TMDL Development for Hurricane Lake, Putnam County, West Virginia

U.S. Environmental Protection Agency
Region 3
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Philadelphia, PA 19103

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The objective of this study was to identify the background information and framework needed for developing TMDLs for siltation, nutrients, and iron for Hurricane Lake. The West Virginia Division of Environmental Protection (WVDEP) has identified the Hurricane water supply reservoir (designated code K(L)-22-(1)) as being impacted by these pollutants, as reported in the 1998 303(d) list of water-quality-affected limited waters (WVDEP 1998). WVDEP has determined that the uses affected include human health (by iron) and aquatic life (affected by nutrients, siltation, and iron).

The applicable state standards for iron include a 1.5 mg/L chronic (4-day averaging period) aquatic life criterion and a 1.5 mg/L acute human health criterion. Nutrients and siltation have no specific numeric water quality criteria; however, elevated inputs of nutrients and sediment have been demonstrated to cause impairment of the water supply and recreational uses of the lake. In the case where no numeric criteria are available, an evaluation is made of alternative numeric targets that can be used for development of an acceptable loading. For nutrients a numeric value was selected based on the trophic state. The measure selected for trophic state was a chlorophyll *a* concentration of less than 15 µg/L (based on summer mean values). For the development of a TMDL for siltation for Hurricane Lake, the endpoint chosen was the average accumulation rate of sediment on the reservoir bottom.

To evaluate the relationship between the sources, their loading characteristics, and the resulting conditions in the lake, a combination of analysis tools were used. Assessments of the nonpoint source loading into the lake were developed for the Hurricane Lake watershed using the Hydrologic Simulation Program-FORTRAN (Version 11) (Bicknell et al. 1996). The watershed was divided into six land use categories and five subwatersheds. The lake was evaluated using a water quality simulation model. The Environmental Fluid Dynamics Code (EFDC) was used to simulate the lake as a two-dimensional system (Hamrick 1996; Hamrick and Wu 1996). The lake was segmented into multiple cells and two layers to better represent the system. The lake model was used to evaluate iron, nutrients and chlorophyll *a*, and siltation. The results of the watershed and reservoir models were compared with literature values, previous studies, and reservoir conditions to evaluate their performance.

Total Maximum Daily Loads (TMDLs) are composed of the sum of individual waste load allocations (WLAs) for point sources, load allocations (LAs) for nonpoint sources, and natural background levels. The analysis was used to identify the appropriate load allocations to meet the in-lake numeric target identified. The representative hydrologic simulation year used for testing and development of the TMDL was 1993. The resulting load allocations from nonpoint sources for the three listed pollutants included a 30% reduction of iron, 45% reduction of nutrients (expressed as total phosphorus), and 30% reduction of sediment load. It was assumed that the lake would be dredged, in keeping with previous recommendations of the Hurricane Lake Clean Lakes study (Shaw Weiss & De Naples 1993). The loads are described as average annual load reductions, which is typically appropriate for reservoirs and

impoundments. The margin of safety was addressed through a series of conservative assumptions in the development of the TMDL analysis. The load reductions can be achieved through a combination of land use and restoration practices such as agricultural best management practices, erosion and sediment control practices, nutrient management programs, and forest management and stream restoration.

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1.0 INTRODUCTION

1.1 Background

Section 303(d) of the Clean Water Act and EPA's Water Quality Planning and Management Regulations (40 CFR Part 130) require states to develop Total Maximum Daily Loads (TMDLs) for waterbodies that are not meeting designated uses under technology-based controls. The TMDL process establishes the allowable loadings of pollutants or other quantifiable parameters for a waterbody based on the relationship between pollution sources and in-stream or in-lake water quality conditions. By following the TMDL process, states can establish water-quality-based controls to reduce pollution from both point and nonpoint sources and restore and maintain the quality of their water resources (USEPA 1991).

The Hurricane Lake watershed is located in Putnam County, West Virginia, approximately 20 miles to the west-northwest of Charleston. The lake's watershed is located within the Lower Kanawha hydrologic cataloging unit (05050008) (Figure 1.1). The land area of the watershed is approximately 3,415 acres. Runoff from the watershed flows into Hurricane Lake from three main tributaries—Mill Creek, Cow Creek II, and McCalister Creek. Mill Creek flows into Hurricane Lake on the eastern side of the lake; Cow Creek II and McCalister Creek come to a confluence a relatively short distance above the lake's northeast side, with the combined stream flowing south into the lake. Discharge from the lake continues in Mill Creek, eventually flowing to Hurricane Creek and then to the Kanawha River.

Hurricane Lake was originally impounded for water supply for the city of Hurricane in 1947. In 1966, the existing impoundment structure was constructed and more area was excavated to increase the reservoir area from 3.39 acres to 12.98 acres. The city of Hurricane water treatment plant, located on the western shore of the lake, withdraws on average approximately 715,000 gallons per day (gpd) of water from the lake. Minimum withdrawal during the winter averages approximately 650,000 gpd, while summer maximum withdrawal averages approximately 750,000 gpd (T. Stowers, personal communication 1998). The lake is also used for recreational activities such as fishing and boating. The West Virginia Department of Natural Resources reportedly stocks rainbow and golden trout annually on a seasonal basis (Shaw Weiss & De Naples 1993). An 8-acre city park is located on the western side of the lake, which is used for recreation.

The primary land uses in the watershed are forest, agricultural land (hay/pasture, row crops), and relatively localized areas of urban development. The watershed has experienced significant population growth during the last 15 years, causing an increase in the amount of residential and commercial areas (Shaw Weiss & De Naples 1993). Despite the reported population increase, the watershed remains primarily rural since forest and agricultural land uses represent a majority of the watershed area.

1.2 Purpose of the Study

The objective of this study was to identify the background information and framework needed for developing TMDLs for siltation, nutrients, and iron for Hurricane Lake. The West Virginia Division of Environmental Protection (WVDEP) has identified the Hurricane water supply reservoir (designated

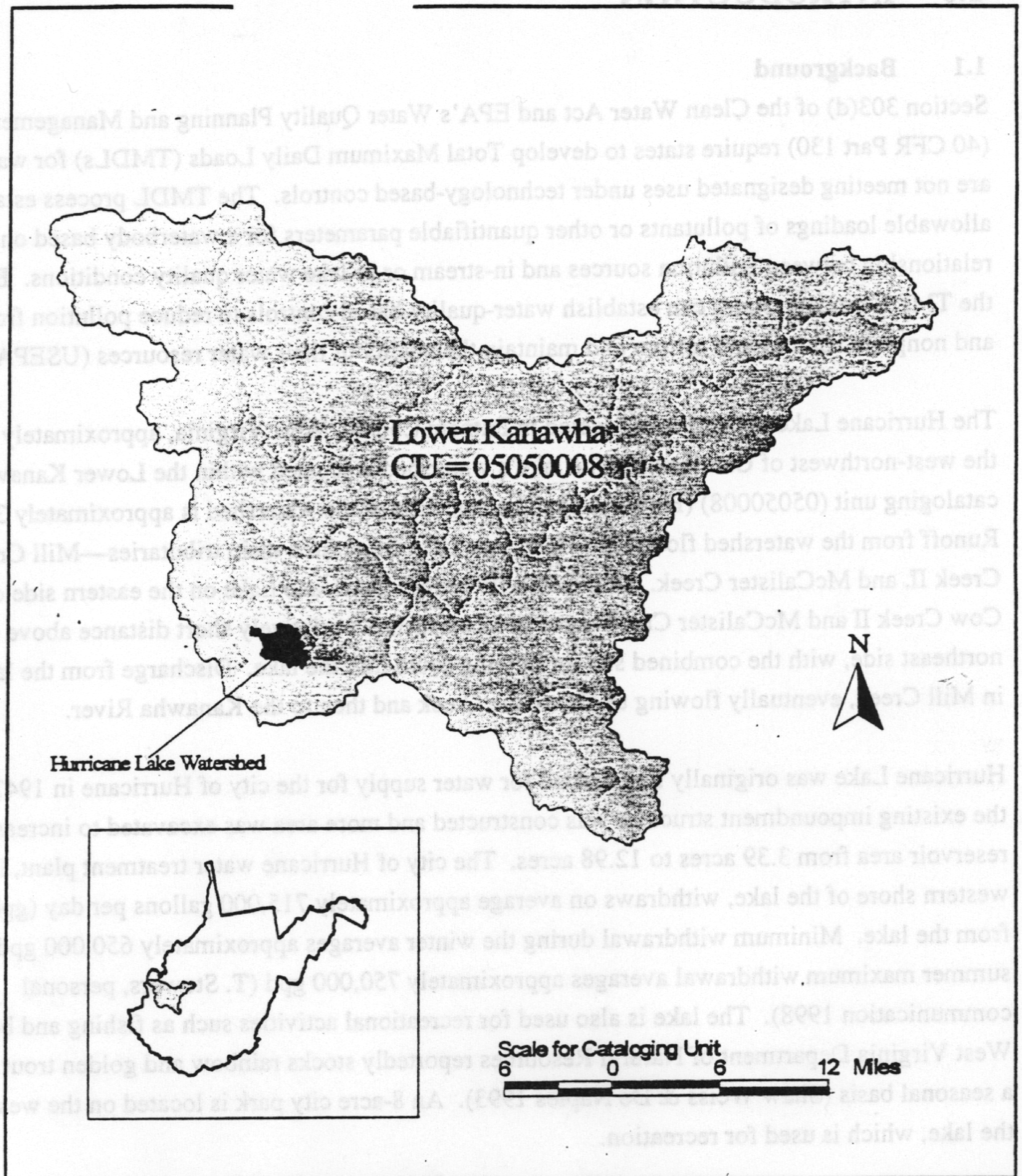

Figure 1.1. Location of Hurricane Lake watershed.

code K(L)-22-(1)) as being impacted by these pollutants, as reported in the 1998 303(d) list of water-quality-limited waters (WVDEP 1998). WVDEP has determined that the uses affected include human health (affected by iron) and aquatic life (affected by nutrients, siltation, and iron).

1.3 Selection of TMDL Endpoints

One of the major components of a TMDL is the establishment of in-lake endpoints, which are used to evaluate the attainment of acceptable water quality. In-lake endpoints, therefore, represent the water quality goals that are to be achieved by implementing the load reductions specified in the TMDL. The endpoints allow for a comparison between predicted in-lake conditions and conditions that are expected to restore beneficial uses; the endpoints are usually based on either the narrative or numeric criteria available in state water quality standards. When no established narrative or numeric criteria exist, other criteria must be used. Endpoints for each of the listed pollutants for Hurricane Lake are discussed below.

1.3.1 Iron

For the designated contaminants for Hurricane Lake, only iron has an established state water quality standard. Excessive iron concentrations can pose toxicological concerns to both human health (if the water is used for potable purposes) and aquatic life. Because the lake is used as a water supply reservoir, it is classified as a Category A water (Water Supply, Public), and the applicable human health criterion is 1.5 mg/L (not to exceed) (WV Code 46CSR1). The lake is also designated as a B1 Category water (Warm Water Fishery); therefore, the applicable aquatic life criterion is 1.5 mg/L (4-day average concentration) (WV Code 46CSR1).

