e-6	1e-6	1e-6
802-804	0.001	0.001	0.001	0.001	0.001	0.001	0.001	0.001	0.001	0.001	0.001	0.001
806	1e-5	1e-5	1e-5	1e-5	1e-5	1e-5	1e-5	1e-5	1e-5	1e-5	1e-5	1e-5
807	0.15	0.15	0.15	0.15	0.15	0.15	0.3	0.3	0.3	0.3	0.15	0.15
808	0.2	0.2	0.2	0.2	0.4	0.4	0.4	0.4	0.4	0.4	0.3	0.3
901	1e-6	1e-6	1e-6	1e-6	1e-6	1e-6	1e-6	1e-6	1e-6	1e-6	1e-6	1e-6
902-903	0.001	0.001	0.001	0.001	0.001	0.001	0.001	0.001	0.001	0.001	0.001	0.001
906	1e-5	1e-5	1e-5	1e-5	1e-5	1e-5	1e-5	1e-5	1e-5	1e-5	1e-5	1e-5
907	0.15	0.15	0.15	0.15	0.15	0.15	0.15	0.15	0.15	0.15	0.15	0.15
908	0.3	0.3	0.3	0.3	0.3	0.3	0.3	0.3	0.3	0.3	0.3	0.3

Appendix 3. Parameter values used in calibrated model to simulate fecal coliform concentrations.—Continued

Table 3-4. First order decay rate (per day).

[FSTDEC, first order decay rate]

Subbasin	FSTDEC	Subbasin	FSTDEC	Subbasin	FSTDEC	Subbasin	FSTDEC
1	0.3	14	1.2	27	0.4	40	0.4
2	0.4	15	0.7	28	1.2	41	0.3
3	2.0	16	0.8	29	1.2	42	0.3
4	0.3	17	1.2	30	1.2	43	1.2
5	0.2	18	0.6	31	0.2	44	1.2
6	0.3	19	1.2	32	0.4	45	0.7
7	0.4	20	0.8	33	0.4	46	1.2
8	0.4	21	0.8	34	1.2	47	1.2
9	0.3	22	0.8	35	1.2	48	1.2
10	0.25	23	1.2	36	0.8	49	1.2
11	0.3	24	0.7	37	0.3	50	0.8
12	0.2	25	1.2	38	0.4	51	0.2
13	10000	26	0.2	39	0.4	52	1.2

Appendix 3. Parameter values used in calibrated model to simulate fecal coliform concentrations.—Continued

Table 3-5. Susceptibility of fecal coliform to washoff (per inch).

[PERLAND, permeable land segment]

PERLAND		PERLAND	
101	11.5	601	11.5
102 - 104	2.6	602 - 604	2.6
105	2.3	605	2.3
106	2.6	606	2.6
107 - 108	2.6	607 - 608	2.6
201	11.5	701	11.5
202 - 204	2.6	702 - 704	2.6
205	2.3	705	2.3
206	2.6	706	2.6
207 - 208	2.6	707 - 708	2.6
301	11.5	801	11.5
302 - 304	2.6	802 - 804	2.6
305	2.3	805	2.3
306	2.6	806	2.6
307 - 308	2.6	807 - 808	2.6
401	11.5	901	11.5
402 - 404	2.6	902 - 904	2.6
405	2.3	905	2.3
406	2.6	906	2.6
407 - 408	2.6	907 - 908	2.6
501	11.5		
502 - 504	2.6		
505	2.3		
506	2.6		
507 - 508	2.6		

Appendix 4. Parameter values used in calibrated model to simulate nitrate concentrations.

Table 4-1. Monthly accumulation rate (pounds per acre per day).

