IMPACT OF HISTORIC TRENDS IN NUTRIENT LOADING ON THE TROPHIC STATUS OF MEANDER CREEK RESERVOIR

by

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Of Meander Creek Reservoir

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ABSTRACT

Trends in nonpoint source pollutant loading to Meander Creek Reservoir were investigated as a possible factor responsible for recent taste and odor problems in the water. Export coefficients for phosphorus, nitrogen, and suspended solids, along with land use estimates for 1965 and 1994 were used to estimate the loadings to the reservoir. After using the Vollenweider model to predict the trophic status of Meander Creek Reservoir, it was concluded that the reservoir is probably naturally mesotrophic. Historic land development trends have increased the level of productivity, although recent changes in land use do not appear to have caused a significant increase in nutrient loading. However, malfunctioning residential septic systems are potentially a major source of nutrients and could be partly responsible for the recent onset of taste and odor problems in Meander Creek Reservoir.

ACKNOWLEDGEMENTS

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INTRODUCTION

1.1 Background on Taste and Odor Problems in Meander Creek Reservoir

The United States Environmental Protection Agency (U.S. EPA) establishes secondary standards for taste and odor in drinking water, indicating that they are only an aesthetic concern. However, they are the parameters most noticed by the public, and therefore produce numerous complaints.

Taste and odor problems in the Meander Creek Reservoir have been linked to *Synura petersenii*, the only algal species known to produce trans-2, cis-6-nonadienal. Trans-2, cis-6-nonadienal and trans-2, cis-4, cis-7-decatrienol, another byproduct of *Synura petersenii* Korshikov, are known to produce "cucumber" and "fishy" odors respectively in drinking water (Schroeder and Martin, 2001).

The algal blooms associated with the odor problems have occurred five times since 1984. The fact that the problem was nonexistent earlier leads to the conclusion that changes in the trophic status of Meander Creek Reservoir have occurred in the past twenty years, therefore causing these odors.

Synura petersenii are always present in the reservoir. But the fact that the odor problem occurs sporadically means that a set of environmental conditions initiates the growth of *Synura* populations to a level that produces odor detectable by the consumer. The environmental conditions that can cause the algal blooms can be either direct or indirect factors. The potential direct factors identified in Meander Creek Reservoir are changes in light, phosphorus, nitrate, silica, pH, dissolved carbon dioxide, iron, heavy metals, temperature, and allopathic chemicals. The indirect factors identified that potentially could trigger algal blooms are: time of ice formation, duration of ice cover, depth and duration of snow cover, changes in water level, runoff incidents, water temperature, change in dissolved solids, or blooms of other algae (Schroeder and Martin, 2001).

1.2 Project Objectives

This study had three objectives. The first one was to quantify the nonpoint source loadings of total phosphorus (TP), nitrogen (TN), and suspended solids (TSS) to Meander Creek Reservoir. These parameters (TP, TN, and TSS) were chosen for study because it is believed that they are potentially responsible for the algal blooms that cause the taste and odor problems in the reservoir. The study's second objective was to evaluate factors likely to have caused changes in nonpoint source loadings over the past 30-40 years. The final objective was to evaluate the hydraulic characteristics and trophic status of Meander Creek Reservoir.

CHAPTER 2

LITERATURE AND DATABASE REVIEW

2.1 Watershed Characteristics

2.1.1 Watershed Location and General Characteristics

The Meander Creek Watershed is located in Mahoning and Trumbull counties of Northeast Ohio. The watershed covers about 84.3 square miles of area, including parts of Austintown, Weathersfield, Jackson, Ellsworth, Green, Goshen, Berlin, and Milton Townships, and the City of Canfield. Meander Creek Reservoir is also a part of the watershed. The reservoir, built in 1932, is used by the Mahoning Valley Sanitary District as a water supply for over 300,000 residents of Youngstown, Niles, and surrounding areas. The reservoir has a volume of 10 billion gallons and a surface area of 2010 acres. A map of the watershed is shown in Figure 2.1. All watershed maps presented in this report were developed by John Bralich of the YSU Center for Urban Studies from a GIS (Geographic Information System) database using ArcView software.

2.1.2 Climate

Climate data presented include precipitation, snowfall and evaporation data. The precipitation and snowfall data were obtained from the National Weather Service (NWS) of the National Oceanic and Atmospheric Administration (NOAA). A weather station is located at Mineral Ridge Water Works, OH at a latitude of $41^{\circ}09'$N, longitude of $80^{\circ}47'$W, and an elevation of 889.9' above sea level. The period of record was between

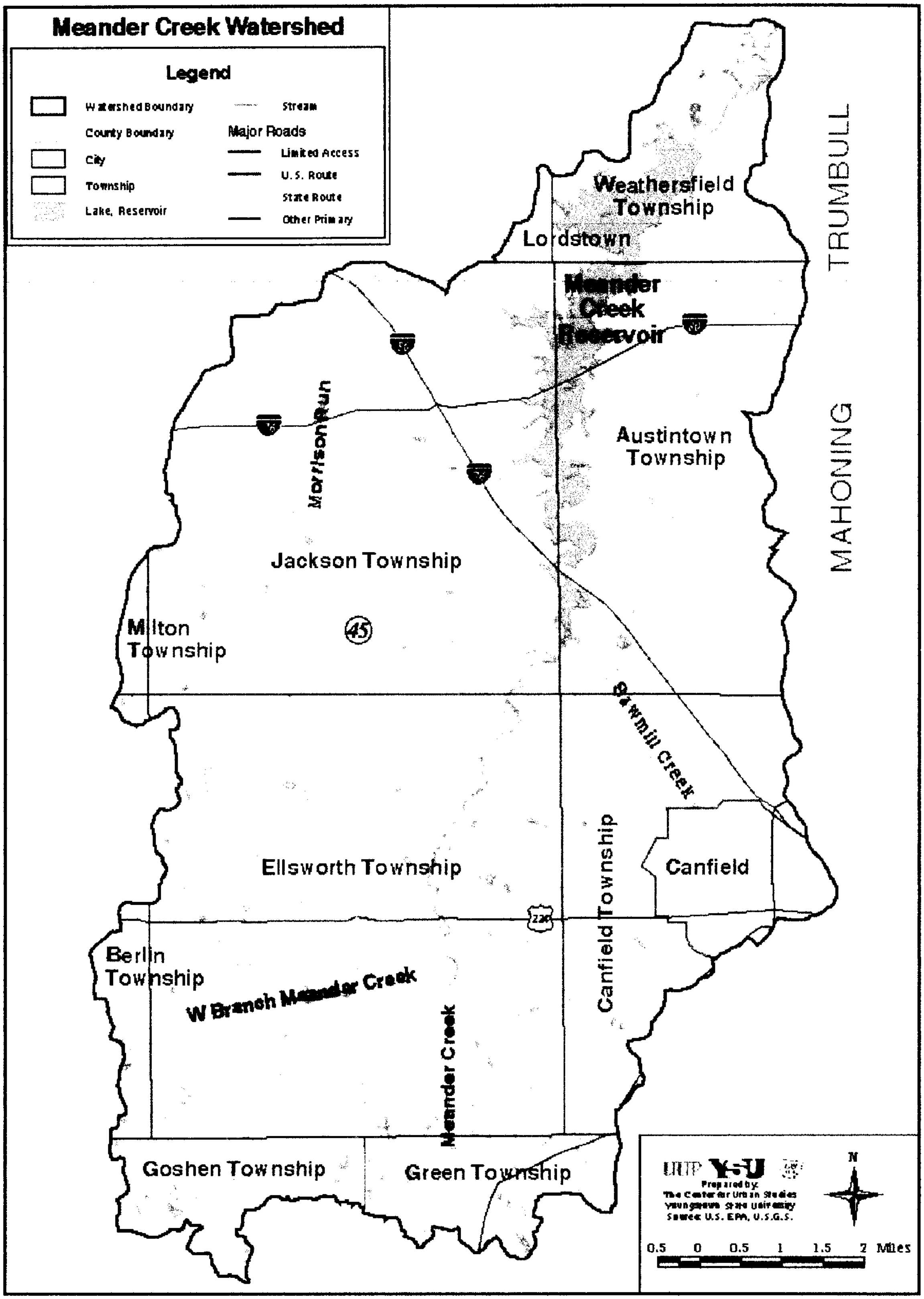

Figure 2.1. Meander Creek Watershed

Figure 2.2. Ohio Evaporation Map (ODNR, 2002)

the years 1931 and 2000. Evaporation for Meander Creek Reservoir was determined to be 31 in/yr by using Figure 2.2. The monthly precipitation means are presented in Table 2.1 and the monthly snowfall means are presented in Table 2.2, whereas all the data obtained are presented in the Appendix, Tables A-1 and A-2.

Table 2.1. Mean Precipitation (1931-2000) for Meander Creek Reservoir (inches)

Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Total
2.405	1.911	2.786	3.282	3.406	3.767	3.980	3.247	3.155	2.577	2.700	2.249	35.466

Source: NOAA

Table 2.2. Mean Snowfall (1931-2000) for Meander Creek Reservoir (inches)

Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Total
9.9	7.9	8.0	1.6	0.1	T	T	0.0	0.0	0.2	3.2	8.3	39.2

Source: NOAA

2.1.3 USGS Gaging Stations and Data

The gaging data available for Meander Creek were from station 03097500 at Mineral Ridge, OH for the years between 1929 and 1951. The station is located at a latitude of 41°09'26", longitude of 80°46'31" and an elevation of 854.81 feet above sea level. The drainage area for this station is 84.30 mi^2. The mean streamflow was obtained for each month of the year; values ranged from 2.33 ft^3/s to 136.49 ft^3/s. The mean for the entire period of record was 20.49 ft^3/s. The yearly mean streamflow was 44.26 ft^3/s. The flow is greater in the months of March and April due to snow melting and lower in the months of September and October. The gaging data obtained are presented in Table 2.3.

Table 2.3. Monthly Streamflow Statistics for USGS Station 03097500 on Meander Creek at Mineral Ridge, OH

Year	Monthly Mean Streamflow (ft^3/s)											
	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
1929									4.2	7.7	106	88
1930	290	126	145	48.3	31.8	7.26	2.88	2.23	3.26	5.21	7.52	6.36
1931	5.85	7.18	5.61	4.35	8.23	4.07	4.68	6.24	3.42	1.67	2.5	5.83
1932	88.8	96.3	40.3	131	57.1	3.76	14	1.55	0.85	1.65	2.09	1.49
1933	3.81	10.7	245	162	45.6	6.29	0.94	0.87	3.47	0.85	0.79	0.73
1934	0.67	0.52	0.74	7.91	0.75	1.14	0.73	0.81	22.7	11.3	15.5	33.8
1935	109	111	116	3.59	136	2.02	0.92	59.2	0.8	0.69	0.67	22.4
1936	66.9	135	299	70	6.08	3.06	1.18	1.4	0.72	0.74	0.73	0.87
1937	486	40.8	94.7	179	109	46.2	20.9	0.8	0.64	20.9	0.45	4.41
1938	40.4	133	289	196	134	55.4	7.88	15.4	0.84	0.53	0.94	0.73
1939	1.74	232	208	175	7.6	1.31	0.64	0.6	0.83	0.6	0.45	0.5
1940	0.49	0.64	220	323	46.7	74.4	1.28	0.56	0.34	0.49	0.78	44.9
1941	57.7	84.7	77.1	25.8	0.79	1.14	1.01	0.74	0.69	0.6	0.82	0.65
1942	0.82	34.6	229	146	99	14.4	0.71	0.66	0.75	0.79	30.4	253
1943	190	116	169	96.3	72.7	49.1	10.7	0.81	0.8	0.78	0.9	0.84
1944	0.99	0.84	12.3	106	6.97	1.9	0.84	0.84	0.67	0.8	0.7	0.8
1945	0.9	0.8	242	56.1	41	2.07	0.87	0.92	1.25	0.7	0.8	49.9
1946	60.7	111	94.5	3.64	312	20.9	1.17	1.17	1.36	1.78	1.95	2.76
1947	6.02	39	11.9	186	155	169	1.62	2.08	1.43	1.48	1.52	2.12
1948	1.8	1.8	15.3	152	130	1.63	1.6	1.8	1.6	1.6	1.8	2.1
1949	24.6	106	29.3	45.4	4.62	1.7	1.5	1.6	1.4	1.24	1.24	1.38
1950	1.51	122	195	143	36.3	12.8	1.47	1.57	1.54	1.52	1.19	15.3
1951	141	262	264	113	23.1	1.71	1.36	1.58	1.88			
Mean	**71.80**	**80.54**	**136.49**	**107.88**	**66.56**	**21.88**	**3.59**	**4.70**	**2.33**	**2.54**	**3.35**	**20.49**

Source: USGS

2.1.4 Mahoning Valley Sanitary District Withdrawals

The Mahoning Valley Sanitary District (MVSD) uses Meander Creek Reservoir as a water supply for approximately 300,000 area residents. Mean yearly withdrawals from 1953 to 2000 obtained from MVSD are presented in Figure 2.3. The mean yearly withdrawal from Meander Creek Reservoir is 23.65 million gallons per day (MGD).