1.3.2 Nutrients

With regard to nutrients, nitrogen and phosphorus (in the forms of total nitrogen [TN] and total phosphorus [TP]) were selected as the nutrient endpoints. An increase of loading of these nutrients into lakes can detrimentally affect designated uses. Loadings of nutrients (primarily phosphorus for lakes) can cause impairments due to their role in accelerating the eutrophication process, the nutrient enrichment of aquatic systems that results in the aging of a lake to a swamp. Phosphorus and nitrogen are essential nutrients for the growth of plants in lakes, and increased loadings resulting from human influences can result in an undesirable abundance of plant growth, particularly phytoplankton, periphyton, and macrophytes. Eutrophication can impair the designated uses of waterbodies as follows:

- Eutrophication can cause the depletion of oxygen and/or the production of un-ionized ammonia, which can adversely affect both aquatic life and fisheries.

- Excessive algal growth can cause operational problems for water treatment plants, can result in finished water containing potentially carcinogenic disinfection by-products such as triholomethanes, and may result in taste and odor problems in finished drinking water.

- Excessive plant growth can cause disruption to recreational activities such as swimming, boating, and fishing. Additionally, excessive plant growth can also negatively affect the aesthetic appeal of a waterbody.

Elevated nutrient concentrations can also represent other concerns not specifically associated with eutrophication. For example, drinking water supplies can be impaired by nitrogen when nitrate concentrations exceed 10 mg/L and cause methemoglobinemia in infants (USEPA 1998a).

Chlorophyll *a*, the major photosynthetic pigment in plants (both algae and macrophytes), is often used as an estimator of algal biomass (Carlson 1980; Chapra 1997; Watson et. al. 1992) and is a good surrogate measure for nutrients because algae are either the direct or indirect cause of most problems related to excessive nutrient enrichment (USEPA 1998a). Because the relationship between chlorophyll *a* concentrations and nutrients (primarily phosphorus) is well established, chlorophyll *a* concentrations (i.e., seasonal mean and instantaneous measure) can be used to predict nutrient levels resulting in impaired or nonimpaired conditions. Several states, such as Oregon and North Carolina, have adopted chlorophyll *a* concentrations as a criterion for lake quality (USEPA 1998a). In general, published desirable endpoints for chlorophyll *a* for lakes range from approximately 10 µg/L to 25 µg/L (USEPA 1998a; NALMS 1992). WVDEP has not established specific narrative or numeric water quality criteria for nutrient-related impairments. In the absence of a numeric criterion, a surrogate endpoint of 15.0 µg/L chlorophyll *a* was chosen for development of the nutrient TMDL for Hurricane Lake. This value is consistent with published criteria for chlorophyll *a* and represents a relatively conservative value. The chlorophyll *a* endpoint will be used to define the acceptable nutrient load that can be introduced into the lake. Based on previous evaluation of Hurricane Lake data, and typical characteristics of lakes in the West Virginia area, it is likely phosphorus is the limiting nutrient.

1.3.3 Siltation

The West Virginia water quality standards do not include numeric criteria for siltation. Excessive inputs of sediment to a lake can significantly impair the lake's aquatic life designated use. For example, sediment deposition on a lake bottom can deplete fish food sources. The fish habitat is also impaired due to the need for dredging and the lack of deepwater habitat for winter ice-over. Additionally, high concentrations of suspended sediment can cause physical harm to aquatic organisms and can alter feeding patterns. Excessive sediments can alter taste and odor of drinking water supplies and cause physical complications and increased processing costs for water treatment plants. Increased sedimentation of a drinking water reservoir can significantly reduce the planned lifespan of the reservoir. High levels of sediment can impair recreational activities such as swimming and boating by altering shorelines and reducing visibility in the water column. If fish habitat and physical conditions amenable to fish populations are impaired, recreational fishing can suffer from a decline in fish populations or from a change in the makeup of fish species present in the lake.

For the development of a TMDL for siltation for Hurricane Lake, the endpoint chosen is based on the evaluation of the average accumulation rate of sediment on the reservoir bottom. Reductions in sediment load may also result in changes in the algal growth dynamics and algal species, reductions of in-lake turbidity, and reductions of suspended sediment concentrations.

2.0 SOURCE ASSESSMENT

This section presents an overview of the in-lake and in-stream water quality monitoring data available for Hurricane Lake and its inflows and then discusses the type, magnitude, and location of potential point and nonpoint sources of pollutant loading. A "Clean Lakes" study on Hurricane Lake and its watershed, prepared in 1993, provides an assessment of the water quality problems associated with the lake and the potential sources within the lake's watershed that are causing impairment to the lake water quality (Shaw Weiss & De Naples 1993). According to the Clean Lakes study, the major impact on the lake is caused by sedimentation and turbidity that result from high sediment inputs entering from the three main tributaries. The main sources of sediment were identified as being primarily construction sites that were not using erosion control measures. Expansion of residential areas in the Cow Creek II and McCalister - run subwatersheds over a 10-year period prior to the study was noted by the Clean Lakes report to be a significant factor exacerbating the deterioration of lake quality.

2.1 Water Quality Monitoring Data

Limited water quality monitoring activities have been conducted for Hurricane Lake and its inflows. Water quality data reviewed as part of this report were collected as indicated below:

- Approximately monthly sampling of Hurricane Lake and the inflows Cow Creek II and Mill Creek during the course of the Clean Lakes Study August 1991 to July 1992 (a total of 16 sampling events).

- WVDEP seasonal sampling of Hurricane Lake and one (unnamed) inflow from spring 1993 through fall 1994 (total of five sampling events) and sampling of the lake and two inflows in April and May 1998 (four sampling dates). The WVDEP data are provided in the appendix.

- U.S. Geological Survey (USGS) sampling of Mill Creek (Station No. 382631081585701) between October 1993 and September 1994 (a total of 11 sampling events).

The Clean Lakes Study (Shaw Weiss & De Naples, 1993) evaluated in-lake sampling data and reached the following conclusions:

- The lake is phosphorus-limited with an N:P ratio of 17:1.

- There were no violations of water quality criteria although Dissolved Oxygen (DO) values in the hypolimnium were periodically less than 5.0 mg/L.

- Chlorophyll *a* values ranged from 0.002 µg/L to 30 µg/L, with a summer average value of 18.14 µg/L.

- High sedimentation rates are expected to be the cause of excessive siltation in the reservoir and resulting impairment of beneficial uses.

Examination of more recently collected in-lake monitoring data (1993-94 and 1998), summarized in Table 2.1, results in the following observations:

- Periodic exceedances of the total iron criterion (1.5 mg/L - chronic) in both surface and bottom water column sampling.

- Continued high chlorophyll *a* and total phosphorus concentrations indicative of eutrophic conditions.

- Continued high suspended sediment concentrations.

Table 2.1. Summary of WVDEP sampling observations of selected pollutants, Hurricane Lake, 1993-94, 1998.

Pollutant Type	Pollutant	Units	Criteria	Sample Type[a]	Total Obs	Minimum	Maximum	Mean	No. Exceedance	Percent Exceedance
Metal	Iron	mg/L	1.5	Surface	7	0.81	3.40	1.80	4	57.T
		mg/L	1.5	Bottom	5	1.80	4.40	2.62	5	100.0
Nutrient	TKN	mg/L		Surface	7	0.50	1.50	0.81		
		mg/L		Bottom	5	0.48	1.18	0.78		
	NO2-NO3-N	mg/L	10	Surface	7	ND[c]	0.40	0.14	0	0.0
		mg/L	10	Bottom	5	ND[c]	0.34	0.11	0	0.0
	TP	mg/L	0.02[b]	Surface	5	0.0260	0.1030	0.0580	5	100.0
		mg/L	0.02[b]	Bottom	4	0.0410	0.1240	0.0710	4	100.0
		mg/kg		Sediment	2	45.5	93.6	69.6		
	Chlorophyll a	µg/L	15[b]	Surface	5	9.49	40.26	27.90	4	80.0
		µg/L	15[b]	Surface, Summer	2	35.02	40.26	37.64	2	100.0
Siltation	Suspended Solids	mg/L		Surface	7	15	90	40		
		mg/L		Bottom	4	36	72	54		
	Turbidity	NTU		Surface	2	40.4	63.4	51.9		
		NTU		Bottom	1	66.0	66.0	66.0		

[a] Water sample from 1993-94 and 1998 unless noted otherwise.
[b] Eutrophic condition threshold
[c] non-detect, assigned a value of zero for purposes of calculating the mean value of observations

2.2 Assessment of Point Sources

A review of the Permit Compliance System (PCS) database indicates one point source discharger in the watershed, the Hurricane water treatment plant. The water treatment plant is listed as having a National Pollutant Discharge Elimination System (NPDES) permit (No. WV0110167); however, no effluent data are contained in the permit and no specific information about the permit is available from PCS. The Clean Lakes report identified no point source dischargers in the watershed (Shaw Weiss & De Naples 1993). For purposes of this TMDL development, no point sources were included in the analysis.

2.3 Assessment of Nonpoint Sources

Nonpoint sources of pollutants within the watershed can generally be associated with the different types of land uses in the watershed. For example, sediment and nutrient loadings can originate from runoff and erosion from agricultural land uses (i.e., row crops, pasture, and animal operations), and expansion of residential and commercial/industrial areas can cause an increase in storm water flows and metals loading from impervious areas and an increase in sediment loads through the wash-off and erosion of sediment from construction sites. High rates of sediment loading can potentially also mean increased phosphorus and iron loads since these pollutants can readily be adsorbed onto soil particles.

To characterize flows and pollutant loadings from different parts of the Hurricane Lake watershed, the watershed was divided into five subwatersheds (Figure 2.1). Four of the five subwatersheds represent individual stream reaches, while the fifth subwatershed includes Hurricane Lake and the area that drains directly to it. The subwatersheds and their associated areas are listed in Table 2.2.