[PERLAND, permeable land segment]

PERLAND	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
101	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01
102 - 104	0.015	0.02	0.02	0.025	0.025	0.025	0.005	0.005	0.005	0.02	0.015	0.015
105	0.015	0.015	0.015	0.015	0.015	0.015	0.005	0.005	0.005	0.015	0.015	0.015
106	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01
107 - 108	0.1	0.1	0.25	0.5	0.5	0.5	0.25	0.1	0.1	0.1	0.1	0.1
201	0.05	0.055	0.065	0.07	0.07	0.07	0.07	0.07	0.07	0.065	0.055	0.05
202	0.03	0.03	0.03	0.03	0.03	0.03	0.03	0.03	0.03	0.03	0.03	0.03
203 - 204	0.06	0.08	0.08	0.1	0.1	0.1	0.1	0.1	0.1	0.08	0.06	0.06
205	0.03	0.03	0.03	0.03	0.03	0.03	0.03	0.03	0.03	0.03	0.03	0.03
206	0.065	0.07	0.075	0.09	0.09	0.09	0.09	0.09	0.09	0.075	0.07	0.065
207	3	3	3	3	3	3	3	3	3	3	3	3
208	3.5	3.5	3.5	3.5	3.5	3.5	3.5	3.5	3.5	3.5	3.5	3.5
301	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02
302	0.03	0.03	0.03	0.03	0.03	0.03	0.03	0.03	0.03	0.03	0.03	0.03
303 - 304	0.03	0.04	0.04	0.05	0.05	0.05	0.05	0.05	0.05	0.04	0.03	0.03
305	0.03	0.03	0.03	0.03	0.03	0.03	0.03	0.03	0.03	0.03	0.03	0.03
306	0.065	0.07	0.075	0.09	0.09	0.09	0.09	0.09	0.09	0.075	0.07	0.065
307	6	6	9	9	9	6	6	6	6	6	6	6
308	10	10	12	12	12	10	10	10	10	10	10	10
401	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01
402	0.03	0.03	0.03	0.03	0.03	0.03	0.03	0.03	0.03	0.03	0.03	0.03
403 - 404	0.03	0.04	0.04	0.05	0.05	0.05	0.05	0.05	0.05	0.04	0.03	0.03
405	0.03	0.03	0.03	0.03	0.03	0.03	0.03	0.03	0.03	0.03	0.03	0.03
406	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01
407 - 408	0.5	0.5	1	1.5	1.5	1.5	1	0.1	0.1	0.1	0.1	0.5

Appendix 4. Parameter values used in calibrated model to simulate nitrate concentrations.—Continued

Table 4-1. Monthly accumulation rate (pounds per acre per day).—Continued

PERLAND	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
501	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02
502 - 504	0.03	0.04	0.04	0.05	0.05	0.05	0.05	0.05	0.05	0.04	0.03	0.03
505	0.03	0.03	0.03	0.03	0.03	0.03	0.03	0.03	0.03	0.03	0.03	0.03
506	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02
507	3	3	3	3	3	3	3	3	3	3	3	3
508	3.5	3.5	3.5	3.5	3.5	3.5	3.5	3.5	3.5	3.5	3.5	3.5
601	0.05	0.055	0.065	0.07	0.07	0.07	0.07	0.07	0.07	0.065	0.055	0.05
602 - 604	0.03	0.04	0.04	0.05	0.05	0.05	0.05	0.05	0.05	0.04	0.03	0.03
605	0.03	0.03	0.03	0.03	0.03	0.03	0.03	0.03	0.03	0.03	0.03	0.03
606	0.065	0.07	0.075	0.09	0.09	0.09	0.09	0.09	0.09	0.075	0.07	0.065
607	3	3	3	3	3	3	3	3	3	3	3	3
608	3.3	3.3	3.3	3.3	3.3	3.3	3.3	3.3	3.3	3.3	3.3	3.3
701	0.05	0.055	0.065	0.07	0.07	0.07	0.07	0.07	0.07	0.065	0.055	0.05
702 - 704	0.03	0.04	0.04	0.05	0.05	0.05	0.05	0.05	0.05	0.04	0.03	0.03
706	0.065	0.07	0.075	0.09	0.09	0.09	0.09	0.09	0.09	0.075	0.07	0.065
707	3	3	3	3	3	3	3	3	3	3	3	3
708	3.5	3.5	3.5	3.5	3.5	3.5	3.5	3.5	3.5	3.5	3.5	3.5
801	0.05	0.055	0.065	0.07	0.07	0.07	0.07	0.07	0.07	0.065	0.055	0.05
802 - 804	0.03	0.04	0.04	0.05	0.05	0.05	0.05	0.05	0.05	0.04	0.03	0.03
806	0.065	0.07	0.075	0.09	0.09	0.09	0.09	0.09	0.09	0.075	0.07	0.065
807	3	3	3	3	3	3	3	3	3	3	3	3
808	3.1	3.1	3.1	3.1	3.1	3.1	3.1	3.1	3.1	3.1	3.1	3.1
901	0.05	0.055	0.065	0.07	0.07	0.07	0.07	0.07	0.07	0.065	0.055	0.05
902 - 903	0.03	0.04	0.04	0.05	0.05	0.05	0.05	0.05	0.05	0.04	0.03	0.03
906	0.065	0.07	0.075	0.09	0.09	0.09	0.09	0.09	0.09	0.075	0.07	0.065
907	4	4	4	4	4	4	4	4	4	4	4	4
908	5	5	5	5	5	5	5	5	5	5	5	5