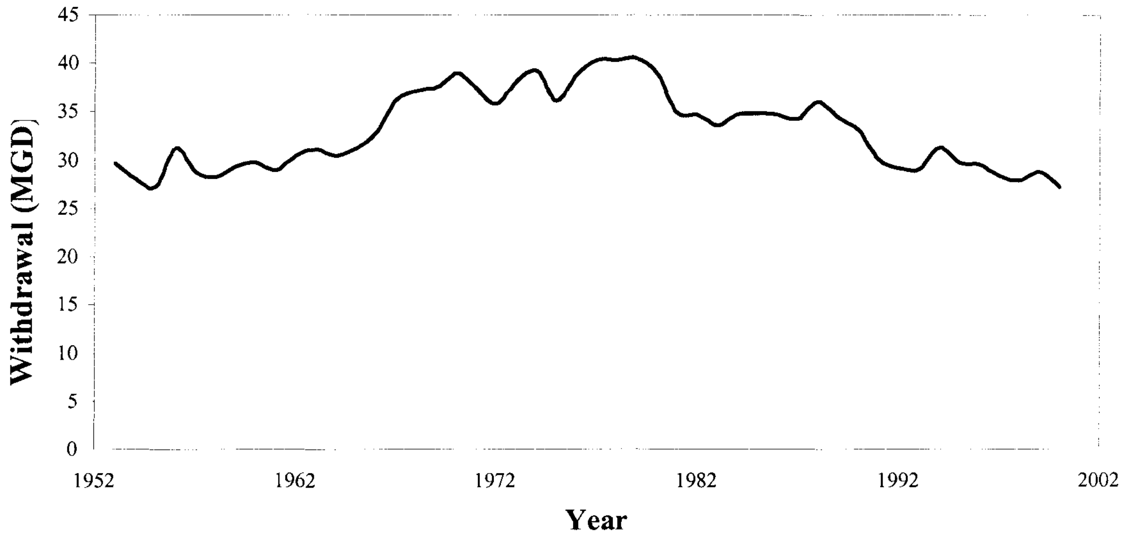

Figure 2.3. Mean Yearly Withdrawal from MVSD

2.1.5 Land Use and Land Cover

The east part of the watershed is mostly urban whereas the west and the south parts are predominantly agricultural and forested. The land use data and land cover data were obtained via the Internet along with BASINS, a GIS based software package published by the U.S. Environmental Protection Agency (EPA). The data obtained show that about 70.0 percent of the Meander Creek Watershed is agricultural land, 16.0 percent is forested, 9.7 percent is urban, and 3.5 percent is open water. The land use data are presented in Table 2.4; a land use map of the watershed is presented in Figure 2.4; a legend for the land use map is presented in Figure 2.5; a land cover map is presented in Figure 2.6. The land cover map shows considerably more forest and less agriculture than the land use map. However, there are some inconsistencies in the land cover map, for example, most of the City of Canfield is shown as forest.

Table 2.4. Meander Creek Watershed Land Use for 1994

	Acres	%
Urban or Built-Up Land		
Residential	2,496	4.6
Commercial and Services	756	1.4
Industrial	38	0.1
Trans., Comm., Utilities	1,585	2.9
Mixed Urban or Built-Up	314	0.6
Other Urban or Built-Up	112	0.2
Subtotal	**5,301**	**9.7**
Agricultural Land		
Cropland and Pasture	38,189	70.0
Orch., Grove, Vineyard, Nurs., Orn.	0	0.0
Confined Feeding Ops	0	0.0
Other Agricultural Land	7	0.0
Subtotal	**38,196**	**70.0**
Forest Land		
Deciduous Forest Land	5,768	10.6
Evergreen Forest Land	2,961	5.4
Mixed Forest Land	0	0.0
Subtotal	**8,729**	**16.0**
Water		
Lakes	41	0.1
Reservoirs	1,867	3.4
Subtotal	**1,908**	**3.5**
Wetland		
Forested Wetland	114	0.2
Nonforested Wetland	0	0.0
Subtotal	**114**	**0.2**
Barren Land		
Strip Mines	286	0.5
Transitional Areas	0	0.0
Subtotal	**286**	**0.5**
Unclassified	**0**	**0.0**
Total Acreage	**54,534**	**100.0**

Source: U.S. EPA

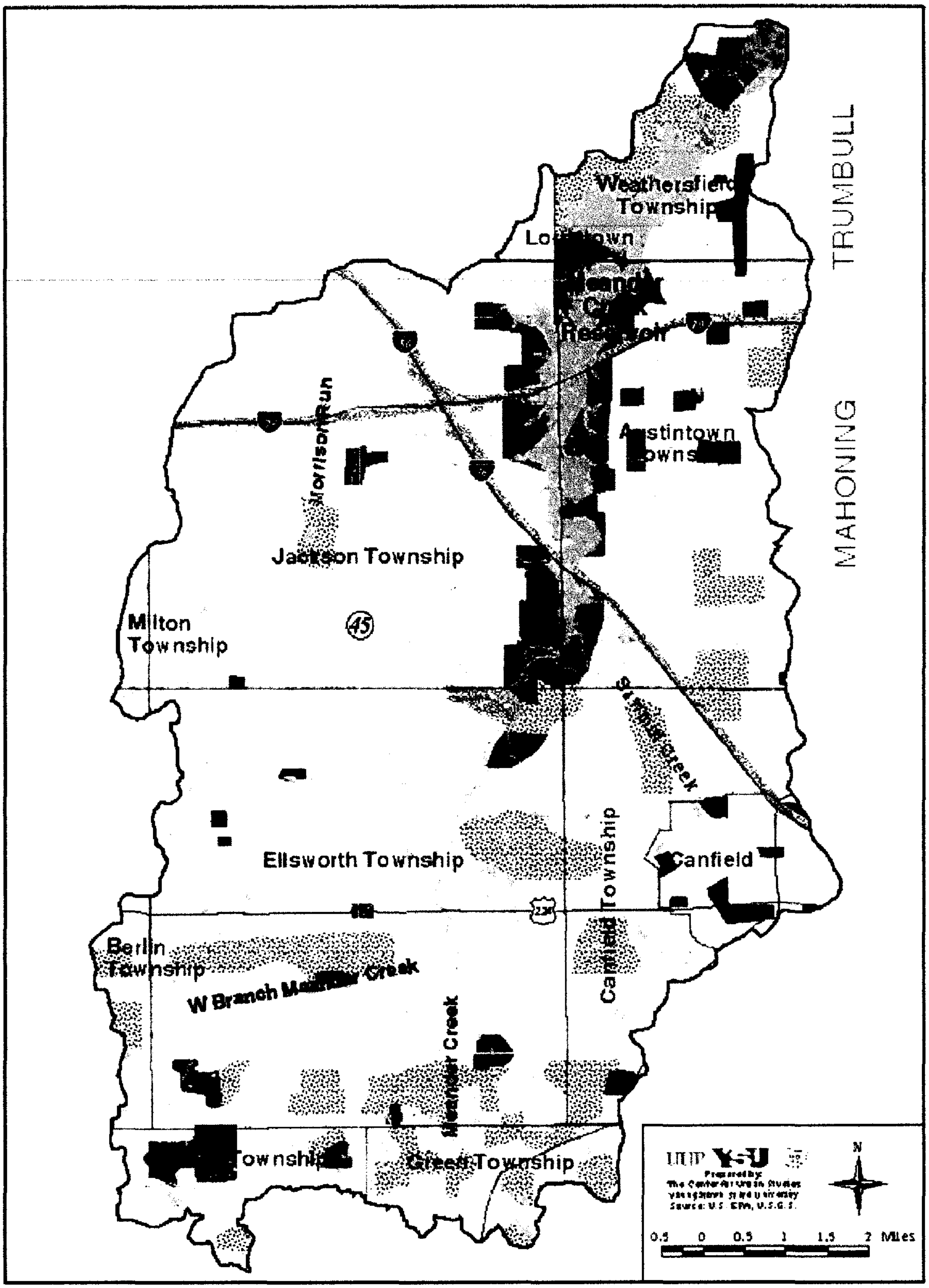

Figure 2.4. Meander Creek Watershed Land Use

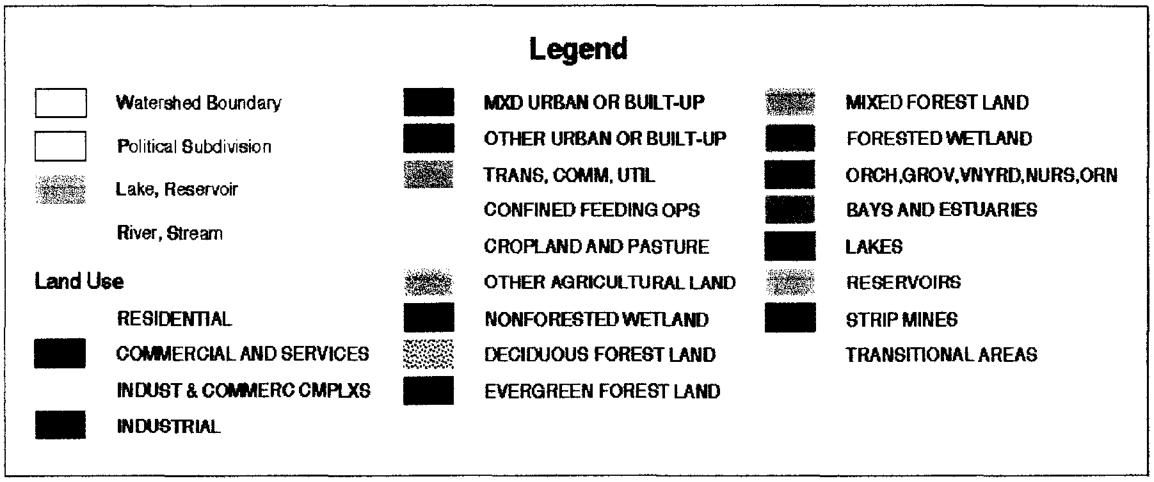

Figure 2.5. Legend for Land Use Figure

The agricultural part of the watershed was studied in more detail to decide whether trends in agricultural practices are likely to have changed pollutant export rates. Mahoning County agricultural surveys were used to determine the historic trends in crop production, yield, total area harvested, number of farms, fertilizer deliveries, and livestock. The crop production data are shown in Figure 2.7, the total area harvested with comparison to total area in farms is presented in Figure 2.8, fertilizer deliveries are shown in Figure 2.9, and livestock populations are presented in Figure 2.10.