Land use for the Hurricane Lake subwatersheds was identified using the Federal Region 3 Land Cover Data Set (USGS 1998). This land cover data set was developed from Multiresolution Land Use Classification (MRLC) Landsat thematic mapper (TM) data sets acquired in 1991, 1992, and 1993. The

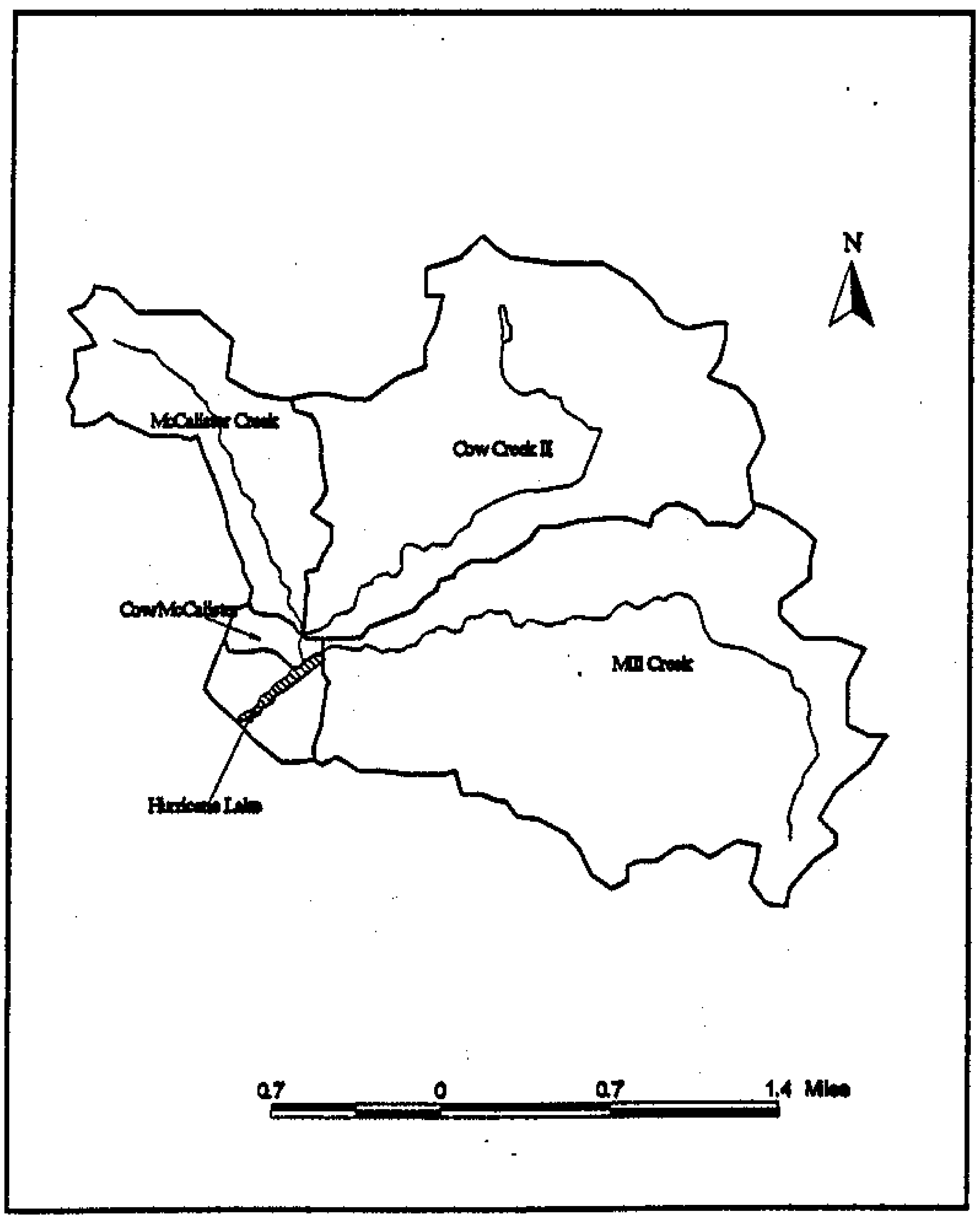

Figure 2.1. Hurricane Lake watershed and subwatersheds.

pixel size of the TM data is 30 X 30 meters. The MRLC data set contains 15 separate land use classes. The analysis of land use classification for the Hurricane Lake watershed identified the presence of 11 of the MRLC land use classes, not including the "water" class. For purposes of the source assessment and the subsequent modeling of runoff and pollutant loadings from each land use in the subwatersheds, the MRLC land use classes were aggregated into land use classes designated for this TMDL study. Table 2.3 shows the how the MRLC land uses were consolidated and also indicates the breakdown of certain land use classes into pervious and impervious components.

A breakdown of land uses by subwatershed is provided in Table 2.4. A review of the land use information shows that the watershed is composed mainly of forest (52%) and pasture (27%). Cropland (6%) and built-up areas including residential and commercial/industrial (14%) land uses represent relatively smaller areas in the watershed.

Table 2.2. Hurricane Lake subwatersheds and associated areas.

Subwatershed Number[a]	Reach Name	Total Area (acres)
15	Hurricane Lake	110.09
16	Mill Creek	1617.21
17	Combined Cow Creek and McCalister Creek	38.01
18	Cow Creek II	1213.81
19	McCalister Creek	436.30
Total	-	3415.42

[a] Subwatershed numbers are arbitrary; assigned during model setup.

Table 2.3. Hurricane Lake watershed land use class groupings.

TMDL Land Use Classes	Pervious/Impervious (Percentage)	MRLC Land Use Class (Class No.)
Residential	Pervious (50%) Impervious (50%)	Low-Intensity Developed (21) High-Intensity Residential (22)
Commercial and Industrial	Pervious (30%) Impervious (70%)	High-Intensity Commercial/Industrial (23)
Forest	Pervious (100%)	Deciduous Forest (41) Evergreen Forest (42) Mixed Forest (43)
Cropland/Pasture	Pervious (100%)	Row Crop (82) Hay and Pasture (81)
Barren	Pervious (100%)	Transitional Barren (33)
Other (Assigned as Forest)	Pervious (100%)	Woody Wetland (91) Emergent Herbaceous Wetland (92)

Table 2.4. Hurricane Lake watershed land use distribution by subwatershed (acres).

	Hurricane Lake	Mill Creek	Cow Creek II	McCalister Run	Cow/ McCalister	Totals
Residential	22.91	118.98	224.39	53.60	20.90	**440.78**
Commercial/ Industrial	4.67	8.00	10.90	2.67	4.00	**30.24**
Forest	47.82	1,150.64	334.48	249.52	5.78	**1,788.24**
Cropland	1.33	45.37	148.78	14.46	1.11	**211.05**
Pasture	22.46	289.33	489.70	114.09	6.00	**921.58**
Barren	0	0.22	0	0	0	**0.22**
Other	0	0.89	0	0	0	**0.89**
Water	10.90	3.78	5.56	1.96	0.22	**22.42**
Totals	**110.09**	**1617.21**	**1,213.81**	**436.30**	**38.01**	**3,415.42**

The potential contribution of nutrients from failing septic systems was assessed for the Hurricane Lake watershed. No local information was readily available on the specific locations of septic systems, septic tank densities, or failure rates. Data associated with the number of reported septic systems present in Putnam County were obtained from 1990 U.S. Census data. Based on an evaluation of the total area of the Hurricane Lake watershed in comparison to Putnam County, the estimated number of septic systems in the watershed was estimated at 93. A septic system failure rate of 2.5% was assumed (NSFC 1993), resulting in an estimate of 2.3 failing septic systems in the watershed. The assumed septic system waste flow rate was based on a typical value of 70 gallons per capita per day (Horsely & Whitten 1996) with an assumed 2.5 persons per household served based on 1990 census data. All residences were assumed to be full-time (year-round) occupancy.

2.4 Critical Conditions

To develop a TMDL, it is necessary to consider a range of flow conditions to represent the pollutant loading phenomenon occurring within the watershed. During storm events, runoff from urban and agricultural land uses cause loadings of metals, nutrients, and sediment to be delivered to the lake. Storm events may also temporarily elevate concentrations of metals. During dry periods, little or no land-based runoff occurs, and continued nutrient inputs (i.e., dissolved nitrogen and phosphorus) might be due to groundwater (baseflow inflows). During dry periods in-lake processes might also result in releases of phosphorus from bottom sediments.

For Hurricane Lake, the critical conditions were evaluated depending on the pollutant type and the designated use impact under evaluation. In most cases there are insufficient observed data available to evaluate the relationship between inflow and in-lake conditions. The following critical conditions were identified for Hurricane Lake:

- *Iron.* Violations of the human health criterion (1.5 mg/L acute) and aquatic life criterion (1.5 mg/L chronic) occur during both low flow conditions and time-varying conditions (e.g., immediately following a runoff event).

- *Nutrients.* Nutrients are contributing factors to the eutrophic conditions observed in the reservoir. The eutrophication processes (and the resulting chlorophyll *a* concentrations) are a function of the persistent nutrient loading to the reservoir. Eutrophic conditions (measured as chlorophyll *a*) are manifested during the spring and summer periods. Critical nutrient inputs and subsequent load reductions should be expressed as average annual loads to reduce the availability of nutrients.

- *Siltation.* Sediment inputs result in long-term accumulation of sediment. Sediment inputs are also related to increased turbidity in the reservoir. The relevant critical condition is the long-term average loading characteristics. Modeling of the linkage between sediment loading and in-lake processes of sediment deposition and discharge will evaluate the implications of daily loads for the reservoir siltation process.

A continuous simulation model is necessary to capture the buildup and washoff of pollutants due to nonpoint sources and to compare episodic (wet-weather) loadings to the in-lake conditions. The loading model is linked to a continuous-simulation reservoir model. The reservoir model allows for the examination of the various critical conditions of iron concentrations (1-day and 4-day averaging periods), nutrient and eutrophication processes (expressed as seasonal average chlorophyll *a*), and long-term sediment accumulation rates.

3.0 MODELING PROCEDURE: LINKING THE SOURCES TO THE ENDPOINT

Establishing the relationship between the in-lake water quality target and the source loadings is a critical component of TMDL development. It allows for the evaluation of management options that will achieve the desired source load reductions. The link can be established through a range of techniques, from qualitative assumptions based on sound scientific principles to sophisticated modeling techniques. Ideally, the linkage will be supported by monitoring data that allow the TMDL developer to associate certain waterbody responses to flow and loading conditions.

3.1 Modeling Framework Selection

The development of a TMDL requires that the linkage between the waterbody-specific impairment and the source loading be described. Model selection will depend on the waterbody types, the pollutant of concern, the relevant pollutant processes, and the source loading characteristics. The selection of the modeling needs and capabilities includes examination of reservoir and watershed loading model components.

3.1.1 Reservoir Model Selection

Hurricane Lake is characterized by shallow depth, short residence time, and variable (nonpoint source) inflows. Previous attempts to develop eutrophication models of the system, based on simplified empirical approaches, failed to reasonably characterize the system (Shaw Weiss & De Naples 1993). Possible reasons for the poor simulation included the short residence time and the release of phosphorus from the bottom sediments. The lake is listed for iron, nutrients (related to eutrophication processes), and siltation. Lake impacts due to those pollutants are manifested under both short-term and long-term loadings.

Based on a review of the data, identification of the critical conditions, and the requirements for the development of a TMDL for the listed pollutants, the following modeling capabilities were identified for the reservoir model.:

- Representation of the lake with 11 cells and two layers (2-dimensional modeling).
- Simulation of lake sediment deposition.
- Simulation of lake eutrophication processes, including flux from bottom sediments.
- Simulation of metals (i.e., iron) in the water column, deposition of sediment associated metals, and adsorption/desorption processes.

From a review of the available public domain models (USEPA 1997), the Environmental Fluid Dynamics Code (EFDC) model was selected (Hamrick 1996; Hamrick and Wu 1996). The EFDC is a general-purpose modeling package for simulating one-, two-, or three-dimensional flow, transport, and biogeochemical processes in surface water systems, including rivers, lakes, estuaries, reservoirs, and wetlands. The EFDC model was originally developed at the Virginia Institute of Marine Science and is considered public domain software. In addition to hydrodynamic and temperature transport simulation capabilities, EFDC is capable of simulating sediment behavior, eutrophication processes, and the transport and fate of toxic contaminants in the water and sediment phases. The EFDC code has been extensively tested and documented and used for more than 20 modeling studies. The code is currently used by university, governmental, and engineering and environmental consulting organizations.