Appendix 4. Parameter values used in calibrated model to simulate nitrate concentrations.—Continued

Table 4-2. Monthly storage limit (pounds per acre).

[PERLAND, permeable land segment]

PERLAND	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
101	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.01	0.01	0.01	0.01	0.05
102 - 105	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.01	0.01	0.01	0.01	0.05
106	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.01	0.01	0.01	0.01	0.05
107	0.2	0.2	0.25	0.25	0.25	0.2	0.1	0.01	0.01	0.01	0.01	0.2
108	0.1	0.1	0.3	0.3	0.3	0.25	0.1	0.01	0.01	0.01	0.01	0.1
201	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05
202 - 205	1	1	1	1	1	1	1	1	1	1	1	1
206	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1
207	0.45	0.45	0.6	0.6	0.6	0.6	0.6	0.6	0.6	0.6	0.6	0.45
208	1.2	1.2	1.2	1.2	1.2	1.2	1.2	1	1	1	1	1.2
301	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05
302 - 305	1	1	1	1	1	1	1	1	1	1	1	1
306	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1
307	3	3	4	4	4	3	3	3	3	3	3	3
308	6	6	10	10	10	8	6	6	6	6	6	6
401	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.01	0.01	0.01	0.01	0.05
402 - 405	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.01	0.01	0.01	0.01	0.1
406	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.01	0.01	0.01	0.01	0.1
407	0.2	0.2	0.25	0.25	0.25	0.1	0.1	0.01	0.01	0.01	0.01	0.1
408	0.4	0.4	0.6	0.6	0.6	0.1	0.1	1	0.01	0.01	0.01	0.1
501	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05
502 - 505	1	1	1	1	1	1	1	1	1	1	1	1
506	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1
507	0.45	0.45	0.6	0.6	0.6	0.6	0.6	0.6	0.6	0.6	0.6	0.45
508	1.2	1.2	1.2	1.2	1.2	1.2	1.2	1.2	1.2	1.2	1.2	1.2

Appendix 4. Parameter values used in calibrated model to simulate nitrate concentrations.—Continued

Table 4-2. Monthly storage limit (pounds per acre).—Continued

PERLAND	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
601	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05
602 - 605	1	1	1	1	1	1	1	1	1	1	1	1
606	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1
607	0.45	0.45	0.6	0.6	0.6	0.6	0.6	0.6	0.6	0.6	0.6	0.45
608	1.2	1.2	1.2	1.2	1.2	1.2	1.2	1.2	1.2	1.2	1.2	1.2
701	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05
702 - 704	1	1	1	1	1	1	1	1	1	1	1	1
706	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1
707	0.45	0.45	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.45
708	1	1	1	1	1	1	1	1	1	1	1	1
801	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05
802 - 804	1	1	1	1	1	1	1	1	1	1	1	1
806	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1
807	1.1	1.1	1.1	1.1	1.1	1.1	1.1	1.1	1.1	1.1	1.1	1.1
808	1.6	1.6	1.6	1.6	1.6	1.6	1.6	1.6	1.6	1.6	1.6	1.6
901	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05
902 - 903	1	1	1	1	1	1	1	1	1	1	1	1
906	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1
907	0.6	0.6	0.8	0.8	0.8	0.8	0.8	0.8	0.8	0.8	0.8	0.6
908	1.8	1.8	1.8	1.8	1.8	1.8	1.8	1.8	1.8	1.8	1.8	1.8

Appendix 4. Parameter values used in calibrated model to simulate nitrate concentrations.—Continued

Table 4-3. Monthly interflow concentrations (milligrams per liter).