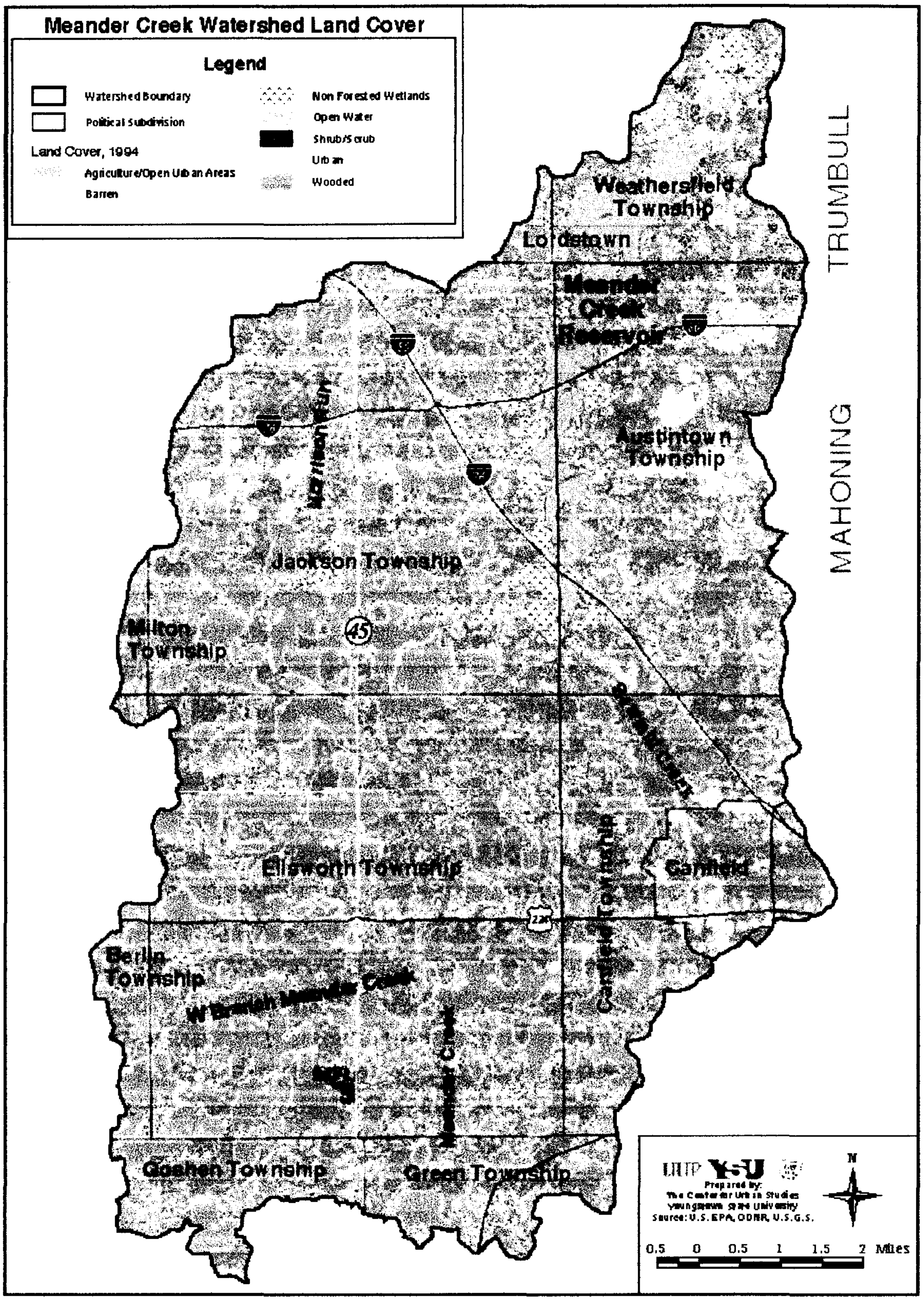

Figure 2.6. Meander Creek Watershed Land Cover

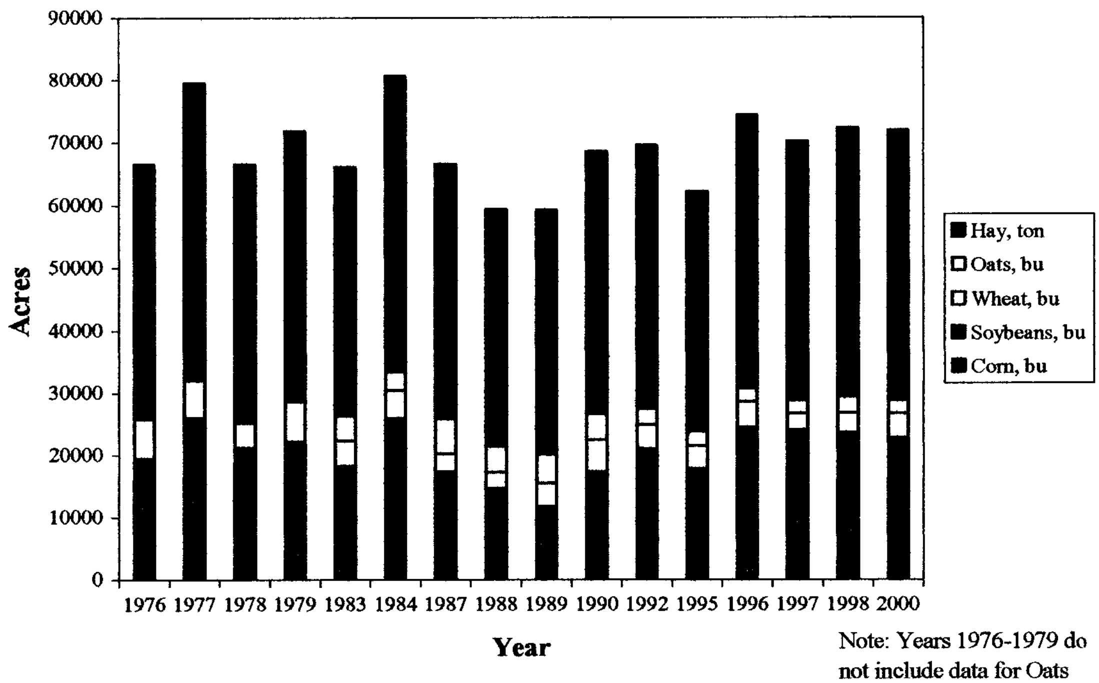

Figure 2.7. Mahoning County Crop Production (Ohio Agricultural Statistics Service)

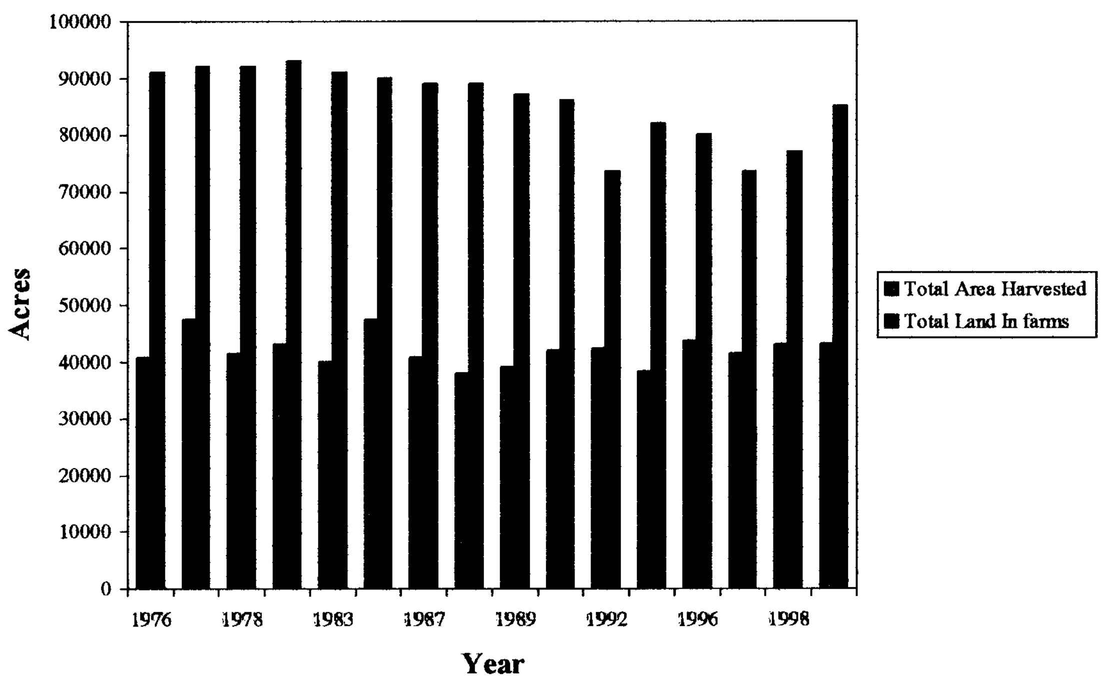

Figure 2.8. Mahoning County Area Harvested vs. Total Area in Farms (Ohio Agricultural Statistics Service)

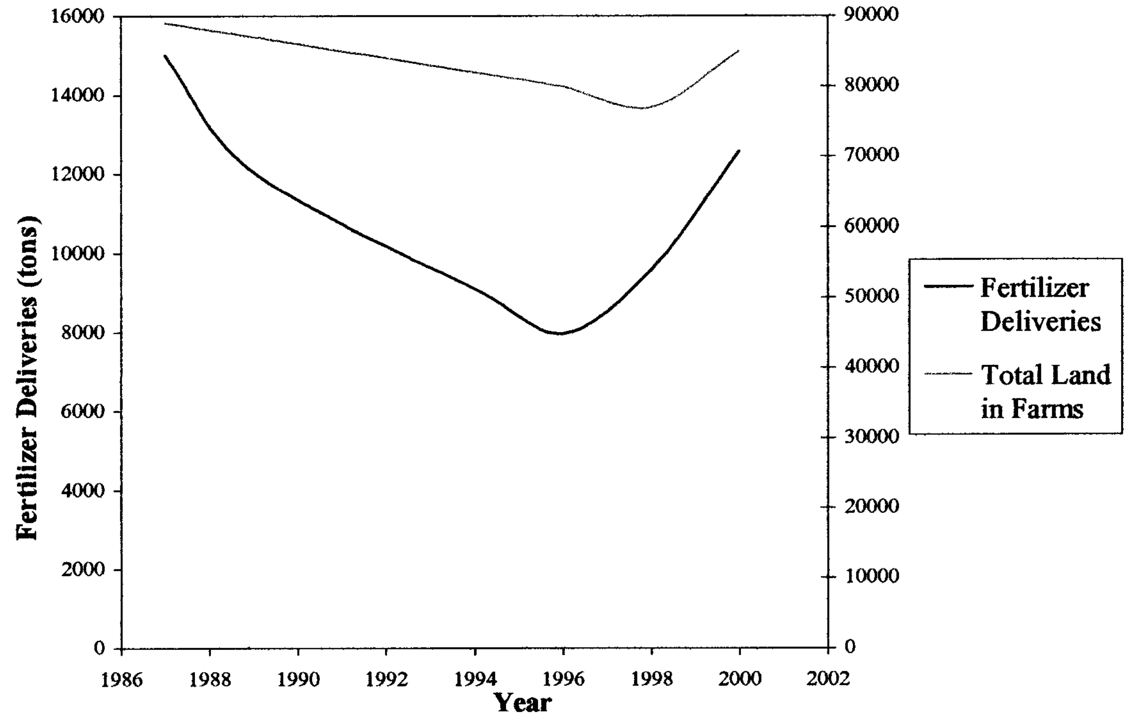

Figure 2.9. Mahoning Fertilizer Deliveries &Total Land in Farms (Ohio Agricultural Statistics Service)

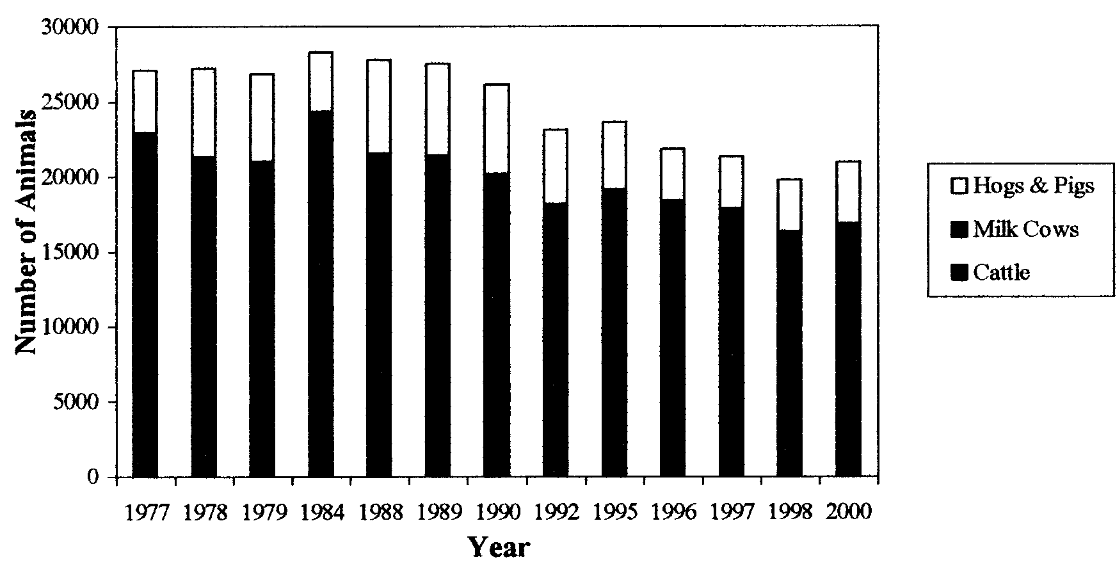

Figure 2.10. Mahoning County Livestock Population (Ohio Agricultural Statistics Service)

2.1.6 Human Population

The population in the watershed has increased somewhat since 1970.The data obtained for political subdivisions in and around the watershed are provided in Table 2.5.