The EFDC has the capability to be applied at various levels of detail as deemed appropriate for specific modeling applications. For the Hurricane Lake application, the model was applied in two dimensions (longitudinal and depth). Simulation processes included

- Hydrodynamics
- Sediment deposition
- Eutrophication cycle
- Iron adsorption/desorption (suspended and deposited sediment)

3.1.2 Watershed Loading Model

For Hurricane Lake the inputs to the lake are exclusively derived from nonpoint sources. Delivery of the nutrients to the system occurs under both baseflow and runoff conditions. Delivery of iron and sediment occurs primarily during runoff events. The frequency and timing of loadings to the reservoir are important factors in the eutrophication indicator (i.e., chlorophyll *a*) and iron concentrations manifested in the reservoir. For siltation, both the long-term loading and the trap efficiency for individual storm events are factors in the evaluation of the accumulation of sediment in the reservoir.

Based on a review of the data, identification of the critical conditions, and the requirements for the development of a TMDL for the listed pollutants, the following modeling capabilities were identified for the watershed loading model:

- Simulation of baseflow and runoff-related inputs from nonpoint sources using continuous simulation (output expressed as daily inputs to reservoir).

- Simulation of loadings of sediment, nutrients (TN and TP), and iron from nonpoint sources.

Based on a review of the available public domain models (USEPA 1997) the Hydrologic Simulation Program-FORTRAN (HSPF) Version 11.0 was selected (Bicknell et al. 1996). HSPF can simulate a wide range of nonpoint source and point source loadings within a watershed or multiple subwatersheds. HSPF is an EPA-supported model. A major portion of the HSPF model is included within the Nonpoint Source Model (NPSM) of the EPA BASINS 2.0 modeling system (USEPA 1998b).

HSPF has the capability to be used at various levels of detail depending on the requirements of the modeling application. For this application, the following components of HSPF were employed:

- Runoff and erosion from nonpoint source land use classes (landscape modules IMPLND and PERLND).
- In-stream transport and delivery (RCHRES).

3.2 Model Setup

3.2.1 Hurricane Lake

Eleven cells were used for the model in a horizontal direction (Figure 3.1). The maximum width of the cells was 85 m and the minimum was 40 m. The cells of the lake model were parameterized based on the lake bathymetry data developed for the Clean Lakes study (Shaw Weiss & De Naples 1993). The surface area of the lake is about 53,000 m^2. Because the lake experiences very weak stratification and is relatively shallow, two layers were used in the vertical.

Two major tributaries provide inflow, suspended sediment loads, metals (iron), and nutrients (expressed as TN and TP). The tributary inflows are directly into cells 9 and 11; cell 11 corresponds to Mill Creek and cell 9 corresponds to Cow Creek.

A drinking water intake is set to withdraw from cell 1. Outflow through the spillway is implemented through the use of flow control, one of the built-in functions of the model. The amount of the water intake was set at 715,000 gpd, the estimated average withdrawn by the water treatment plant.

EFDC was used to simulate advection and diffusion processes. Two sediment classes were used to

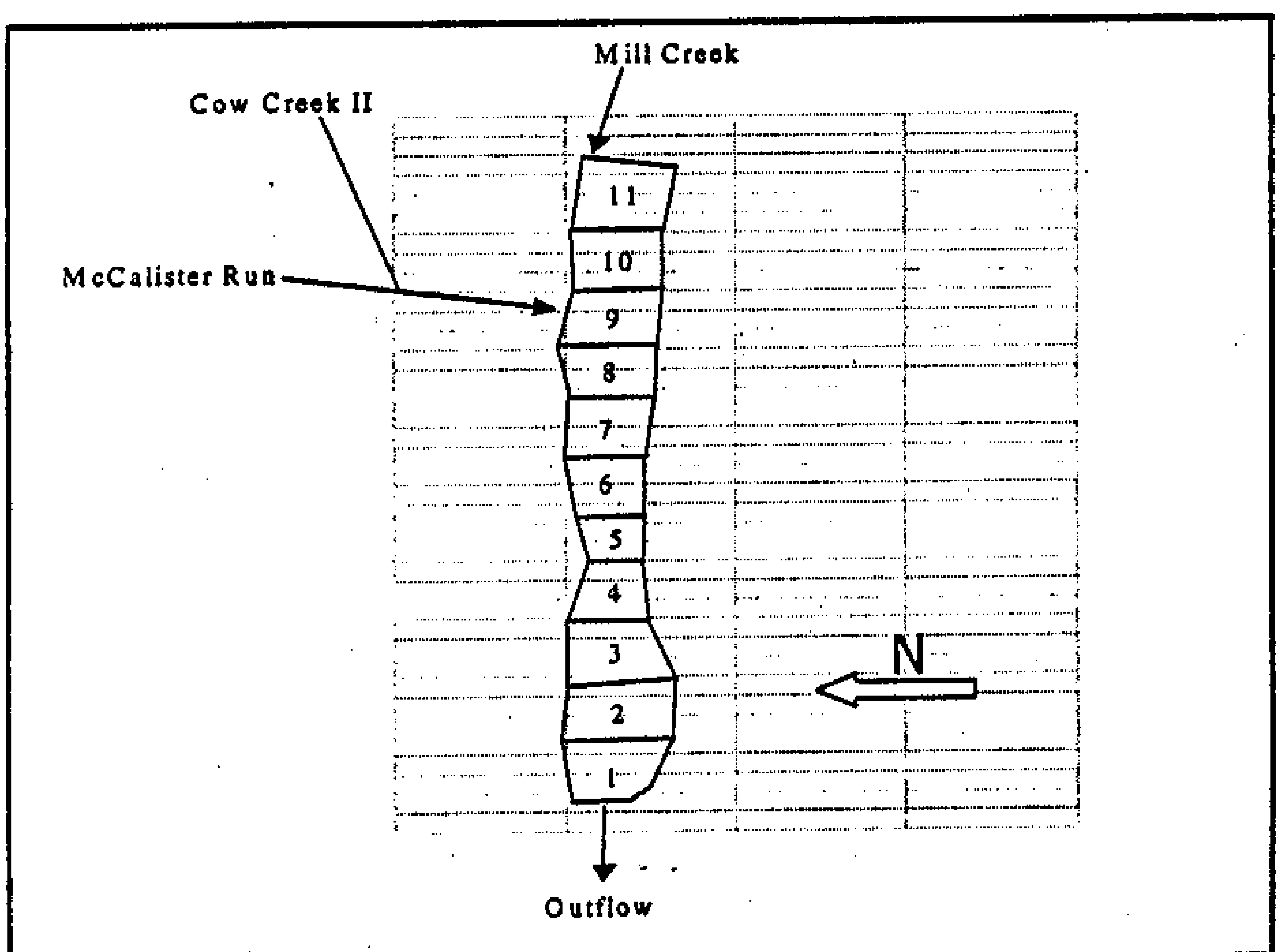

Figure 3.1. Model segmentation for Hurricane Lake.

simulate suspended sediment—one to represent silt and clay, and one to represent fine and medium sand.

The EFDC model is capable of simulating up to 21 state variables. For this application only one algae class was simulated. Instead of using refractory particulate and labile particulate, only one particulate organic matter was used to simulate particulate phosphorus and nitrogen. Other state variables include dissolved nitrogen, NH_4, NO_3, and dissolved phosphorus and total phosphate. Partition methods were used to distribute TN and TP into loads of the relevant nitrogen and phosphorus state variables. The ratios were calculated based on the observed data for 1993 and 1995. The temperature and solar radiation were calculated using a SINE function with specified maximum and minimum solar radiation, and the time at which maximum solar radiation has occurred since January 1. A similar technique was used to simulate temperature values.

Characteristics of Hurricane Lake were obtained from the Clean Lakes report. A summary of lake characteristic information is provided in Table 3.1.

3.2.2 Watershed

To obtain a spatial variation of the concentration and loadings of iron, nutrients, and sediment entering Hurricane Lake, the watershed was subdivided into five subwatersheds. This approach allowed analysts to address the relative contribution of sources within each subwatershed to the different tributaries and inflow points to the lake. The watershed subdivision was based primarily on topographic data analysis in order to isolate each individual reach of the main tributaries.

Table 3.1. Hurricane Lake characteristics.

Area	12.98 acres / 5.34 square miles
Volume (at crest elevation)	46.07 acre feet / 15,011,786 gallons
Mean Depth	3.55 feet
Maximum Depth	7.25 feet
Maximum Length	2387.50 feet
Hydraulic Residence Time	3.78 days
Maximum Width	474.00 feet

Data taken from Shaw Weiss & De Naples 1993.

3.3 Stream Characteristics

The channel geometry for reaches in the watershed was determined using WVDEP channel measurements for selected stream segments. Channel geometry for remaining reaches was extrapolated from observation data, topographic maps, and evaluation of contributing areas.

3.4 Source Representation

Due to the absence of point source dischargers in the watershed, only nonpoint sources were represented. Nonpoint sources were represented by the six land use categories established for the watershed. Septic system discharges were quantified based on the following information: the population distribution within each of the five subwatersheds based on 1990 U.S. Census data, an assumed average daily discharge of 70 gallons per person per day (Horsley & Whitten 1996), assumed septic effluent concentrations of 56 mg/L TN and 20 mg/L TP, and a 2.5% failure rate (NSFC 1993). Additionally, these septic system discharges were assumed to be constant throughout the year.

The initial default values for the pollutant loading parameters needed for each land use were based on general literature values (USEPA 1988). Parameters were adjusted to reflect typical values observed in the Hurricane Lake tributaries and sedimentation rates observed in the reservoir (Shaw Weiss & De Naples 1993). The limited number of tributary samples and lack of continuous flow gaging data precluded development of formal calibration and validation analyses.

3.5 Model Development and Testing Process

3.5.1 Hurricane Lake

Inflows to the reservoir were based on predicted values supplied by the HSPF model application. Discharge from the reservoir was estimated from the water budget analysis provided in the Clean Lakes study (Shaw Weiss & De Naples 1993). The hydrodynamic simulation was examined over time to verify that the lake volume and condition corresponded to observed conditions. Year 1993 was selected for calibration purposes since in-lake monitoring observations are available for that time period. The calibration parameters for suspended sediment are the settling velocity and resuspension rates for both classes of sediments. For the present model simulation, bottom flux of NH_4, NO_3, orthophosphorus, and DO are also specified.

Nutrient inflows were provided by the HSPF simulation. Monitoring data were used to characterize initial conditions in the reservoir system. Literature values were used to set initial rates in the model for settling velocities and algal growth. Model results were compared with observed values for the 1993 calendar year, and parameters were adjusted to provide the best fit with observed data.

3.5.2 Watershed

To develop a representative linkage between the sources and the in-lake water quality response in Hurricane Lake, model parameters were adjusted to the extent possible for hydrology, iron, and sediment loading in the tributaries and in-lake processes. Adjustment of the hydrologic parameters for the watershed portion of the model required comparison of the modeled overall water balance and stream flows. Two types of comparisons were performed. A hydrologic simulation was performed for a nearby watershed since no gage was available within the watershed (upstream of Hurricane Lake). The gage selected was Poplar Fork at Teays (USGS gage #03201410). The drainage area is 8.71 mi^2 at the gage, which is slightly larger than the 5.33-mi^2 drainage area of the Hurricane Lake watershed. The historical record available for Poplar Fork covers January 26, 1967, to October 11, 1978.