[PERLAND, permeable land segment]

PERLAND	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
101	0.25	0.25	0.25	0.25	0.25	0.25	0.25	0.25	0.25	0.25	0.25	0.25
102 - 105	1	1	1	1	1	1	0.5	0.5	0.5	0.5	0.5	0.5
106	0.25	0.25	0.25	0.25	0.25	0.25	0.25	0.25	0.25	0.25	0.25	0.25
107 - 108	0.5	1	1	1	1	1	0.5	0.5	0.5	0.5	0.5	0.5
201	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5
202 - 205	4.5	4.5	4.5	4.5	4.5	4.5	4.5	4.5	4.5	4.5	4.5	4.5
206	0.25	0.25	0.25	0.25	0.25	0.25	0.25	0.25	0.25	0.25	0.25	0.25
207	7	7	7	7	7	7	7	7	7	7	7	7
208	8	8	8	8	8.5	8.5	8.5	8.5	8.5	8.5	8	8
301	0.25	0.25	0.25	0.25	0.25	0.25	0.25	0.25	0.25	0.25	0.25	0.25
302 - 305	3	3	3	3	3	3	3	3	3	3	3	3
306	0.25	0.25	0.25	0.25	0.25	0.25	0.25	0.25	0.25	0.25	0.25	0.25
307	4	4	4	4	4	4	4	2	2	2	2	2
308	4	4	4	3	3	3	3	1.5	1.5	1.5	1.5	1.5
401	0.25	0.25	0.25	0.25	0.25	0.25	0.25	0.25	0.25	0.25	0.25	0.25
402 - 403	2	2	2	2	2	2	2	0.5	0.5	0.5	0.5	0.5
404	2.5	2.5	2.5	2.5	2.5	2.5	2.5	0.5	0.5	0.5	0.5	0.5
405	2	2	2	2	2	2	2	0.5	0.5	0.5	0.5	0.5
406	0.25	0.25	0.25	0.25	0.25	0.25	0.25	0.25	0.25	0.25	0.25	0.25
407	1	1	1.25	1.25	1.25	1	0.8	0.5	0.5	0.5	0.5	0.5
408	1	1	1.5	1.5	1.5	1	0.8	0.5	0.5	0.5	0.5	0.5

Appendix 4. Parameter values used in calibrated model to simulate nitrate concentrations.—Continued

Table 4-3. Monthly interflow concentrations (milligrams per liter).—Continued

PERLAND	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
501	0.25	0.25	0.25	0.25	0.25	0.25	0.25	0.25	0.25	0.25	0.25	0.25
502 - 505	4.5	4.5	4.5	4.5	4.5	4.5	4.5	4.5	4.5	4.5	4.5	4.5
506	0.75	0.75	0.75	0.75	0.75	0.75	0.75	0.75	0.75	0.75	0.75	0.75
507	3.5	3.5	3.5	3.5	3.5	3.5	3.5	3.5	3.5	3.5	3.5	3.5
508	4	4	4.5	5	5	5	5	5	4.5	4.5	4	4
601	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5
602 - 605	4.5	4.5	4.5	4.5	4.5	4.5	4.5	4.5	4.5	4.5	4.5	4.5
606	0.25	0.25	0.25	0.25	0.25	0.25	0.25	0.25	0.25	0.25	0.25	0.25
607	9.5	9.5	9.5	10.5	10.5	10.5	10.5	10.5	10.5	10.5	10.5	9.5
608	12	12	12	13	13	13	13	13	13	13	13	12
701	0.25	0.25	0.25	0.25	0.25	0.25	0.25	0.25	0.25	0.25	0.25	0.25
702 - 704	4.5	4.5	4.5	4.5	4.5	4.5	4.5	4.5	4.5	4.5	4.5	4.5
706	0.25	0.25	0.25	0.25	0.25	0.25	0.25	0.25	0.25	0.25	0.25	0.25
707	6	6	6	6	6	6	6	6	6	6	6	6
708	6	6	6.5	6.5	7	7	7	7	6.5	6.5	6	6
801	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5
802	5.5	5.5	5.5	5.5	5.5	5.5	5.5	5.5	5.5	5.5	5.5	5.5
803 - 804	4.5	4.5	4.5	4.5	4.5	4.5	4.5	4.5	4.5	4.5	4.5	4.5
806	0.25	0.25	0.25	0.25	0.25	0.25	0.25	0.25	0.25	0.25	0.25	0.25
807	8.5	8.5	8.5	9.5	9.5	9.5	9.5	9.5	9.5	9.5	9.5	8.5
808	10	10	10	11	11	11	11	11	11	11	11	10
901	0.25	0.25	0.25	0.25	0.25	0.25	0.25	0.25	0.25	0.25	0.25	0.25
902 - 903	9	9	9	9	9	9	9	9	9	9	9	9
906	2.5	2.5	2.5	2.5	2.5	2.5	2.5	2.5	2.5	2.5	2.5	2.5
907	9	9	9	11	11	11	11	11	11	11	11	9
908	14	14	15	15	15	15	15	15	15	15	15	14