Table 2.5. Meander Creek Watershed Population (1970-2000)

	2000	1990	1980	1970
Austintown CDP	31,627	32,371	33,636	29,393
Austintown Township	38,001	36,740	---	---
Canfield City	7,374	5,409	5,535	4,997
Canfield Township	14,624	10,831	---	---
Mineral City CDP	3,900	3,928	---	---
Ellsworth Township	2,234	2,103	---	---
Green Township	3,450	3,321	---	---
Jackson Township	2,167	2,164	---	---

Source: U.S. Census

2.1.7 Septic Systems

The use of septic systems in the watershed is extensive. The number of septic systems in each township of Meander Creek Watershed is presented in Table 2.6.

Table 2.6. Number of Septic Systems in Meander Creek Watershed for 2002

Township	Total Septic Systems in Township	Estimated % of Septic Systems in Watershed	Estimated Septic Systems in Watershed
Austintown	1545	75	1159
Berlin	843	10	84
Canfield	1847	70	1293
Ellsworth	893	100	893
Goshen	1150	20	230
Green	1263	20	253
Jackson	798	90	718
Milton	993	5	50
Total			**4679**

Source: Mahoning County Board of Health

2.2 Water Use Designations

Ohio EPA has designated 20 miles of Meander Creek as warmwater habitat and Meander Creek Reservoir as a public water supply (Ohio EPA, 1998). These designations are defined by the Ohio EPA (1998) as follows:

- *Warmwater Habitat (WWH)*

Capable of supporting and maintaining a balanced community of warmwater aquatic organisms. This is the most widely applied use designation assigned to warmwater rivers and streams in Ohio.

- *Public Water Supply (PWS)*

Suitable for human consumption and meets federal regulations for drinking water with conventional treatment. Criteria associated with this use designation apply within 500 yards of all surface water supply intakes for human consumption.

2.3 Standards and Biotic Indices

Only three out of the twenty miles of Meander Creek have been monitored to determine attainment status. The three miles surveyed (between Meander Creek dam and confluence with Mahoning river) show non-attainment. The attainment status of aquatic life uses is determined by using the biological criteria codified in the Ohio Water Quality Standards (WQS). The biological community performance measures that are used include the Index of Biotic Integrity (IBI), Modified Index of Well-Being (MIwb) (based on fish community characteristics), and the Invertebrate Community Index (ICI) that is based on macro-invertebrate community characteristics. The minimum attainment values for a warmwater habitat classified stream are presented in Table 2.7 (Note that Ohio is divided into five ecoregions. Meander Creek Watershed is located in the Erie-Ontario Lake Plain).

Table 2.7. Biotic Indices for Warmwater Habitat - Erie-Ontario Lake Plain

A) Index of Biotic Integrity (IBI) - Fish	Attainment Value
1) Wading Sites	38
2) Boat Sites	40
3) Headwater Sites	40
B) Modified Index of Well-Being (MIwb) - Fish	
1) Wading Sites	7.9
2) Boat Sites	8.7
C) Invertebrate Community Index (ICI) - Macroinvertebrate	
1) Artificial Substrate Samplers	34

Source: Ohio EPA

Attainment of the aquatic life use is FULL if all three indices (or those available) meet the applicable biocriteria, PARTIAL if at least one of the indices does not attain and performance is at least fair, and NON attainment if all indices fail to attain or any index indicates poor or very poor performance. Partial and non-attainment indicate that the receiving water is impaired and does not meet the designated use criteria specified by the Ohio WQS (Ohio EPA, 1996). The Statewide Water Quality Criteria for the Protection of Aquatic Life of Warmwater Habitats as well as for Public Water Supply are presented in the Appendix, Tables A-3 through A-8.

2.4 Ohio's Total Maximum Daily Load Program

A Total Maximum Daily Load (TMDL) is a calculation of the maximum amount of a pollutant that a waterbody can receive and still meet water quality standards. When the TMDL of a certain pollutant is determined, it is then allocated to the pollutant's sources. The states, territories, and tribes set the water quality standards. They identify the uses for each body of water, for example, public water supply, contact recreation, and aquatic life support, and the scientific criteria to support that use.

A TMDL is the sum of the allowable loads of a single pollutant from all contributing point and nonpoint sources. The calculation must include a margin of safety to ensure that the body of water can be used for the purposes the state has designated. The calculation must also account for seasonal variation in water quality (EPA, 2002).

All designated waters in Ohio are scheduled for TMDL analysis. The anticipated TMDL submittal for Meander Creek and Meander Creek Reservoir is December of 2010 (EPA, 2002).

2.5 Export Factors for Phosphorus, Nitrogen, and Suspended Solids

2.5.1 Export Factors for Phosphorus, Nitrogen, and Suspended Solids for Various Land Uses

The information on export factors for total phosphorus (TP), nitrogen (TN) and suspended solids (TSS) for various land uses is limited. Most of the factors available in the literature are either for specific regions outside Ohio or averages for the whole continental United States. In Tables 2.8, 2.9, and 2.10, export factors used in this study are presented. Additional export factors are provided in the Appendix, Tables A-9 through A-11.

Table 2.8. Average Nutrient Export Factors for the United States

Land Use	TN (kg/ha/yr)	TP (kg/ha/yr)
Forest	1.8	0.11
Corn	11.1	2
Cotton	10	4.3
Soybeans	12.5	4.6
Small Grain	5.3	1.5
Pasture	3.1	0.1
Feedlot Dairy	2900	220
Idle	3.4	0.1
Residential	7.5	1.2
Business	13.8	3
Industrial	4.4	3.8

Source: U.S. EPA & Reckhow *et al.* (1980)

Table 2.9. Phosphorus Export Factors for Wisconsin

Land use	TP ($lb/mi^2/yr$)	TP (kg/ha/yr)
Agriculture > 95%	591	1.04
Agriculture > 75%	424	0.74
Agriculture > 50%	317	0.56
Mixed	553	0.97
Forest	54	0.09
Urban	296	0.52

Source: Panuska & Lillie (1995)

Table 2.10. Suspended Solids Export Factors for Florida

Land Use	TSS (lb/ac/yr)	TSS (kg/ha/yr)
Residential (Low Density)	28	31
Residential (High Density)	344	386
Commercial	586	658
Highway	980	1101
Wetlands	24	27
Pasture	591	664
Agriculture	1997	2243
Woodland	57	64

Source: Northeast Florida Water Management District, 1994

2.5.2 Export Factors for Phosphorus and Nitrogen from Septic Systems

The typical daily quantities of total phosphorus and total nitrogen discharged per person in residential wastewater are presented in Table 2.11. When on-site septic systems do not function properly, a portion of these nutrients may enter the streams and lakes of a watershed.

Table 2.11. Pollutant Discharges in Residential Wastewater

	Typical without ground up kitchen waste	Typical with ground up kitchen waste	Average
TP Export Coefficient (g/cap-d)	3.2	3.5	3.35
TN Export Coefficient (g/cap-d)	13	14.3	13.65

Source: Metcalf & Eddy, Inc., 2003

2.6 Simple Phosphorus Models for Lakes

Many models exist to predict how phosphorus loadings affect the eutrophication of lakes and reservoirs. The model used in this study was the Vollenweider model as modified by Dillon and Rigler (1975). A Vollenweider-type model defines the trophic state of a lake based on phosphorus concentration. It classifies lakes with an annual average total phosphorus concentration of less than 10 μg/L as oligotrophic, between 10 μg/L and 20 μg/L as mesotrophic and a concentration of above 20 μg/L as eutrophic. Equations and graphs relating phosphorus loading and hydraulic characteristics to phosphorus concentration and trophic status are also available to aid in the classification.

Wetzel's trophic status classification was also used in order to estimate the trophic status of Meander Creek Reservoir. The average values and the ranges of the calculated parameters for each level of trophic status are presented in Table 2.12.

Table 2.12. Wetzel's Trophic Status Classification

Calculated Parameter	Oligotrophic	Mesotrophic	Eutrophic
Total Phosphorus (μg/L)	8 (3.0 - 17.7)	26.7 (10.9 - 95.6)	84.4 (16 – 386)
Chlorophyll *a* (μg/L)	1.7 (0.3 - 4.5)	4.7 (3 – 11)	14.3 (3 – 78)
Secchi Disk Depth (m)	9.9 (5.4 - 28.3)	4.2 (1.5 – 8.1)	2.45 (0.8 – 7.0)

Source: Wetzel, 1983

CHAPTER 3

METHODS AND PROCEDURES

3.1 Land Use Estimates

The land use was estimated by the utilization of aerial photographs. First the aerial photographs included in the Mahoning County Soil Survey (USDA, 1971) were used to estimate the land use for 1965. The watershed area was outlined in the index of the aerials and the correct sheets representing the watershed were identified. The watershed area was then outlined on these sheets and divided into smaller sections. The area of each section was then estimated. It was decided that the land use would be divided into four categories: agricultural, forested, urban, and open water. Each section was examined and its land use was approximated as a percentage.

In order to estimate the land use for 1994, aerial photographs obtained by USGS (TerraServer, 2002) were used. The watershed area was again outlined and it was then divided into twenty-two roughly equal sections. Breaking it up into geometrical sections whose area was easily calculated and summing those areas calculated the area of each section. The categories for this land use approximation were agricultural, shrub, forested, urban, and open water.

The two estimates produced a discrepancy in the total area of the watershed. Therefore the area of the watershed was taken to be that of the area above the gaging station, which is just below the dam. Also, the open water estimate should have been closer to 4% since the main open water region in the watershed is Meander Creek

Reservoir. Taking these two factors into consideration, the land use estimates for both 1965 and 1994 were adjusted by using Equation 1.

$$\text{Area (acres)} = (\text{W.A.} - \text{O.W.A}) \times \frac{\text{Estimated \% for land use}}{(100 - \text{Estimated \% for water})} \quad (1)$$

where, W.A. = Watershed area, acres

O.W.A. = Open Water Area, acres

3.2 Pollutant Loading Estimates

The most important factor in estimating the pollutant loading from the watershed was the selection of the correct export rates for phosphorus, nitrogen and suspended solids. This was difficult since the literature values were scarce. The biggest problem was that the reported values were either for a specific region or average values for the whole United States, and none of them were obtained for Northeast Ohio. First, the average values presented in Table 2.8 (Reckhow *et al.*, 1980) were used for phosphorus and nitrogen, and for suspended solids Table 2.10 (Northeast Florida Water Management District, 1994) was used. The areas for each land use category were already calculated (in hectares), and since the export factors were given in terms of kilograms per hectare per year (kg/ha-yr), these two values were multiplied to give the loadings for phosphorus, nitrogen and suspended solids in kg/yr. These loadings were used in the water quality models that will be discussed in the next section. The predicted trophic status of Meander Creek Reservoir was highly eutrophic which does not match the present conditions of the reservoir. Hence a new set of export factors was selected.

The new export factors selected for phosphorus are presented in Table 2.9 (Panuska and Lillie, 1995), for nitrogen in Table 2.8 (Reckhow *et al.*, 1980), and for suspended solids in Table 2.10 (Northeast Florida Water Management District, 1994). The same procedure was applied, and when these loadings where used in the water quality models, trophic status predictions for Meander Creek Reservoir matched the present conditions somewhat better. The procedure was then repeated for the land use conditions of 1965 and 1700 (assumed completely forested).

3.3 Septic System Pollutant Loading

The information obtained from the Mahoning County Board of Health for the number of septic systems in the watershed and the export coefficients obtained from Metcalf & Eddy, Inc. (2003) were used to estimate potential pollutant loading from septic systems to the Meander Creek Reservoir.

First, the percentage of each township included in the watershed was estimated. These percentages were used to calculate the number of septic systems in the watershed from each township. It was then assumed that 25% of these systems provided no removal of nitrogen and phosphorus, 25% provided 50% removal, and the remaining 50% provided 100% removal. These assumptions were based on the results of septic system inspections conducted by the Mahoning County Board of Health in 2001 and 2002, which showed that roughly one half of systems have some operational problem(s).

The export coefficients were in terms of grams per capita per day, so in order to express them in grams per day, a household of 4 people was assumed. The export coefficients were then multiplied by the number of septic systems and the level of removal to obtain the loading to Meander Creek Reservoir in terms of grams per day (g/d) and kilograms per year (kg/yr).

3.4 Hydrologic Data

The precipitation, evaporation, and runoff data obtained are in terms of inches per year. In order to calculate the annual hydrologic budget of Meander Creek Reservoir, these hydrologic data must be manipulated to represent the flow in or out of the reservoir per year. The yearly means of precipitation and evaporation were used in conjunction with the reservoir surface area in order to calculate the direct precipitation into the reservoir and the total evaporation out of it, respectively. The yearly mean runoff rate (13 in/yr), obtained from the Ohio Hydrologic Atlas (ODNR, 2002), was multiplied by the watershed area to obtain the total runoff into the reservoir.