For hydrologic model setup the period from January 1, 1970, to October 11, 1978, was used with the matching precipitation records available for Griffithsville, West Virginia (Station No. 3749). A variety of parameters relating to surface water runoff, water balance, and groundwater flows were adjusted within their reasonable range of values until the predicted flows adequately matched observed values. Some of these parameters represented groundwater storage, evapotranspiration, infiltration capacity of the soil, interflow inflow, and length of assumed overland flow. These setup values were then employed in testing the model on the Hurricane Lake watershed. Simulation results were then compared to the previously derived estimates of the water balance for the 1991-92 period (Shaw Weiss & De Naples 1993). Based on this evaluation it was deemed that the parameter values were reasonable and that the model was adequately representing the hydrologic inflow to Hurricane Lake.

Parameters related to iron, nutrients (TP and TN), and sediment loading were adjusted by comparing average annual loading estimates to previously derived estimates and literature values (Shaw Weiss & De Naples, 1993). The modeled in-stream concentrations were also compared to available observed data from tributary sampling performed in 1990-91 and 1998. This process was limited by the absence of data for high flow and storm flow conditions. The predicted 3 years of annual loads were also compared to the previous study, which had derived estimates of long-term average annual loads using the Universal Soil Loss Equation (USLE). The predictions of loading to the reservoir developed for the Clean Lakes study were considered low relative to typical loading values for the simulated land use categories. This underestimation might be due to the limited number of storm sampling events that were used to derive sediment delivery ratios. In addition, the load calculation using the USLE did not consider elevated sediment loading due to stream erosion or construction activities. The parameter values were adjusted within a range of acceptable values, in a manner that retained consistency between relative contributions from the different land use groups. The relatively higher loading values were retained as more representative of the 3-year period simulated. This provided a conservative loading basis for development of a TMDL allocation.

3.6 Existing Loadings

3.6.1 Watershed Loading

The model was run for the representative hydrologic period (October 1990 through September 1997). The modeling run represents the existing condition of iron, nutrients (TP and TN), and sediment concentrations and loadings at various reaches of Hurricane Lake. For the existing conditions, the overall iron, nutrient, and sediment loadings by land-use category for Hurricane Lake watershed are given in Table 3.2.

Table 3.2. Annual nonpoint source pollutant loads (kg/yr).

Land Use Category	Iron	TP	TN	Sediment
Residential	4718.5	142.1	1013.1	395962.8
Commercial and	485.6	13.0	70.8	67913.6
Forest	1915.3	106.0	1612.6	429248.7
Cropland/Pasture	1212.5	586.9	7289.2	2396776.7
Barren	1.2	0.0	0.3	98.8
Total	8333.1	848.0	9866.0	3290000.6

3.6.2 Evaluation of Reservoir Conditions

Model simulations were found to adequately characterize in-lake conditions within the constraints of the data available. Figures 3.2, 3.3, 3.4, and 3.5 show predicted iron, chlorophyll *a*, sediment accumulation, and suspended sediment accumulations, respectively. The predicted iron showed periodic violations of water quality standards. The selected endpoint for nutrients is the chlorophyll *a* concentration. The simulation showed periodic chlorophyll *a* concentrations between 20 and 40 µg/L, varying on a seasonal basis.

A supplementary analysis was performed to evaluate the siltation of the reservoir and the implications of the accumulation information derived from the model analysis. Siltation of lakes and reservoirs can be quantified by the fraction of inflowing sediment retained in the waterbody. This fraction is commonly referred to as the trap efficiency. For a constant annual sediment inflow load, trap efficiency increases with water body volume, while for a fixed waterbody volume, trap efficiency decreases with increasing sediment load. The trap efficiency is also influenced by the types of sediments entering the waterbody, with the trap efficiency for bed load and suspended sands being higher than that for silts and clays.

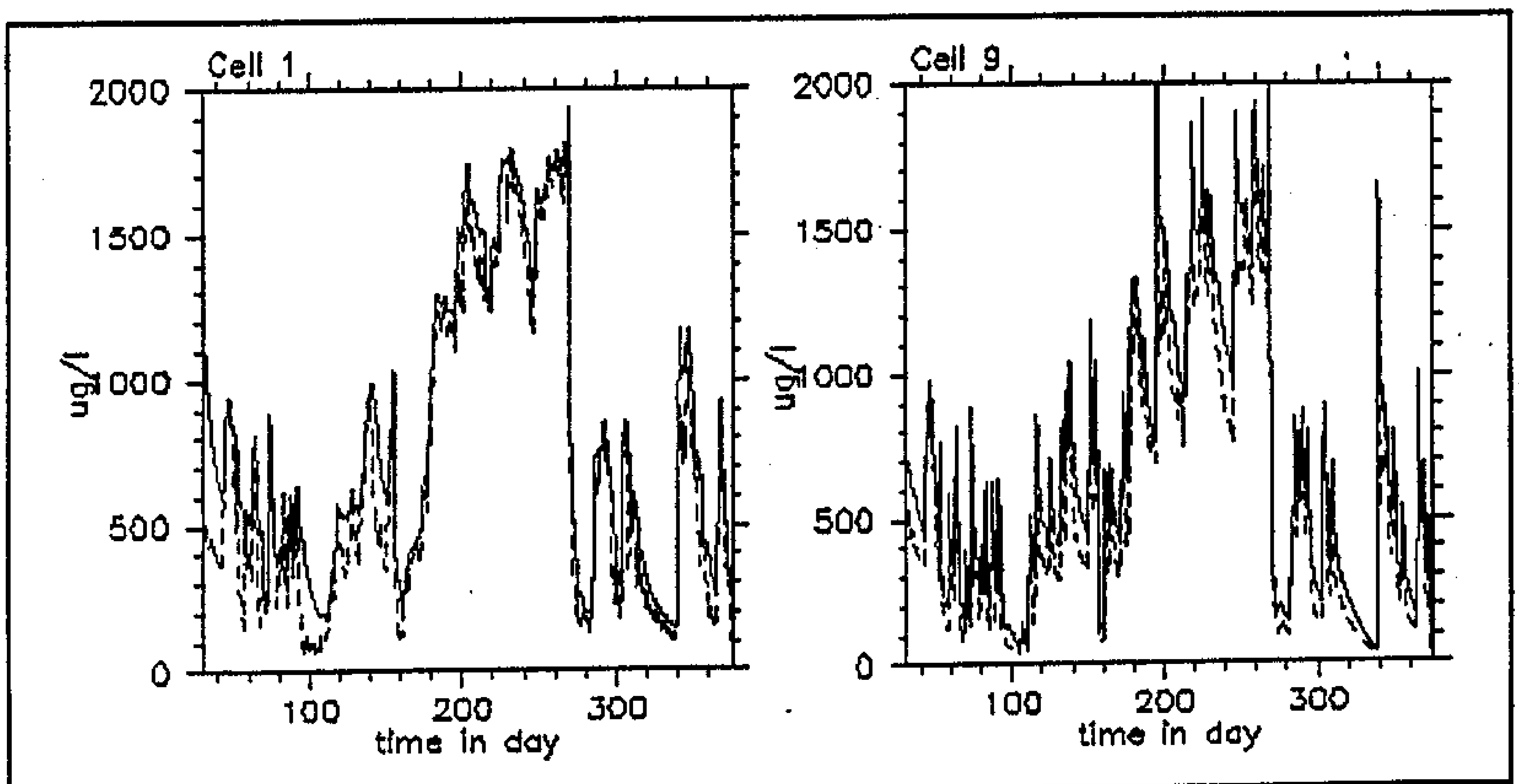

Figure 3.2. Predicted iron concentration (mg/L).

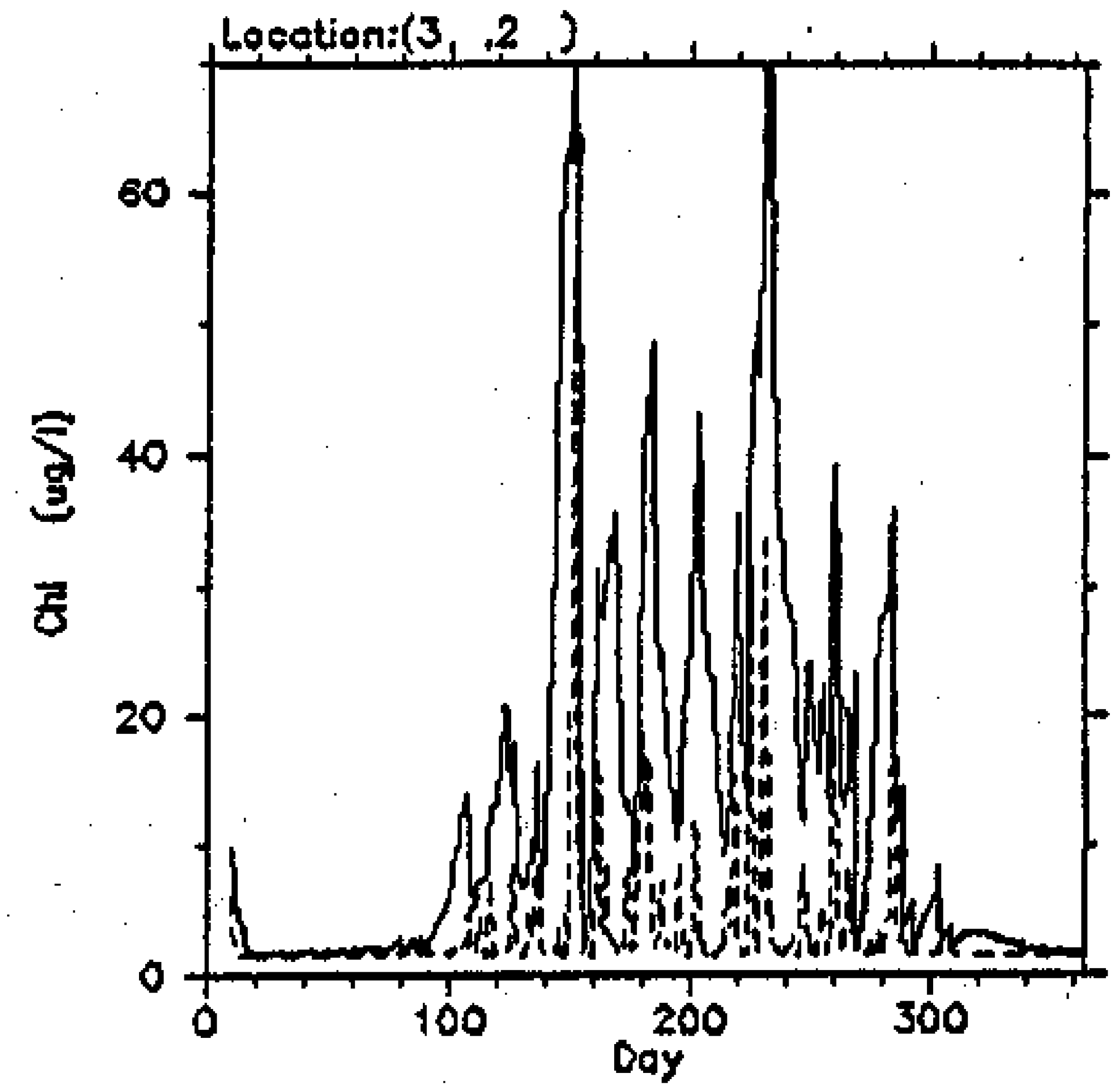

Figure 3.3. Predicted chlorophyll *a* concentration for simulation year.