Appendix 4. Parameter values used in calibrated model to simulate nitrate concentrations.—Continued

Table 4-4. Monthly ground-water concentrations (milligrams per liter).

[PERLAND, permeable land segment]

PERLAND	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
101	0.3	0.3	0.3	0.3	0.3	0.3	0.3	0.1	0.1	0.1	0.1	0.1
102	0.8	0.8	0.8	0.8	0.8	0.8	0.8	0.25	0.25	0.25	0.25	0.25
103	0.8	0.8	0.8	0.8	0.8	0.8	0.8	0.25	0.25	0.25	0.25	0.25
104 - 105	0.8	0.8	0.8	0.8	0.8	0.8	0.8	0.25	0.25	0.25	0.25	0.25
106	0.3	0.3	0.3	0.3	0.3	0.3	0.3	0.1	0.1	0.1	0.1	0.1
107	0.25	0.25	1	1	1	1	0.8	0.25	0.25	0.25	0.25	0.25
108	0.25	0.25	1	1	1	1	0.8	0.25	0.25	0.25	0.25	0.25
201	0.3	0.3	0.3	0.3	0.3	0.3	0.3	0.3	0.3	0.3	0.3	0.3
202	3	3	3	3	3	3	3	3	3	3	3	3
203 - 204	2	2	2	2	2	2	2	2	2	2	2	2
205	2	2	2	3	3	3	3	2	2	2	2	2
206	0.3	0.3	0.3	0.3	0.3	0.3	0.3	0.3	0.3	0.3	0.3	0.3
207	4.6	4.6	4.6	4.6	4.6	4.6	4.6	4.6	4.6	4.6	4.6	4.6
208	5.7	5.7	5.7	5.7	5.7	5.7	5.7	5.7	5.7	5.7	5.7	5.7
301	0.3	0.3	0.3	0.3	0.3	0.3	0.3	0.3	0.3	0.3	0.3	0.3
302 - 303	1.5	1.5	1.5	1.5	1.5	1.5	1.5	1.5	1.5	1.5	1.5	1.5
304 - 305	2	2	2	2	2	2	2	2	2	2	2	2
306	0.3	0.3	0.3	0.3	0.3	0.3	0.3	0.3	0.3	0.3	0.3	0.3
307	3	3	3	3	3	3	3	3	3	3	3	3
308	4	4	4	4	4	4	4	4	4	4	4	4
401	0.3	0.3	0.3	0.3	0.3	0.3	0.3	0.1	0.1	0.1	0.1	0.1
402 - 405	0.25	0.25	1	1	1	1	1	0.25	0.25	0.25	0.25	0.25
406	0.3	0.3	0.3	0.3	0.3	0.3	0.3	0.1	0.1	0.1	0.1	0.1
407	0.8	0.8	0.8	0.8	0.8	0.8	0.8	0.25	0.25	0.25	0.25	0.25
408	0.8	0.8	0.8	0.8	0.8	0.8	0.8	0.25	0.25	0.25	0.25	0.25

Appendix 4. Parameter values used in calibrated model to simulate nitrate concentrations.—Continued