The data obtained from the USGS gaging station as well as the mean MVSD yearly withdrawal provide the total outlet flow from the reservoir. The groundwater infiltration was obtained from a flow balance by assuming steady-state conditions. Groundwater outflow is equal to the difference between the sums of all other outflows and inflows.

The hydraulic residence time (t_R) of the reservoir is equal to the ratio of volume of the reservoir to the sum of all the outflows and is calculated by Equation 2.

$$t_R = V / (O.F. + G.F.) \qquad (2)$$

where, V = Reservoir Volume, ft^3

O.F. = Outlet Flow, ft^3/yr

G.F. = Groundwater Outflow, ft^3/yr

The flushing rate (ρ) of the reservoir was also calculated and it is equal to the inverse of the hydraulic retention time. Equation 3 presents the equation used to calculate the flushing rate.

$$\rho = 1/HRT \tag{3}$$

3.5 Water Quality Models

The data needed to apply the Vollenweider model include the volume (V) of the reservoir in m^3, its surface area (A_s) in m^2, mean depth (z) in m, the total outflow (Q) in m^3/yr, and the annual total phosphorus loading (W) to the reservoir in g/yr. From these data the areal total phosphorus loading rate (L) was calculated by using Equation 4.

$$L = \frac{W}{A_S} \tag{4}$$

Then the hydraulic residence time (t_R) and the hydraulic loading rate (q_S) were calculated by using Equations 5 and 6, respectively.

$$t_R = \frac{V}{Q} \tag{5}$$

$$q_S = \frac{z}{t_R} \tag{6}$$

In order to estimate the trophic status of the reservoir the total phosphorus loading rate and the hydraulic loading rate were plotted on the Vollenweider graph, presented in Figure 3.1.

The predicted total phosphorus concentration was also calculated by using Equation 7 (Dillon and Rigler, 1975).

$$[TP] = \frac{L(1-R)}{q_S} \quad (7)$$

where, R= phosphorus retention coefficient

$$= 0.426\exp(-0.271q_S) + 0.574\exp(-0.00949q_S) \quad (8)$$

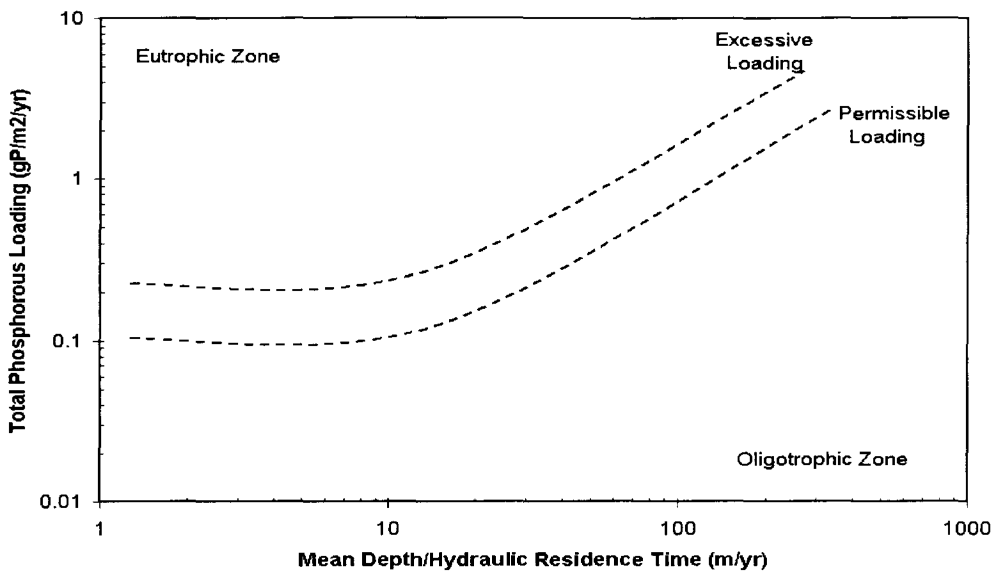

Figure 3.1. Vollenweider's Phosphorus Loading Plot

The last two parameters calculated were the predicted chlorophyll concentration (Chl *a*) and the predicted secchi disk transparency (SD). The predicted chlorophyll was calculated by using Equation 9 (Dillon and Rigler, 1974) and the predicted secchi transparency depth was calculated by using Equation 10 (Carlson, 1977).

$$\log[Chl\ \mathrm{a}] = 1.449\log[TP] - 1.136 \quad (9)$$

$$\ln \mathrm{SD} = 2.04 - 0.68\ln[\mathrm{Chl\ a}] \quad (10)$$

CHAPTER 4

RESULTS AND DISCUSSION

4.1 Hydrologic Budget for Meander Creek Reservoir

The hydrologic budget for Meander Creek Reservoir is presented in Figure 4.1. The direct runoff is equal to 2.56×10^9 ft^3/yr, total evaporation is 0.23×10^9 ft^3/yr, direct precipitation is 0.26×10^9 ft^3/yr, outlet flow is 2.29×10^9 ft^3/yr, and groundwater flow is 0.31×10^9 ft^3/yr. The hydraulic retention time of the reservoir is 0.515 yr, and its flushing rate is 1.94 yr^{-1}.

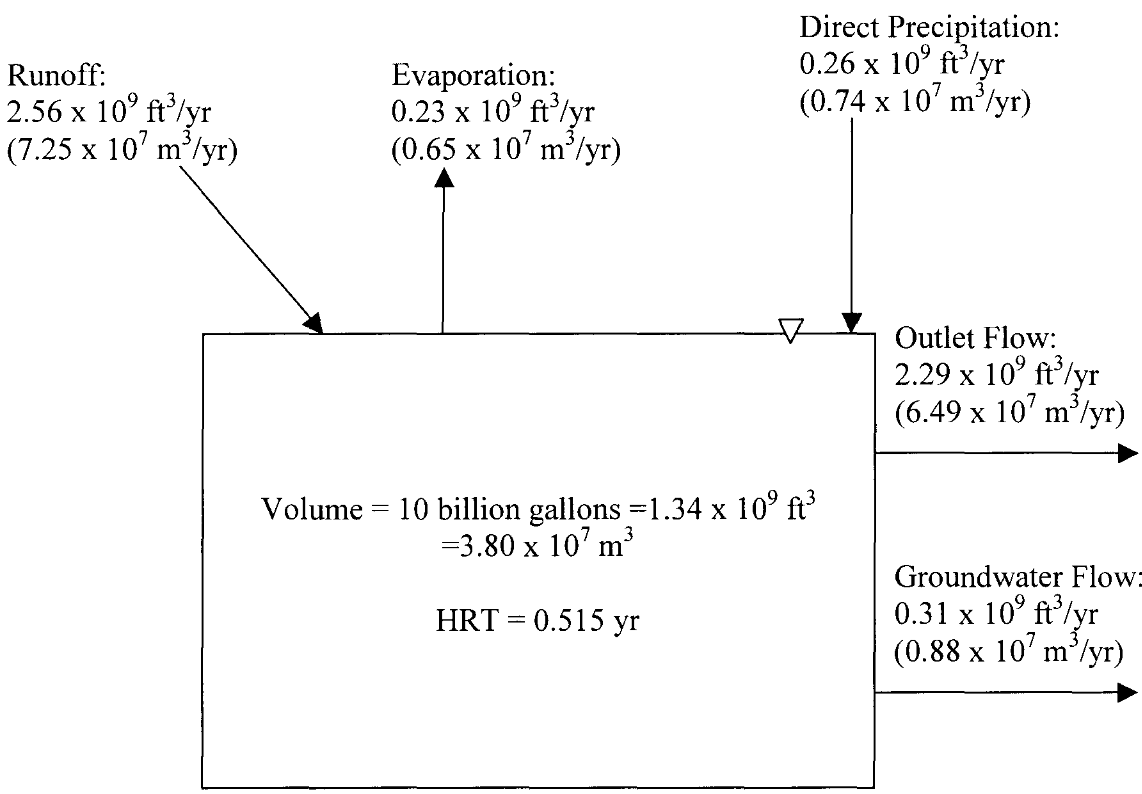

Figure 4.1. Total Annual Hydraulic Budget for Meander Creek Reservoir

4.2 Land Use Trends

The land use data obtained from BASINS, a GIS-based software, and the estimated land use for 1994 varied significantly. The 1994 land use estimated from aerial photos is presented in Table 4.1; the values obtained from BASINS are presented in Table 2.4 and are repeated in Table 4.1 for comparison. This discrepancy can be attributed to differences in the interpretation of agricultural and forested land use. The BASINS database apparently includes inactive farmland with shrubs and even larger trees in the "agricultural" category.

Table 4.1. 1994 Meander Creek Reservoir Land Use Estimates

Land Use	% of Watershed	BASINS %
Forested	36.94	16.0
Agricultural	25.13	70.0
Shrub	19.03	
Urban	13.57	9.7
Water	5.33	3.5

The estimated land use for 1965 is shown in Table 4.2. For the purposes of developing pollutant loading calculations, the land use estimates obtained from aerial photos were used.

Table 4.2. 1965 Meander Creek Reservoir Land Use Estimates

Land Use	% of Watershed
Forested	39.41
Agricultural	52.67
Urban	4.77
Water	3.16

Comparison of the land use for 1994 and 1965 reveals that urban areas have increased by 8.8%, a trend to be expected in a period of 30 years. Most of the development has taken place in the east part of the watershed, mainly in Austintown and Canfield Townships. Although some development has taken place in the rest of the watershed, it is not as significant; hence the rest of the watershed can be classified as mostly agricultural or forested. The forested areas have remained relatively constant, decreasing only slightly from 39.31% in 1965 to 36.94% in 1994. The agricultural use for 1965 was estimated as the total of the agricultural areas and shrub areas, whereas for 1994 these two categories were broken down. The agricultural land use has decreased by 8.44% in the period between the two land use estimates.

There is definitely some error in the land use estimation, and this can be seen from the estimate for the open water land use category for 1994. The main open water region in the watershed is Meander Creek Reservoir, which is 3.65% of the total area; hence an estimate of about 4% for open water is reasonable. However, 5.33% and 3.16% were obtained for 1994 and 1965, respectively. Therefore the estimated land use was adjusted to compensate for that error. The new estimated land use is presented in Table 4.3 for 1994 and Table 4.4 for 1965.

It was concluded that the agricultural practices in the watershed have remained relatively constant since 1976. Although the number of farms has decreased by about twenty percent, the land in farms has only decreased by approximately five percent (Ohio Agricultural Statistics Service, 1979-2000). Statewide data show that crop yields have increased in this period of time presumably due to the increased application of fertilizers.

However, agricultural practices have improved in several ways over the past 40-50 years, including:

- Better nutrient management (i.e. adjusting application rates for soil residuals and crop demands);
- Increased use of conservation tillage to reduce soil erosion; and
- Better manure management.

Table 4.3. 1994 Meander Creek Reservoir Adjusted Land Use Estimates

	Areas	
Land Use	**Acres**	**Hectares**
Forested	20,229	8,186
Agricultural	13,760	5,569
Shrub	10,423	4,218
Urban	7,428	3,006
Water	2,160	874
Total	**54,000**	**21,854**

Table 4.4. 1965 Meander Creek Reservoir Adjusted Land Use Estimates

	Areas	
Land Use	**Acres**	**Hectares**
Forested	21,094	8,537
Agricultural	28,193	11,409
Urban	2,553	1,033
Water	2,160	874
Total	**54,000**	**21,854**

4.3 Pollutant Loading Estimates

In order to estimate the pollutant loadings into the Meander Creek Reservoir from nonpoint sources, the export factors from the literature review were used. The loadings presented in Table 4.5 were calculated by using the export factors presented in Tables 2.8-2.10. The TP export coefficients were calculated by using the data in Table 2.9, with the agricultural export coefficient being that of more than 50% agricultural land. The urban total nitrogen (TN) export coefficient used was the average of residential, business, and industrial rates from Table 2.8. The agricultural and pasture TN export coefficient used was the average of the values for corn, soybeans, small grain, and pasture. The urban TSS export coefficient was the average of the values for low and high density residential, commercial and highway from Table 2.10.