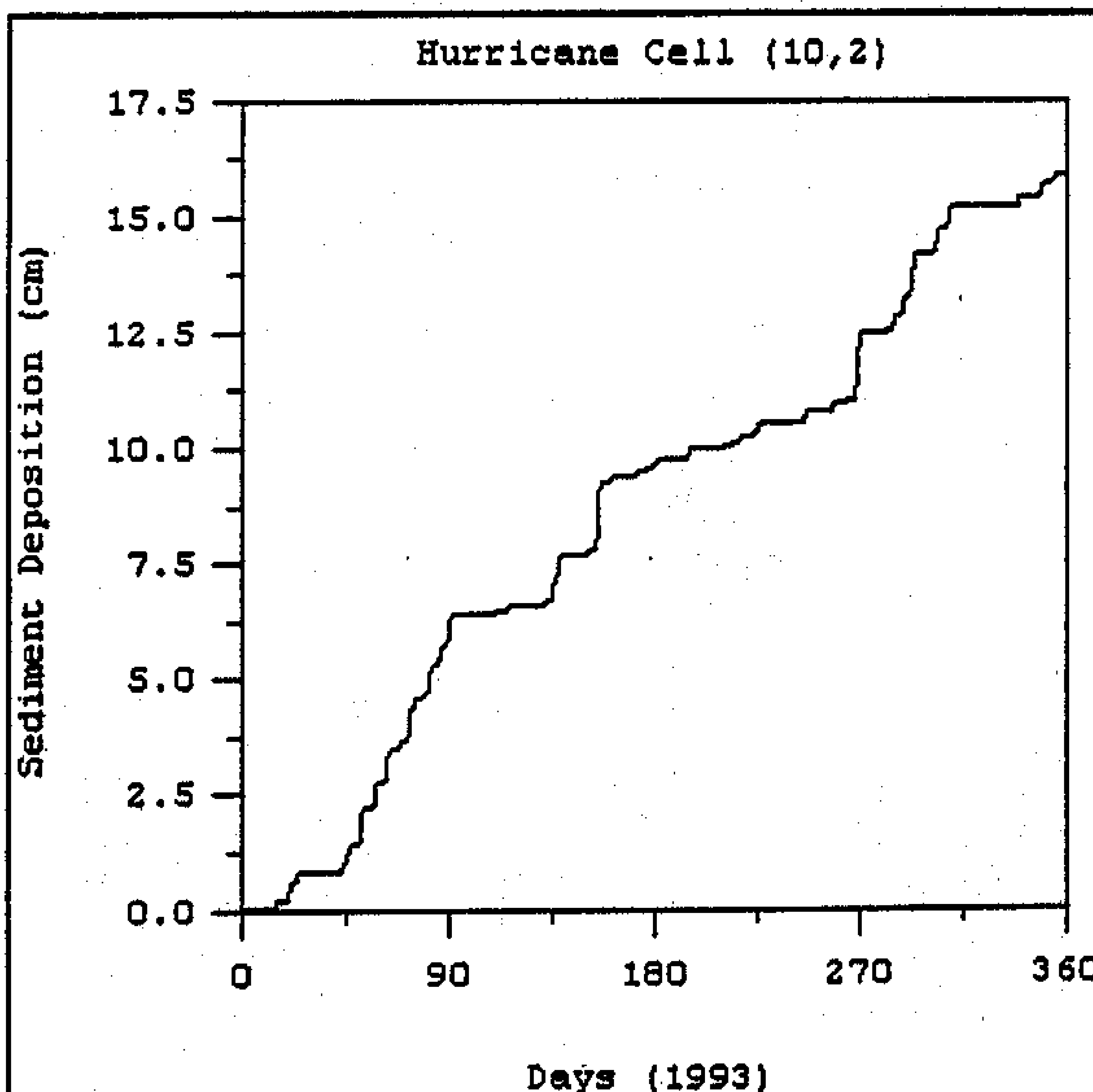

Figure 3.4. Accumulation of sediment in representative cell for 1993 simulation year.

Trap efficiency can be estimated by three different approaches. The first approach requires measurement of both sediment load and deposit over an interval of time. Direct measurements of sediment loads over long intervals require extensive field sampling, while measurement of sediment retention requires multiple bathymetric surveys to quantify deposition. The second approach is the use of empirical relationships between waterbody volume, annual volumetric inflow, and trap efficiency measurements for similar waterbodies. The Brune method (Brune 1953) exemplifies this approach, using a graphical relationship between trap efficiency and the ratio of waterbody volume to annual volumetric inflow based on field measurement for a variety of lakes and reservoirs. Using a volume of 57,000 cubic meters and an annual inflow volume of 5.8 million cubic meters, the Brune parameter is approximately 0.01, corresponding to a trap efficiency in the range of 32% to 58%.

The third approach for determining trap efficiency is direct simulation. For Hurricane Lake, a year-long simulation for hydrodynamic and sediment transport was conducted using 1993 inflows and sediment loading derived from a watershed model. The annual inflow to the lake was 6.8 million cubic meters, and the annual sediment load was 3.3 million kg. Using the mass of sediment deposited during the simulation, the trap efficiency was calculated to be 77%. The average annual siltation rate was estimated to be 5 cm/yr. This compared well with the high accumulation rates observed in the lake. Direct comparison with estimated sedimentation rates was not possible since some dredging had occurred previously and was not documented.

Table 3.3. Calculated trap efficiencies for Hurricane Lake.

Estimated Trap Efficiency Range (Brune 1953)	Simulated Trap Efficiency
32%-58 %	77 %

The trap efficiency for Hurricane Lake was calculated at 32%-58%. This represents a long-term estimation. For 1993, the simulation model used estimated the siltation of the lake due to the suspended load at 77%. Although this trapped load corresponded to a 5 cm/year average (uniformly distributed over the lake), the accumulation of sediment in individual cells (preferential deposition areas) shows accumulation in excess of 10 cm/year. The cells located in proximity of the inflow points are also exposed to deposition of the bed load, making siltation of the cells even higher.

As the cells located downstream from the inflow points are rapidly silted, the usable lake area is reduced. Three ways in which the lake are impacted are reduction of surface area, reduction of access (e.g., public boat use), and reduction of habitat quality.

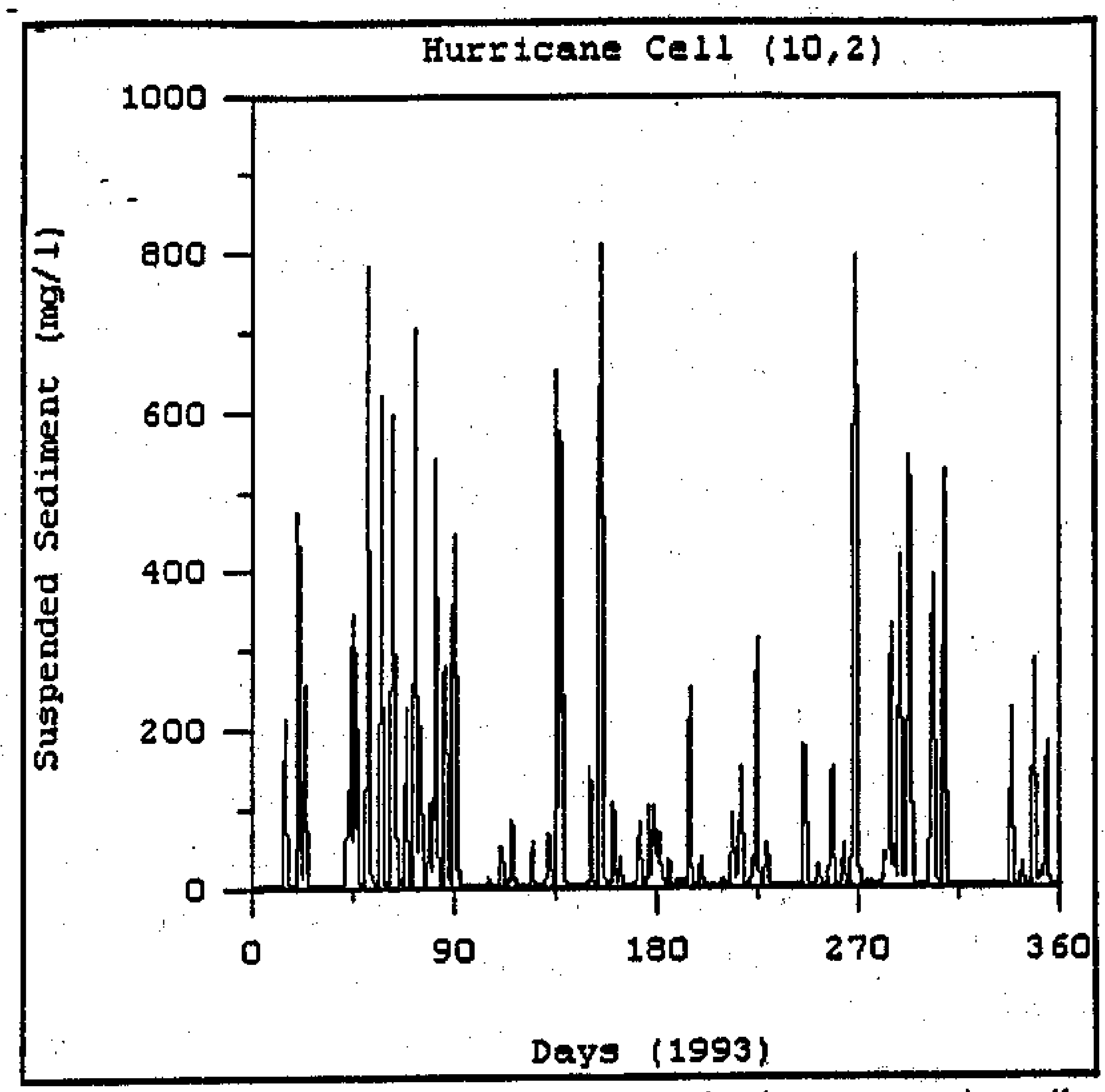

Figure 3.5. Suspended sediment concentration in representative cell for 1993 simulation year.

4.0 ALLOCATIONS

Total Maximum Daily Loads (TMDLs) are composed of the sum of individual waste load allocations (WLAs) for point sources, load allocations (LAs) for nonpoint sources, and natural background levels. In addition, the TMDL must include a margin of safety (MOS), either implicitly or explicitly, that accounts for the uncertainty in the relation between pollutant loads and the quality of the receiving water body. Conceptually, this definition is denoted by the equation

$$\text{TMDL} = \Sigma \text{ WLAs} + \Sigma \text{ LAs} + \text{MOS}$$

The TMDL is the total amount of a pollutant that can be assimilated by the receiving water while still achieving water quality standards.