Table 4-4. Monthly ground-water concentrations (milligrams per liter).—Continued

PERLAND	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
501	0.3	0.3	0.3	0.3	0.3	0.3	0.3	0.3	0.3	0.3	0.3	0.3
502 - 503	3	3	3	3	3	3	3	3	3	3	3	3
504	2	2	2	2	2	2	2	2	2	2	2	2
505	2	2	2	3	3	3	3	2	2	2	2	2
506	0.3	0.3	0.3	0.3	0.3	0.3	0.3	0.3	0.3	0.3	0.3	0.3
507	2	2	2	2.5	2.5	2.5	2.5	2.5	2.5	2.5	2	2
508	2.5	2.5	3	3	3	3	3	3	3	3	2.5	2.5
601	0.3	0.3	0.3	0.3	0.3	0.3	0.3	0.3	0.3	0.3	0.3	0.3
602 - 603	3	3	3	3	3	3	3	3	3	3	3	3
604	2	2	2	2	2	2	2	2	2	2	2	2
605	2	2	2	3	3	3	3	2	2	2	2	2
606	0.3	0.3	0.3	0.3	0.3	0.3	0.3	0.3	0.3	0.3	0.3	0.3
607	7	7	7	7	7	7	7	7	7	7	7	7
608	8.5	8.5	8.5	8.5	8.5	8.5	8.5	8.5	8.5	8.5	8.5	8.5
701	0.3	0.3	0.3	0.3	0.3	0.3	0.3	0.3	0.3	0.3	0.3	0.3
702	3	3	3	3	3	3	3	3	3	3	3	3
703	2.5	2.5	2.5	2.5	2.5	2.5	2.5	2.5	2.5	2.5	2.5	2.5
704	2	2	2	2	2	2	2	2	2	2	2	2
706	0.3	0.3	0.3	0.3	0.3	0.3	0.3	0.3	0.3	0.3	0.3	0.3
707	2.5	2.5	2.5	2.5	2.5	2.5	2.5	2.5	2.5	2.5	2.5	2.5
708	2.8	2.8	2.8	2.8	2.8	2.8	2.8	2.8	2.8	2.8	2.8	2.8
801	0.3	0.3	0.3	0.3	0.3	0.3	0.3	0.3	0.3	0.3	0.3	0.3
802 - 803	3	3	3	3	3	3	3	3	3	3	3	3
804	2	2	2	2	2	2	2	2	2	2	2	2
806	0.3	0.3	0.3	0.3	0.3	0.3	0.3	0.3	0.3	0.3	0.3	0.3
807	7	7	7	7	7	7	7	7	7	7	7	7
808	8	8	8	8	8	8	8	8	8	8	8	8
901	0.3	0.3	0.3	0.3	0.3	0.3	0.3	0.3	0.3	0.3	0.3	0.3
902 - 903	8	8	8	8	8	8	8	8	8	8	8	8
906	0.3	0.3	0.3	0.3	0.3	0.3	0.3	0.3	0.3	0.3	0.3	0.3
907	8	8	8	8	8	8	8	8	8	8	8	8
908	9	9	9	9	9	9	9	9	9	9	9	9

Appendix 4. Parameter values used in calibrated model to simulate nitrate concentrations.—Continued

Table 4-5. Susceptibility of nitrate to washoff (per inch).

[PERLAND, permeable land segment]

PERLAND		PERLAND	
101	11.5	601	11.5
102 - 104	2.6	602 - 604	2.6
105	2.3	605	2.3
106	2.6	606	2.6
107 - 108	2.6	607 - 608	2.6
201	11.5	701	11.5
202 - 204	2.6	702 - 704	2.6
205	2.3	705	2.3
206	2.6	706	2.6
207 - 208	2.6	707 - 708	2.6
301	11.5	801	11.5
302 - 304	2.6	802 - 804	2.6
305	2.3	805	2.3
306	2.6	806	2.6
307 - 308	2.6	807 - 808	2.6
401	11.5	901	11.5
402 - 404	2.6	902 - 904	2.6
405	2.3	905	2.3
406	2.6	906	2.6
407 - 408	2.6	907 - 908	2.6
501	11.5		
502 - 504	2.6		
505	2.3		
506	2.6		
507 - 508	2.6		

USGS

David C. Reutter, Barry M. Puskas, and Martha L. Jagucki—**Simulation of Streamflow and Water Quality to Determine Fecal Coliform and Nitrate Concentrations and Loads in the Mad River Basin, Ohio**—Scientific Investigations Report 2006–5160

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