Table 4.5. Estimates of 1994 Nonpoint Source Pollutant Loading for Meander Creek Reservoir

Land Use	Area (ha)	TN Export Coefficient (kg/ha/yr)	TN Loading (kg/yr)	TP Export Coefficient (kg/ha/yr)	TP Loading (kg/yr)	TSS Export Coefficient (kg/ha/yr)	TSS Loading (kg/yr)
Residential	3,006	8.60	25,853	0.52	1,563	544	1,635,880
Forest & Wetland	8,186	1.80	14,736	0.09	737	46	375,592
Agricultural & Pasture	9,787	8.00	78,295	0.56	5,481	1,454	14,225,143
Total	**20,980**		**118,883**		**7,781**		**16,236,615**

The pollutant loadings for 1965 were then calculated in a similar way to that of 1994. The urban total nitrogen (TN) export coefficient was calculated by obtaining the average of residential, business, and industrial rates from Table 2.8. The agricultural and pasture TN export coefficient is the average of the values for corn, soybeans, small grain, and pasture. The TP export coefficients were obtained from Table 2.9 and for TSS from Table 2.10. The agricultural export factor is that of more than 50% agricultural land. The pollutant loadings obtained are presented in Table 4.6.

Table 4.6. Estimates of 1965 Nonpoint Source Pollutant Loading for Meander Creek Reservoir

Land Use	Area (ha)	TN Export Coefficient (kg/ha/yr)	TN Loading (kg/yr)	TP Export Coefficient (kg/ha/yr)	TP Loading (kg/yr)	TSS Export Coefficient (kg/ha/yr)	TSS Loading (kg/yr)
Urban	1,033	8.60	8,886	0.52	537	544	562,252
Forest & Wetland	8,537	1.80	15,366	0.09	768	46	391,666
Agricultural & Pasture	11,409	8.00	91,275	0.56	6,389	1,454	16,583,563
Total	**20,980**		**115,527**		**7,695**		**17,537,481**

In order to estimate the hypothetical loading to the reservoir before any development took place (e.g. land use conditions in the 1700's), it was assumed that the entire watershed was forested. The TN export coefficient was taken from Table 2.8, the TP export coefficient from Table 2.9 and the TSS coefficient from Table 2.10. The loadings calculated are presented in Table 4.7.

Table 4.7. Estimates of 1700 Nonpoint Source Pollutant Loading for Meander Creek Reservoir

Land Use	Area (ha)	TN Export Coefficient (kg/ha/yr)	TN Loading (kg/yr)	TP Export Coefficient (kg/ha/yr)	TP Loading (kg/yr)	TSS Export Coefficient (kg/ha/yr)	TSS Loading (kg/yr)
Forested	20,980	1.80	37,764	0.09	1,888	46	962,562
Total	**20,980**		**37,764**		**1,888**		**962,562**

4.4 Potential Impacts of Septic Systems

The estimate of pollutant loadings from septic systems proved to be very significant. However, the amount of pollutants that actually reaches Meander Creek Reservoir is not known; therefore these loadings were not included in the water quality models used to determine the trophic status of the reservoir. The estimates of potential pollutant loading from septic systems to Meander Creek Reservoir are presented in Table 4.8.

Table 4.8. Estimates of Potential Septic Systems Pollutant Loading for Meander Creek Reservoir

% Removal of N & P	% of Septic Tanks	Number of Septic Tanks	TP Export Coefficient	TP Loading		TN Export Coefficient	TN Loading	
			(g/d)	(g/d)	(kg/yr)	(g/d)	(g/d)	(kg/yr)
0%	25%	1,170	13.4	15,676	5,722	54.6	63,874	23,314
50%	25%	1,170	13.4	7,838	2,861	54.6	31,937	11,657
100%	50%	2,340	13.4	0	0	54.6	0	0
		4,679		**23,514**	**8,583**		**95,811**	**34,971**

The fact that the potential phosphorus loading from septic systems is greater than that of all other nonpoint sources implies that malfunctioning septic systems could play a very important role in the trophic status of Meander Creek Reservoir.

4.5 Water Quality Models

The trophic status of Meander Creek Reservoir was determined by using the Vollenweider model. As a comparison the Wetzel trophic status classification was also used. The areal total phosphorus loading (L) and the hydraulic loading rate (q_s) presented in Table 4.9 were plotted on the Vollenweider graph, which is shown in Figure 4.2. The model does not include pollutant loadings from malfunctioning septic systems.

Table 4.9. Meander Creek Reservoir Areal Total Phosphorus Loading and Hydraulic Loading Rates

Year	L ($gP/m^2/yr$)	q_s (m/yr)
1994	0.96	9.12
1965	0.95	9.12
1700	0.23	9.12

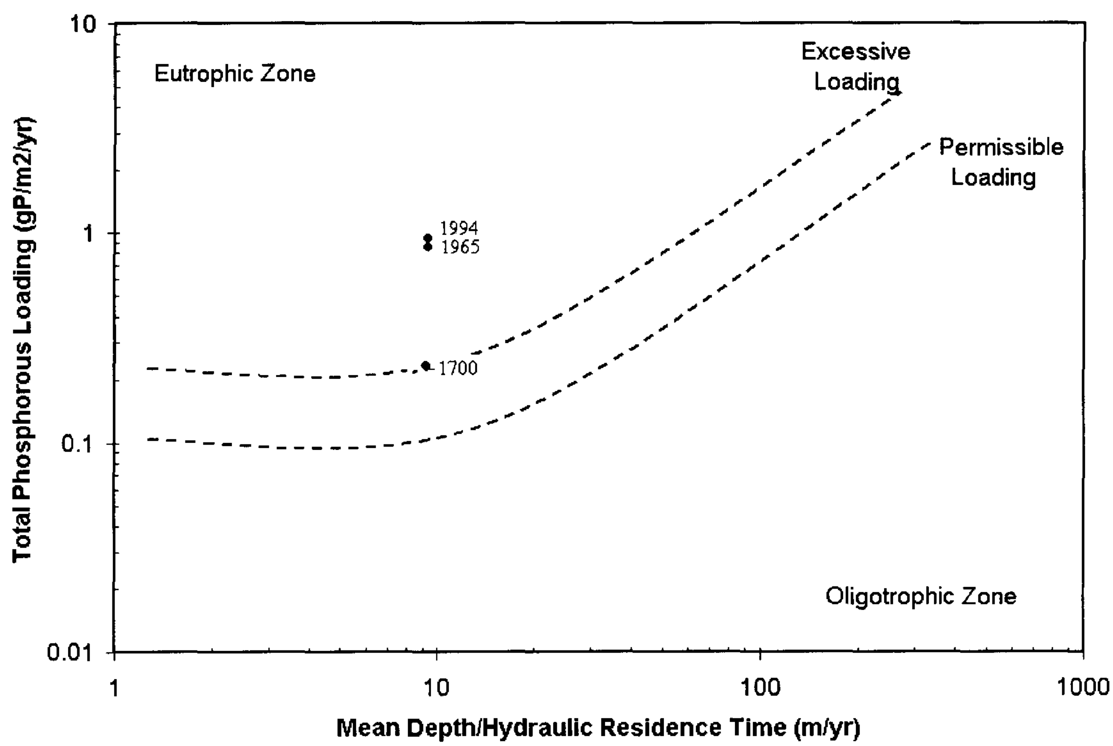

Figure 4.2. Vollenweider's phosphorus Loading Plot for Meander Creek Reservoir

The trophic status predicted for the 20th century according to the Vollenweider model was slightly eutrophic. However, it can be concluded that the reservoir is naturally mesotrophic since the loadings from a completely forested watershed would place the reservoir in the meso-eutrophic range.

The model was also used to predict the total phosphorus concentration in the reservoir, as well as chlorophyll *a* concentrations and Secchi disk transparency. The values obtained are presented in Table 4.10. Comparison of these values to the Wetzel trophic status classification reveals that years 1994 and 1965 are possibly in the meso-eutrophic range when total phosphorus concentrations are used for classification and in the eutrophic range when chlorophyll concentrations and secchi depth are used. The Wetzel classification places the values calculated for 1700 in the oligo-mesotrophic range.

Table 4.10. Meander Creek Reservoir Water Quality Variables

Year	TP (μg/L)	Chl *a* (μg/L)	Secchi Depth (m)
1994	46.12	18.83	1.04
1965	45.61	18.53	1.06
1700	11.19	2.42	4.22

4.5 Comparison to Reservoir Monitoring Results

The water quality variables calculated for 1994 were compared to the values obtained from the reservoir monitoring program. The first set of variables obtained for 1994 did not match the values from the monitoring program. That is why a new set of export factors was selected and the procedure repeated again. The new set of variables matched the monitoring values somewhat better. The comparison can be seen in Table 4.11. The predicted trophic status of Meander Creek Reservoir is still somewhat more eutrophic than observed conditions. Some potential reasons could be:

- Export rates selected were still too high
- Not all phosphorus exported from land actually reaches Meander Creek Reservoir
- The phosphorus retention coefficient in Meander Creek Reservoir may be greater than the Vollenweider model predicts since a great portion of phosphorus load is bound to sediment.

Table 4.11. Comparison of Water Quality Variables

	Monitoring Program Variables	1994 Variables
TP (μg/L)	12-179	46.12
Chl *a* (μg/L)	0-29	18.83
Secchi Disk Depth (m)	0.19-3.00	1.04

Source: Schroeder & Martin, 2001

CHAPTER 5

CONCLUSIONS AND RECOMMENDATIONS

5.1 Conclusions

The trophic status predicted for the 20th century according to the Vollenweider model was slightly eutrophic. However, it can be concluded that the reservoir is naturally mesotrophic since the loadings from a completely forested watershed would place the reservoir in the meso-eutrophic range. The fact that the reservoir is probably mesotrophic is supported by the comparison of the calculated total phosphorus concentration to the Wetzel values. The predicted trophic status of Meander Creek Reservoir is still somewhat more eutrophic than observed conditions. This might be attributed to a number of reasons, like the fact that not all of the estimated phosphorus loading actually reaches the reservoir.

Statewide data show that crop yields have more than doubled since 1956, presumably due to increased application of chemical fertilizers. However, agricultural practices have improved in several ways over the past 40-50 years. Thus, it was assumed that nutrient export rates from farmland have remained relatively constant over the past several decades.

The trophic status of Meander Creek Reservoir is significantly affected by land use trends. 91% of 1994 estimated total phosphorus load comes from developed (agricultural and urban) land. However, changes in land use over the past 30 years do not appear to be significant enough to cause the taste and odor problems observed at the reservoir.

The impact of septic systems on the pollutant loadings and trophic status of Meander Creek Reservoir is potentially very significant. The potential pollutant loadings from septic systems were greater than the loadings from all other nonpoint sources in the watershed.

5.2 Recommendations

In order to improve the findings of this study with future work, the following recommendations can be taken into consideration:

- Obtaining export coefficients for Northeast Ohio would make estimates of pollutant loadings and trophic status of waterbodies in this area more accurate and reliable,
- Routine monitoring of flow and nutrient concentrations in streams of the Meander Creek Watershed would improve the accuracy of loading estimates, and,
- A method of estimating the amount of septic system loadings actually reaching Meander Creek Reservoir should be developed.