For some pollutants, TMDLs are expressed on a mass loading basis (e.g., pounds per day). In some cases a TMDL is expressed as another appropriate measure that is the relevant expression for the reduction of loadings of the specific pollutant to meet water quality standards.

4.1 Incorporating a Margin of Safety

The MOS is part of the TMDL development process. There are two basic methods for incorporating the MOS (USEPA 1991):

- Implicitly incorporate the MOS using conservative model assumptions to develop allocations.
- Explicitly specify a portion of the total TMDL as the MOS; use the remainder for allocations.

For Hurricane Lake, the MOS for this TMDL analysis include the following:

- It is important to understand that any best management practices (BMPs) implemented recently are not explicitly accounted for in the models since their impact on loading rates is not known due to lack of "before and after" monitoring. Since the models do not reflect certain BMPs that might be reducing nonpoint source loads, the overall load allocation reductions computed in this analysis might be overestimated and can be considered as part of the MOS.

- The loading estimates were compared to overall sedimentation rates estimated from bathymetric surveys cited in the Clean Lakes report. These sedimentation rates and related loading estimates provide long-term accumulation and do not consider the possible reduction in loading over time.

- The year used for development of the TMDL loading analysis was considered to have a relatively high loading rate. The loading values are considered to be conservatively high, resulting in an additional MOS.

4.2 Assessing Alternatives

For the allocation runs, the model was run for the same representative hydrologic period (1993). The inputs of iron, nutrients, and sediment were adjusted from the various land use categories to meet the target values defined in Section 1.3. Resulting lake water quality conditions for sediment deposition and suspended sediment concentration based on a 30% loading reduction are shown in Figures 4.1 and 4.2, respectively.

Evaluation of the iron inputs showed that a 30% reduction would be sufficient to consistently meet water quality standards based on the 1.5 mg/L criterion. The modeling of lake eutrophication processes showed that a 45% reduction in phosphorus loading should result in average summer chlorophyll of less than the defined target of 15 µg/L.

For siltation, three types of issues were considered—maintenance of adequate reservoir volume, preservation of reservoir surface area as measured through deposition in entrance points to the reservoir, and reservoir clarity (due to sediment loadings) measured as total suspended sediment. The final appropriate sediment loading was determined by evaluation of these issues through the following factors:

- The annual reservoir siltation accumulation rate (in centimeters per year) and 70% of the average reservoir depth.
- The annual siltation accumulation rate for a depositional cell and associated cell depth.
- The predicted total suspended sediment in the water column.

The recommended reduction in accumulation rate was assumed to be correlated to a corresponding sediment loading rate. The response to sediment loading reduction was tested by repeated application of the reservoir model under various loading scenarios. In determining the required load reduction all three factors were taken into consideration.

For Hurricane Lake the average annual reservoir accumulation rate was predicted to be 5 cm/yr with a mean water depth of 1.08 m and a maximum water depth of 2.21 m. The selected depositional cell has an annual rate accumulation rate of 16 cm per year with a mean water depth of 1.3 m. The shallow depth of the entire lake shows a system severely impacted by siltation. Evaluation of the endpoint is based on the lakewide impacts. Restoration of the lake includes recommendations to perform dredging and concurrent load reductions through erosion and sediment control and best management practices. Since the lake is severely impacted, the analysis assumed that the lake is dredged, resulting in a new average depth of approximately 2 meters. Preservation of the 70% capacity of the lake for 40 years would require a reduction in the accumulation rate and an associated reduction of the average annual sediment load by 30%.

4.3 Recommended Allocations

An overall load allocation reduction was defined for each pollutant type as follows:

- Iron - 30%
- Nutrients (TP) - 45%
- Siltation (sediment) - 30%

These nonpoint source load allocations reduce the loadings to Hurricane Lake to the degree necessary to meet the designated endpoints for iron, nutrients, and sediment. The load reductions are expressed as average annual loads appropriate to control of pollutants to a reservoir system. Each load reduction target, representing the TMDL load allocation, is distributed to land use categories for each pollutant. The overall nonpoint source loadings by land use category for each of the listed pollutants for the Hurricane Lake watershed are given in Tables 4.1, 4.2, and 4.3.

Table 4.1. Iron allocations for Hurricane Lake watershed.

Land Use	Percent Reduction
Urban	45%
Forest	10%
Cropland/Pasture	0%
Barren	10%
Watershed Total	**30%**

Table 4.2. Total phosphorus allocations for Hurricane Lake watershed.

Land Use	Percent Reduction
Urban	50%
Forest	10%
Cropland/Pasture	50%
Barren	0
Watershed Total	**45%**

Table 4.3. Total suspended solids allocations for Hurricane Lake watershed.

Land Use	Percent Reduction
Cropland and Pasture	33%
Residential and Commercial	25%
Forest	20%
Barren	0%
Total	**30%**

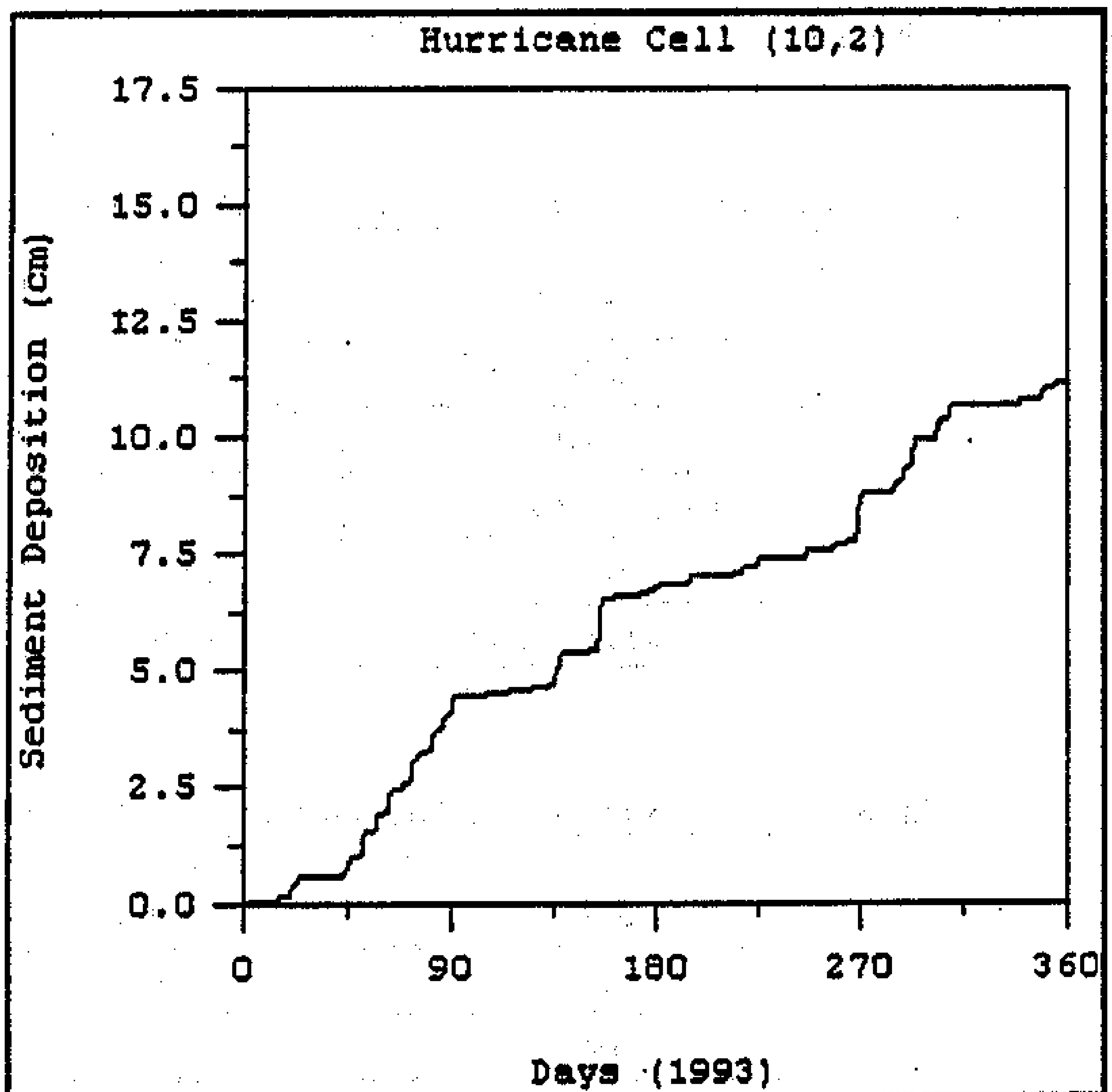

Figure 4.1. Sediment deposition in a representative reach with a 30% reduction in loading.

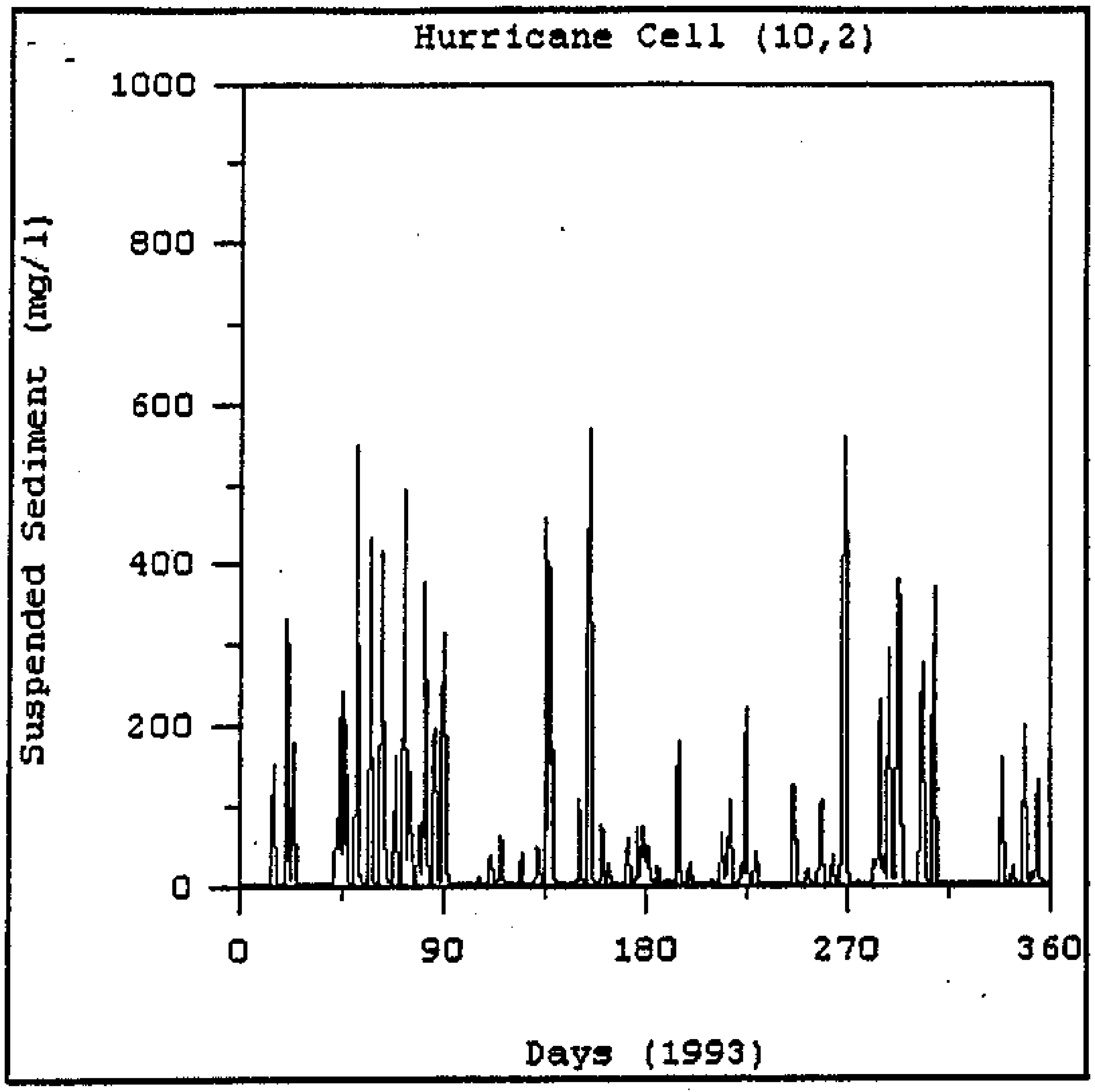

Figure 4.2. Suspended sediment concentration in a representative reach with a 30% reduction in loading.