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APPENDIX

Table A-1. Mean Precipitation (1931-2000) for Meander Creek Reservoir (inches)

Year\ Month	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Total
1931	1.230	1.560	1.290	3.880	4.790	2.360	3.080	4.810	2.490	1.260	1.870	3.230	31.850
1932	4.850	0.780	1.960	3.640	2.430	2.010	6.050	1.530	1.640	2.420	3.830	2.570	33.710
1933	1.230	1.290	4.590	3.280	3.350	1.890	1.050	2.050	2.640	0.980	1.320	1.810	25.480
1934	1.490	0.750	1.830	2.030	0.630	2.950	2.870	5.790	4.470	1.060	1.960	0.930	26.760
1935	2.090	2.040	1.460	1.320	3.710	3.390	5.520	7.110	2.470	2.100	2.390	2.620	36.220
1936	1.270	2.110	3.750	2.010	2.320	1.590	3.650	4.140	2.590	3.800	2.360	1.780	31.370
1937	7.430	0.790	2.290	4.630	3.880	4.810	6.270	2.440	2.370	3.430	1.190	2.720	42.250
1938	0.940	1.170	3.880	2.010	4.030	4.680	4.240	2.840	4.400	0.880	2.720	0.880	32.670
1939	2.010	3.130	3.620	3.670	1.220	4.290	5.370	1.370	2.690	3.600	0.620	1.270	32.860
1940	1.110	3.020	2.850	5.260	4.420	4.780	2.520	3.950	2.050	1.390	3.560	3.550	38.460
1941	1.570	1.490	1.250	1.330	3.200	4.070	6.200	2.860	1.190	4.580	1.400	1.060	30.200
1942	1.440	2.930	3.750	3.000	4.830	2.530	4.660	3.080	2.480	4.120	3.150	4.860	40.830
1943	2.340	1.790	2.660	3.380	4.420	3.560	4.990	2.220	1.410	2.300	1.330	0.720	31.120
1944	1.890	1.640	3.280	3.140	2.780	2.720	1.970	3.250	2.150	1.380	2.050	2.800	29.050
1945	1.550	2.230	4.220	2.690	3.600	2.680	2.570	2.560	5.960	4.180	2.630	1.600	36.470
1946	0.830	2.800	1.780	1.510	7.740	3.910	1.460	2.280	0.840	4.610	1.700	1.720	31.180
1947	4.630	0.300	1.000	4.230	5.460	5.340	2.400	6.990	1.920	0.770	2.390	1.200	36.630
1948	1.640	1.600	2.270	4.100	4.210	4.230	2.830	2.610	1.400	2.770	2.370	2.520	32.550
1949	3.530	1.880	1.830	2.180	3.010	2.640	4.260	1.740	2.450	0.860	0.870	1.790	27.040
1950	6.530	3.920	3.070	4.330	2.340	3.750	1.850	2.580	2.720	2.040	5.060	1.900	40.090
1951	2.090	3.220	5.090	3.610	2.150	2.600	5.060	1.490	3.030	2.060	4.010	3.470	37.880
1952	5.830	2.360	2.360	3.120	3.160	3.000	4.480	2.050	4.150	1.290	1.820	1.840	35.460
1953	3.100	0.700	2.860	2.410	4.400	3.890	2.070	1.570	1.860	0.590	1.160	1.910	26.520
1954	2.010	0.870	4.970	5.550	1.150	1.100	0.890	4.410	2.370	8.440	1.160	2.200	35.120
1955	1.790	2.390	5.430	3.880	2.730	3.090	2.650	2.850	1.650	4.440	3.810	0.340	35.050
1956	1.440	4.620	3.850	4.140	5.510	4.580	5.300	5.190	3.070	0.790	0.970	2.350	41.810
1957	2.090	1.260	1.840	6.610	3.250	5.860	2.470	3.080	3.330	2.160	1.870	3.490	37.310
1958	2.810	1.080	1.110	3.770	3.610	4.360	9.200	3.950	3.050	0.950	3.560	0.750	38.200
1959	5.070	4.350	2.340	3.590	2.610	2.590	4.270	2.520	2.470	5.170	2.790	2.580	40.350
1960	2.490	2.460	1.140	0.680	4.310	3.720	3.480	3.480	0.270	1.240	1.300	1.220	25.790
1961	0.800	3.260	3.500	5.320	2.500	5.090	3.320	2.250	1.580	2.860	3.270	1.200	34.950
1962	2.600	2.270	2.400	1.120	1.910	2.150	3.960	0.790	2.610	2.940	2.420	1.520	26.690
1963	1.000	0.710	3.800	2.510	1.960	2.250	3.310	2.100	1.780	0.220	2.840	1.270	23.750
1964	2.200	1.310	6.240	6.670	2.510	3.560	6.920	3.490	0.740	1.760	1.360	4.100	40.860
1965	4.220	2.940	2.850	2.740	1.050	2.080	2.950	3.050	3.590	5.200	3.080	1.140	34.890
1966	3.310	1.630	1.450	3.460	1.880	1.710	1.380	3.690	1.760	1.640	5.180	1.770	28.860
1967	1.130	1.870	2.840	2.310	4.230	1.930	2.460	2.290	3.350	2.370	2.620	1.840	29.240
1968	3.450	0.590	2.640	2.430	4.940	2.170	1.090	4.520	3.020	3.210	3.620	3.050	34.730
1969	1.880	0.410	1.130	2.810	3.200	2.490	5.990	1.710	1.580	2.560	2.600	2.640	29.000

1970	1.150	1.580	2.100	2.830	4.990	5.190	6.150	0.690	3.130	4.040	2.910	2.690	37.450
1971	1.320	2.620	1.600	0.670	2.900	2.300	2.180	2.030	2.820	1.260	1.790	4.720	26.210
1972	1.180	1.760	3.510	5.330	2.320	3.830	4.520	1.090	5.760	0.770	3.780	2.930	36.780
1973	1.600	2.150	3.490	3.540	3.520	5.020	2.890	4.170	3.690	3.900	2.320	2.960	39.250
1974	3.080	1.140	4.330	2.400	4.930	3.640	2.550	7.170	3.430	1.270	2.640	3.190	39.770
1975	2.810	3.040	3.030	1.160	4.240	6.740	3.840	6.480	5.290	2.350	1.470	2.500	42.950
1976	3.000	3.080	2.870	0.950	1.330	3.840	4.130	2.760	6.160	2.110	0.340	1.330	31.900
1977	1.380	1.210	4.540	4.330	0.620	7.920	4.830	3.760	6.870	1.790	3.200	4.450	44.900
1978	3.230	0.140	1.670	2.740	4.420	4.740	2.680	3.450	2.270	4.860	1.210	3.740	35.150
1979	2.820	1.960	1.330	4.110	5.110	2.390	2.550	4.390	5.540	1.480	2.630	2.970	37.280
1980	1.360	1.040	4.070	2.120	3.200	3.450	6.740	5.330	3.510	2.170	1.580	1.320	35.890
1981	1.070	4.140	1.710	4.740	4.380	5.660	3.190	2.100	4.260	2.820	1.950	2.130	38.150
1982	4.030	1.680	3.060	0.640	3.790	4.910	2.000	1.440	3.150	0.520	4.980	2.500	32.700
1983	0.970	1.050	2.610	4.570	4.300	4.480	3.060	3.100	3.840	3.680	3.970	3.800	39.430
1984	1.070	2.270	2.740	3.030	6.140	3.030	4.100	5.960	2.370	2.670	3.850	3.760	40.990
1985	1.390	1.920	5.280	2.380	3.460	3.110	6.290	3.550	2.200	1.780	11.090	2.450	44.900
1986	1.040	2.510	1.180	1.600	3.860	7.020	5.190	2.080	5.880	3.860	2.660	1.400	38.280
1987	2.220	0.360	1.700	3.200	2.330	4.310	5.430	7.150	4.160	2.620	0.960	1.950	36.390
1988	0.900	1.010	1.360	1.430	2.490	1.130	6.320	3.810	2.620	2.820	3.040	1.010	27.940
1989	1.110	1.580	2.340	2.200	5.700	8.730	3.360	1.370	5.450	2.310	2.930		37.080
1990	1.460	4.010	0.770	3.120	3.910	3.170	8.150	2.670	4.850				32.110
1991		1.840	2.690	3.090	2.520	2.210	3.770	1.010	2.090	2.410	1.530	2.740	25.900
1992	1.790	1.660	4.300	3.660	1.950	1.140	10.140	5.060	4.270	2.230	4.000	3.320	43.520
1993	3.730	1.610	3.900	3.170	0.780	7.930	1.870	1.320	4.580	2.010	4.690	1.590	37.180
1994	3.390	1.530	3.250	5.040	1.980	4.550	2.660	3.920	2.990	1.220	3.320	2.710	36.560
1995	2.550	1.570	1.600	2.580	4.580	3.510	4.970	1.440	2.150	6.490	3.220	2.640	37.300
1996	2.680	1.590	1.290	4.810	4.700	5.480	2.540	3.040	6.510	3.730	3.310	4.360	44.040
1997	1.840	1.710	3.280	3.450	3.680	5.070	0.920	3.650	3.620	1.150	2.120	1.840	32.330
1998	3.840	1.050	2.560	6.730	1.230	4.310	2.660	3.010	1.770	3.450	1.740	1.950	34.300
1999	4.570	1.720	1.930	3.740	2.840	0.930	5.930	3.140	3.750	2.500	3.430	2.000	36.480
2000	2.060	1.780	1.680	4.760									10.280
	2.405	**1.911**	**2.786**	**3.282**	**3.406**	**3.767**	**3.980**	**3.247**	**3.155**	**2.577**	**2.700**	**2.249**	**35.466**

Source: NOAA

Table A-2. Mean Snowfall (1931-2000) for Meander Creek Reservoir (inches)

Year\ Month	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Total
1931	2.8	2.6	6.5	1.3	0.0	0.0	0.0	0.0	0.0	0.0	1.5	0.0	14.7
1932	T	2.0	3.0	0.3	0.0	0.0	0.0	0.0	0.0	0.0	T	5.0	10.3
1933	T	0.5	1.9	T	0.0	0.0	0.0	0.0	0.0	T	8.0	6.0	16.4
1934	3.2	8.9	4.7	1.0	0.0	0.0	0.0	0.0	0.0	1.0	0.9	3.0	22.7
1935	3.5	13.7	T	T	0.0	0.0	0.0	0.0	0.0	0.0	1.0	14.7	32.9
1936	9.2	9.0	15.3	T	0.0	0.0	0.0	0.0	0.0	0.0	2.5	7.0	43.0
1937	3.7	3.0	3.0	T	0.0	0.0	0.0		0.0	T	7.2	2.0	18.9
1938	7.4	0.5	T	4.2	0.0	0.0	0.0	0.0		0.0	3.0	1.6	16.7
1939	13.4	9.7	T	1.5		0.0	0.0	0.0	0.0	T	T	2.0	26.6
1940	9.3	15.6	9.8	2.8	T	0.0	0.0	0.0	0.0	T	4.5	3.4	45.4
1941	12.0	11.8	12.1	0.0		0.0	0.0	0.0			T	T	35.9
1942	5.4	3.4	8.0	T		0.0	0.0	0.0		T	5.0	17.7	39.5
1943	9.0	4.7	6.0	4.2		0.0	0.0	0.0		T	0.5	1.8	26.2
1944	2.0	9.2	7.5	1.5		0.0	0.0	0.0		0.0	0.5	22.6	43.3
1945	18.4	4.4	2.5	T	0.0	0.0	0.0	0.0	0.0	0.0	0.8	10.5	36.6
1946	3.2	2.8	T	T		0.0	0.0	0.0	0.0		0.0	3.5	9.5
1947	1.9	5.7	10.8		T	0.0	0.0	0.0		0.0	2.5	2.2	23.1
1948	15.0	5.7	5.5	T	0.0	0.0	0.0	0.0	0.0	0.0	T	2.4	28.6
1949	6.4	1.5	3.7	T	0.0	0.0	0.0	0.0	0.0	0.0	1.5	2.5	15.6
1950	1.5		5.0	1.8	0.0	0.0	0.0	0.0	0.0	0.0	29.0	12.7	50.0
1951	7.6	12.4	10.1	0.2	0.0	0.0	0.0	0.0	0.0	0.0	11.5	16.8	58.6
1952	5.5	4.9	8.2	1.4	0.0	0.0	0.0	0.0	0.0	1.0	1.5	4.0	26.5
1953	5.6	2.4	2.9	6.2	0.0	0.0	0.0	0.0	0.0	T	4.0	3.1	24.2
1954	5.1	7.8	5.3	T	T	T	T	0.0	0.0	T	0.3	10.2	28.7
1955	11.5	12.9	6.0	T	0.0	0.0	0.0	0.0	0.0	T	3.9	4.6	38.9
1956	8.6	8.2	13.6	0.3	0.0	0.0	0.0	0.0	0.0	0.0	1.5	12.0	44.2
1957	16.4	3.7	6.5	9.2	0.0	0.0	0.0	0.0	0.0	2.0	1.3	4.1	43.2
1958	7.8	8.9	5.0	0.5	0.0	0.0	0.0	0.0	0.0	0.0	9.0	9.8	41.0
1959	10.5	1.7	12.7	0.0	0.0	0.0	0.0	0.0	0.0	0.0	4.7	5.5	35.1
1960	6.0	21.3	22.6	0.7	0.0	0.0	0.0	0.0	0.0	0.2	1.5	18.2	70.5
1961	10.0	11.3	1.3	5.5	T	0.0	0.0	0.0	0.0	0.0	1.3	7.5	36.9
1962	5.6	13.1	18.4	1.9	0.0	0.0	0.0	0.0	0.0	2.7	T	10.3	52.0
1963	11.7	11.9	8.3	T	0.8	0.0	0.0	0.0	0.0	0.0	2.6	11.9	47.2
1964	18.8	12.1	4.0	0.4	0.0	0.0	0.0	0.0	0.0	0.0	1.0	7.4	43.7
1965	6.5	8.6	19.2	0.1	0.0	0.0	0.0	0.0	0.0	0.1	2.7	1.9	39.1
1966	19.3	6.2	5.8	1.7	3.0	0.0	0.0	0.0	0.0	0.0	3.5	5.9	45.4
1967	4.8	17.4	10.4	3.0	T	0.0	0.0	0.0	0.0	0.0	10.2	2.6	48.4
1968	15.3	7.4	7.0	T	0.0	0.0	0.0	0.0	0.0	T	3.5	11.5	44.7
1969	2.2	6.0	2.9	0.0	0.0	0.0	0.0	0.0	0.0	1.5	2.1	17.1	31.8

1970	12.6	9.2	6.5	0.5	0.0	0.0	0.0	0.0	0.0	T	1.0	6.6	36.4
1971	6.4	15.3	20.1	0.7	0.0	0.0	0.0	0.0	0.0	0.0	6.7	3.0	52.2
1972	6.3	12.6	4.7	0.4	0.0	0.0	0.0	0.0	0.0	T	0.8	4.7	29.5
1973	1.9	4.2	16.0	1.0	0.0	0.0	0.0	0.0	0.0	0.0	2.5	4.8	30.4
1974	7.9	5.7	5.0		0.0	0.0	0.0	0.0	0.0	0.1	0.3	20.7	39.7
1975	1.8	5.4	8.1	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.6	8.1	24.0
1976	24.8	5.5	4.4	1.2	0.0	0.0	0.0	0.0	0.0	0.0	0.8		36.7
1977	13.9	8.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	5.5	18.1	45.5
1978	31.7	2.5	1.1	0.0	0.0	0.0	0.0	0.0	0.0	0.0	1.0	7.3	43.6
1979	14.6		4.3	T	0.0	0.0	0.0	0.0	0.0	0.0	1.0	4.0	23.9
1980	7.8	10.8	8.5	0.0	0.0	0.0	0.0	0.0	0.0	0.0		6.0	33.1
1981	12.9	12.5	3.3	0.0	0.0	0.0	0.0	0.0	0.0	0.0		12.0	40.7
1982	6.0	2.7	11.5	4.0	0.0	0.0	0.0	0.0	0.0	0.0	0.4	11.8	36.4
1983	0.1	6.5	9.2	0.1	0.0	0.0	0.0	0.0	0.0	0.0	0.0	4.6	20.5
1984	14.2	17.5	18.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	6.0	8.5	64.2
1985	21.5	19.0	0.5	6.5	0.0	0.0	0.0	0.0	0.0	0.0	0.0	7.6	55.1
1986	7.0	5.0	6.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	9.8	4.5	32.3
1987	16.1	2.5	15.0	12.0	0.0	0.0	0.0	0.0	0.0	0.0	3.5	21.7	70.8
1988	5.8	6.9	13.0	0.5	0.0	0.0	0.0	0.0	0.0	0.0	0.9	9.3	36.4
1989	3.5	3.8	11.3	2.3	T	0.0	0.0	0.0	0.0	0.2	1.8		22.9
1990	0.0		0.8	0.0	0.0	0.0	0.0	0.0	0.0	1.9			2.7
1991		0.6	0.0	0.0	0.0	0.0	0.0	0.0	0.0		0.3	1.3	2.2
1992	2.6	0.0	11.9	0.5	0.0	0.0	0.0	0.0	0.0	0.0	0.6	10.8	26.4
1993	1.2	9.2	15.9	1.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0		27.3
1994	17.4	11.0	2.9	0.2	0.0	0.0	0.0	0.0	0.0	0.0	1.5	0.0	33.0
1995		6.0	5.5	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	19.0	30.5
1996	16.4	5.1	1.6	1.0	0.0	0.0	0.0	0.0	0.0	0.0	T	1.9	26.0
1997	2.0	4.8	T	T	0.0	0.0	0.0	0.0	0.0	0.0	4.1	4.4	15.3
1998	2.1	0.0	2.8	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	4.9
1999	16.3	0.5	5.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	2.6	24.4
2000	3.0	5.5	1.5	0.0									10.0
	9.9	**7.9**	**8.0**	**1.6**	**0.1**	**T**	**T**	**0.0**	**0.0**	**0.2**	**3.2**	**8.3**	**39.2**

Source: NOAA

Table A-3. Statewide Water Quality Criteria for the Protection of Aquatic Life of Warmwater Habitats

Chemical	Form[1]	Units[2]	IMZM[3]	OMZM[3]	OMZA[3]
Ammonia - N	T	mg/l	--	Table 3	Table 4
Arsenic	D[5]	µg/l	680	340	150
Arsenic	TR[6]	µg/l	680	340	150
Chlorine	R	µg/l	--	19	11
Chromium VI	D	µg/l	31	16	11
Cyanide	free	µg/l	92	46	12
Dieldrin	T	µg/l	0.47	0.24	0.056
Dissolved Oxygen[4]	T	mg/l	--	4	5
Dissolved Solids	T	mg/l	--	--	1500[a]
Endrin	T	µg/l	0.17	0.086	0.036
Lindane	T	µg/l	1.9	0.95	--
Mercury	D[5]	µg/l	2.9	1.4	0.77
Mercury	TR[6]	µg/l	3.4	1.7	0.91
Parathion	T	µg/l	0.13	0.065	0.013
pH		s.u.			6.5-9.0
Selenium	D[5]	µg/l	--	--	4.6
Selenium	TR[6]	µg/l	--	--	5

[1] D = dissolved; R = total residual; T = total; TR = total recoverable

[2] mg/l = milligrams per liter (parts per million); µg/l = micrograms per liter (parts per billion); s.u. = standard units

[3] IMZM = inside mixing zone maximum; OMZM = outside mixing zone maximum;
OMZA = outside mixing zone average

[4] For dissolved oxygen, OMZM means outside mixing zone minimum and OMZA
means outside mixing zone minimum twenty four hour average

[5] These criteria are implemented by multiplying them by a translator approved by the
director pursuant to rule 3745-2-04 of the administrative Code

[6] These criteria apply in the absence of a translator approved by the director pursuant to rule 3745-2-04 of the administrative Code

[a] Equivalent 25 °C specific conductance value is 2400 micromhos/cm

Source: Ohio EPA

Table A-4. Statewide water quality criteria for the protection of aquatic life for water pH dependent criteria

Chemical	Form	Units	pH 7.5	pH 8.0	pH 9.0
Pentachlorophenol					
IMZM	T	µg/l	29	48	130
OMZM	T	µg/l	14	24	65
OMZA	T	µg/l	11	18	50

Source: Ohio EPA

Table A-5. Public water supply statewide water quality criteria for the protection of human health

Chemical	Form	Units	OMZA Drinking
Arsenic	TR	µg/l	50
Chlorides	TR	mg/l	250
Dissolved Solids	TR	mg/l	750/500
Iron	S	µg/l	300
Manganese	TR	µg/l	50
Nitrate - N	T	mg/l	10
Sulfates	T	mg/l	250
Zinc	TR	µg/l	5000

Source: Ohio EPA

Table A-6. Statewide water quality criteria for the protection of aquatic life for water hardness dependent criteria

Chemical	Form	Units	Hardness = 200 mg/l $CaCO_3$
Cadmium			
IMZM	D	µg/l	19
OMZM	D	µg/l	9.3
OMZA	D	µg/l	3.9
Cadmium			
IMZM	TR	µg/l	20
OMZM	TR	µg/l	9.9
OMZA	TR	µg/l	4.2
Chromium			
IMZM	D	µg/l	2000
OMZM	D	µg/l	1000
OMZA	D	µg/l	130
Chromium		µg/l	
IMZM	TR	µg/l	6400
OMZM	TR	µg/l	3200
OMZA	TR	µg/l	150
Copper		µg/l	
IMZM	D	µg/l	52
OMZM	D	µg/l	26
OMZA	D	µg/l	16
Copper		µg/l	
IMZM	TR	µg/l	54
OMZM	TR	µg/l	27
OMZA	TR	µg/l	17
Lead		µg/l	
IMZM	D	µg/l	470
OMZM	D	µg/l	230
OMZA	D	µg/l	12
Lead		µg/l	
IMZM	TR	µg/l	590
OMZM	TR	µg/l	300
OMZA	TR	µg/l	16
Nickel		µg/l	
IMZM	D	µg/l	1700
OMZM	D	µg/l	840
OMZA	D	µg/l	93
Nickel		µg/l	
IMZM	TR	µg/l	1700

OMZM	TR	µg/l	840
OMZA	TR	µg/l	94
Zinc		µg/l	
IMZM	D	µg/l	420
OMZM	D	µg/l	210
OMZA	D	µg/l	210
Zinc		µg/l	
IMZM	TR	µg/l	430
OMZM	TR	µg/l	220
OMZA	TR	µg/l	220

Source: Ohio EPA

Table A-7. Warmwater Habitat OMZM total ammonia-nitrogen criteria (mg/l)

pH	7.7	7.8	7.9	8.0	8.1	8.2	8.3	8.4	8.5	8.6
Temp. (°C)										
19	13.0	12.7	10.8	9.1	7.3	5.8	4.7	3.8	3.1	2.5
20	13.0	12.7	10.7	9.1	7.3	5.8	4.7	3.8	3.1	2.5
21	13.0	12.6	10.7	9.1	7.3	5.8	4.7	3.8	3.1	2.6
22	13.0	12.6	10.7	9.0	7.3	5.9	4.7	3.8	3.1	2.6
23	13.0	12.6	10.7	9.1	7.3	5.9	4.7	3.9	3.2	2.6
24	13.0	12.6	10.7	9.1	7.3	5.9	4.8	3.9	3.2	2.6
25	13.0	12.6	10.7	9.1	7.3	5.9	4.8	3.9	3.2	2.6

Source: Ohio EPA

Table A-8. Warmwater Habitat OMZA total ammonia-nitrogen criteria (mg/l)

pH	7.7	7.8	7.9	8.0	8.1	8.2	8.3	8.4	8.5	8.6
Temp. (°C)	Apply during the months of Mar. to Nov.									
19	2.2	1.9	1.6	1.4	1.1	0.9	0.7	0.6	0.5	0.4
20	2.2	1.9	1.6	1.4	1.1	0.9	0.7	0.6	0.5	0.4
21	2.1	1.8	1.5	1.3	1.0	0.8	0.7	0.5	0.4	0.4
22	1.9	1.6	1.4	1.2	0.9	0.8	0.6	0.5	0.4	0.3
23	1.8	1.5	1.3	1.1	0.9	0.7	0.6	0.5	0.4	0.3
24	1.7	1.4	1.2	1.0	0.8	0.7	0.5	0.4	0.4	0.3
25	1.6	1.3	1.1	1.0	0.8	0.6	0.5	0.4	0.3	0.3

Source: Ohio EPA

Table A-9. Export Factors for the United States

Land use	TP (lb/mi^2/yr)
Forest > 90%	52
Forest > 75%	74
Forest > 50%	95
Agriculture > 90%	152
Agriculture > 75%	146
Agriculture > 50%	121

Source: Panuska & Lillie (1995)

Table A-10. Export Factors for Unknown Areas

Land Use	TN (kg/ha/yr)	TP (kg/ha/yr)
Urban		
Developed	7.5	1.06
Residential	6	0.4
Residential	6.7	0.96
Residential	8.4	1.3
Commercial	22.4	3.4
Developing	11.9	46.9
Urban	5	1.12
Urban	5.6-28	0.56-3.36
Other		
Agriculture	14	0.94
Agriculture	9.8	0.99
Pasture	6	0.82
Pasture	2.9	0.5
Forest-Wetland	2.33	0.13
Forest	2.5	0.23
Atmospheric	12.4	0.65

Source: Line et al. (2002)

Table A-11. Major Water-Resource Regions of the Conterminous United States

Region	TN (kg/ha/yr)	TP (kg/ha/yr)
Northeast	6.7	0.41
Mid Atlantic	9.0	0.68
Southeast Atlantic-Gulf	5.9	0.54
Great Lakes	8.0	0.49
Ohio	11.0	0.93
Tennessee	8.3	0.67
Upper Mississippi	13.0	1.1
Lower Mississippi	7.6	0.53
Red Rainy	3.5	0.22
Missouri	2.1	0.19
Ark-Red	3.9	0.36
Texas-Gulf	3.7	0.38
Rio Grande	1.0	0.12
Upper Colorado	1.9	0.14
Lower Colorado	0.7	0.10
Great Basin	0.9	0.09
Pacific Northwest	4.2	0.30
California	4.8	0.41
United States	4.7	0.37

Source: Smith & Alexander (2002)