5.0 SUMMARY

Hurricane Lake watershed was divided into five subwatersheds, and the HSPF (Version 11.0) and EFDC models were selected as the modeling framework for performing TMDL allocations. Supplemental analysis was performed to evaluate trap efficiency and accumulation rates.

For this TMDL analysis, load allocations were calculated with margins of safety to meet water quality standards and established water quality goals because of uncertainty in the available data or lack of key information. For this study implicit conservative assumptions were used as the margin of safety. Additional data gathering is recommended to continue to track progress in achievement of water quality standards in the lake.

5.1 Findings

The modeling study confirmed that there are periodic violations of the in-lake iron standard. The model predictions also showed periodically high chlorophyll *a* and increased sedimentation rate. After applying the load allocations, the lake model indicated an achievement of the numeric goals identified.

5.2 Recommendations

This TMDL analysis was performed with very limited water quality data for characterizing point and nonpoint sources as well as for characterizing in-stream water quality conditions. Because of the lack of high-frequency, long-term data sets, the water quality calibration of the EFDC and HSPF models should be considered to be a "qualitative" calibration only. As additional data become available, they can be incorporated into the model and/or used to determine whether implemented controls are having the intended effect on improving water quality. The remainder of this section is a discussion that includes the key areas of data uncertainty as well as recommendations for filling the data gaps for future TMDL analyses.

5.2.1 Hydrologic Flow Data

There were no stream USGS gages available in or directly downstream of the Hurricane Lake watershed. Daily flow values obtained from a USGS gage located in an adjacent watershed were used to calibrate the hydrologic flow in the NPSM model. Establishment of a gage within the watershed would likely improve the hydrologic calibration process and improve confidence in the computed stream flows in the model.

5.2.2 Water Quality Monitoring

In general, water quality conditions in Hurricane Lake and its inflows are monitored infrequently. The only long-term monitoring study in the watershed was the Clean Lakes study conducted during 1991-92, which collected data approximately once per month at one location in the lake and at one location in two of the main inflows. Because sediment runoff problems in the study area generally coincide with storm runoff events, sampling at intervals of less than once per day will almost certainly miss the highest concentrations since storms tend to be short-term events. The ideal pollutant data set would consist of weekly samples collected during dry-weather periods or composited during storm events. The cost of such an ambitious monitoring program might be prohibitive.

In 1998, WVDEP performed a sampling sweep for selected water quality variables at locations in Hurricane Lake and its main inflows to support this TMDL development effort. It is recommended that the sampling program be continued on a regular basis during the spring-to-autumn seasons to develop the long-term database necessary to (1) provide additional data for future modeling efforts and (2) determine the "before-and-after" impacts of BMPs implemented in the study watershed.

5.2.3 Point Sources

No point sources were identified as being located in the watershed. No point sources are expected to be located within a 5-mile radius of the drinking water intake, in accordance with drinking water regulations.

5.2.4 Septic System Information

The assumed failure rate of 2.5% for septic systems, as well as the estimated number of septic systems present in the watershed, is a source of some uncertainty. A septic survey of the watershed would be useful to determine more precisely the number of septic systems in use and whether the assumed failure rate is valid. Failing septic systems that are in close proximity to surface waters have the potential to cause elevated nutrient concentrations, especially during low-flow periods.

5.2.5 Agricultural Data

The land use analysis indicates that agricultural land uses (i.e., row crops and hay/pasture) represent less than 35 percent of the total watershed land area. No specific agricultural data (e.g., number of feedlots, livestock counts, fertilizer application rates) were evaluated as part of this analysis. Agricultural land uses potentially could be contributing to pollutant loading concerns (most specifically nutrient loadings), and incorporating more detailed agricultural data into the watershed model would likely improve the TMDL analysis.

5.2.6 Wildlife Information

The contribution to pollutant loads (most specifically nutrient loads) from wildlife populations (e.g., duck, geese, and deer) was not evaluated during this study. If local data on wildlife populations are collected, an evaluation of potential impact could possibly be conducted for a future TMDL analysis.

5.2.7 Rainfall Data and Representative Hydrologic Year

The representative hydrologic year used for this TMDL was the 1990-91 water year. The hourly rainfall database available for this project covered the period 1970-97. A rain gage situated at Griffithsville, West Virginia, was used for the watershed runoff modeling for the Hurricane Lake watershed. Although this gage is relatively close to the watershed (approximately 15 miles to the south), the precipitation data set should be further evaluated to account for some dates that lack associated data entries.

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1993 - 1994 WVDEP Water Quality Sampling of Hurricane Lake

Sample Date	Spring 93 5-27	Summ 93 7-21	Spring 94 4-26	Summ 94 8-10	Fall 94 10-18
Temperature, °C					
surface	22.8	28.00	20.3	24.9	16.2
bottom	17.9	27.70	15.1	23.2	+++
inflow	18.6	22.00	16.7	20.2	15.1
PH, Standard Units					
surface	8	7.60	7.5++	7.3	8.2
bottom	7.5	7.50	7.5++	7	+++
inflow	7.9	7.40	7.4++	7.4	7.2
Conductivity, umhos/cm					
surface	227	237.00	178	162	225
bottom	232	237.00	127	163	+++
inflow	245	254.00	161	232	259
Dissolved Oxygen, mg/L					
surface	6.2	5.50	8.8	6.6	10.3
bottom	1.6*	5.20	4.9*	2.3*	+++
inflow	7.7	5.10	9.2	8.4	8.8
Total Acidity, mg/L					
surface	3	1.00	2	2	2
bottom	4	2.00	3	5	+++
inflow	3	2.00	2	5	3
Total Alkalinity, mg/L					
surface	72	77.00	51	59	67
bottom	73	358.00	50	61	+++
inflow	90	100.00	45	130	87
Suspended Solids, mg/L					
surface	21	15.00	40	42	49
bottom	36	48.00	62	72	+++
inflow	6	22.00	28	1	<1
Total Phosphorus, mg/L					
surface	0.072	0.10	0.05	0.037	0.026
bottom	0.075	0.12	0.041	0.043	+++
inflow	0.031	0.06	0.019	0.02	0.018
Orthophosphorus, mg/L					
surface	<.01	<.01	<.01	<.01	<.01
bottom	<.01	0.12	<.01	<.01	+++
inflow	0.029	<.01	<.01	<.01	<.01
Total Kjeldahl Nitrogen, mg/L					
surface	0.71	0.96	0.35	1.07	1.5
bottom	0.73	1.02	0.48	1.18	+++

Sample Date	Spring 93 5-27	Summ 93 7-21	Spring 94 4-26	Summ 94 8-10	Fall 94 10-18
inflow	0.25	0.30	0.17	0.33	23.4
Ammonia Nitrogen, mg/L					
surface	0.11	0.10	0.12	0.13	0.18
bottom	0.18	0.14	<.01	0.15	+++
inflow	0.1	0.27	0.12	0.05	0.11
Nitrate-Nitrite Nitrogen, mg/L					
surface	0.19	<.01	0.03	0.35	0.4
bottom	0.18	<.01	0.02	0.34	+++
inflow	0.2	0.11	0.01	0.16	0.11
Total Iron, mg/L					
surface	0.815	1.10	1.1	3.400*	2.100*
bottom	1.800*	2.600*	1.600*	4.400*	+++
inflow	---	1.20	0.51	0.45	0.215
Total Manganese, mg/L					
surface	0.705	0.68	0.45	0.5	0.675
bottom	0.9	0.80	0.465	0.545	+++
inflow	---	0.28	0.105	0.125	0.05
Total Aluminum, mg/L					
surface	0.84	0.63	0.635	3.400*	1.600*
bottom	1.63	3.20	1.000*	4.600*	+++
inflow	---	0.39	0.225	<.050	<.050
Chlorophyll a, mg/m3					
surface	22.56	35.02	9.49	40.26	32.16
Secchi Depth, ft	1.75	1.00	1.5	0.58	0.75

* = Violation of state WQ standards

++ = laboratory pH

+++ = No bottom samples collected due to shallow water

		Lake					Cow Creek II			Mill Creek		
		5/4/98	5/4/98	5/4/98	5/4/98	5/4/98	28-Apr	5/5/98	5/11/98	4/28/98	5/4/98	5/11/98
		Near Dam	Near Dam	Near Dam	Below Mill Cr	Below Mill Cr.						
		Surface	Bottom		Surface							
		water	water	sediment	water	sediment	water	water	water	water	water	water
Tot. Acidity	mg/L	1.6	1.8		1.6		1.7	6.6	3.2	1.1	1.8	1.8
Alkalinity	mg/L	46.2	45.5		47.8		61.3	54	62.1	58.3	45.4	53.1
Tubidity	NTU	40.4	66		63.4		18.4	136	16.2	15.4	26.5	14.7
BOD_5	mg/L	ND	ND		2.3		ND	4.4	ND	ND	ND	ND
TSS	mg/L	21	47		90		16	211	12	13	12	13
TP	mg/L	0.0918	0.103		0.0918		0.0402	0.514	0.0492	0.0402	0.0356	0.0402
Ortho P	mg/L	0.0222	0.0312		ND		ND	ND	ND	ND	0.0267	ND
TKN	mg/L	0.5	0.5		0.6		ND	1.3	ND	ND	ND	ND
Ammonia-N	mg/L	ND	ND		ND		ND	ND	ND	ND	ND	ND
NO_2-NO_3-N	mg/L	0.346	0.324		0.31		0.432	0.502	0.538	0.0841	0.163	0.119
Al	ug/L	847	1608		1186		512	3583	211	303	522	258
Fe	ug/L	1673	2703		2588		1290	6635	1036	684	1081	613
Chlor a	mg/m3	9.8			46.8							
TP	mg/kg			93.6		45.5						
Al	mg/kg			8257		4074						
Fe	mg/kg			18020		11660						
Bulk Density	g/cc			1.34		1.46						