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EPA

TMDL Case Study

Sycamore Creek, Michigan

Key Feature: A watershed analysis that links dissolved oxygen problems to sediment loads and establishes NPS load allocations

Project Name: Sycamore Creek
Location: USEPA Region V/Ingham County, Michigan
Scope/Size: Watershed area 274 km^2; subwatershed area 96 km^2
Land Type: Irregular plains
Type of Activity: Agriculture
Pollutant(s): Sediment
TMDL Development: NPS
Data Sources: State and local
Data Mechanisms: DO model, NPS loading model
Monitoring Plan: Yes
Control Measures: BMPs

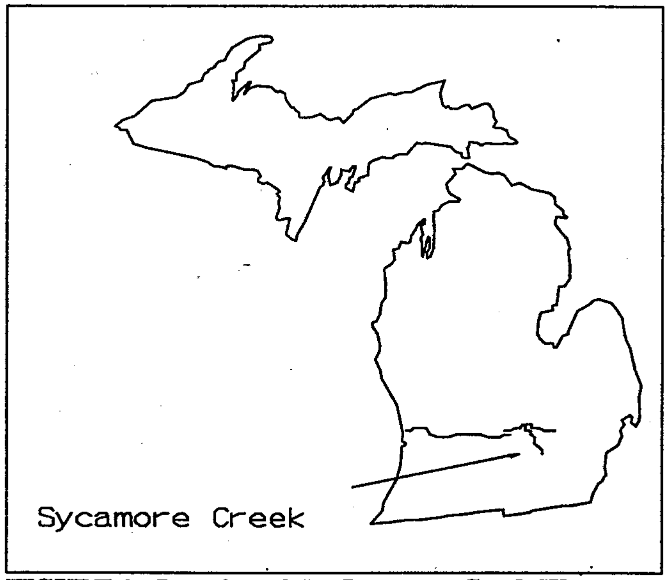

FIGURE 1. Location of the Sycamore Creek Watershed in Michigan

Summary: Sycamore Creek (Figure 1) was targeted for intensive watershed analysis because its water quality problems are representative of many streams that drain primarily agricultural land in southern Michigan. It is listed on Michigan's §303(d) list. Sediment is the pollutant most responsible for impairment of Sycamore Creek. It has destroyed aquatic habitat, and dissolved oxygen (DO) modeling results have indicated that sediment oxygen demand (SOD) is the most significant oxygen sink under drought conditions. Model simulations have also shown that respiration by aquatic plants contributes significantly to the DO deficit at some locations in the Creek. Aquatic plants depend on available nutrients to grow, and since most nutrients are transported to Sycamore Creek while adsorbed to suspended sediment, reducing sediment loadings will address this problem. Instream monitoring supported these conclusions by revealing State water quality standard violations for dissolved oxygen (DO) at seven of eight locations in Sycamore Creek.

Michigan's Department of Natural Resources (MDNR) believes that reducing suspended solids loadings to Sycamore Creek is the best overall strategy for increasing DO concentrations in the creek to meet the DO standard and improve aquatic habitat. Less sediment in the Creek will improve fish and macroinvertebrate habitat; provide a firmer stream bottom that is more appealing for recreation; deepen the channel, thereby improving navigation potential; and increase oxygen concentrations by reducing SOD and aquatic plant respiration. The first step in this direction was to estimate annual average sediment loading to the stream from urban runoff, stream bank erosion, agricultural fields, septic tanks, and point sources using modeling, channel surveying, and monitoring. Stream bank erosion, agricultural erosion, and urban runoff were all significant sediment sources. Analyses indicated that suspended solids loading would have to be reduced by 52 percent in order to reduce DO levels sufficiently to meet the standard at all locations (except downstream of the marsh) during drought flow. MDNR has no final plan on how to achieve the necessary reductions; however, one possible allocation scheme that is reasonable and can achieve the 52 percent reduction is presented.

Contact: John D. Suppnick, Michigan Department of Natural Resources, Surface Water Quality Division, P.O. Box 30028, Lansing, MI 48909, phone (517)335-4192

BACKGROUND

Sycamore Creek is a small warm-water stream that drains 274 square kilometers of gently rolling, sometimes flat, land in the middle of Michigan (Figure 1). However, the watershed analysis described in this case study focuses on the 96 square kilometers upstream of Harper Road (Figure 2). The area was first settled and farmed in the 1800s; shortly after, its drainage density was greatly expanded by dredging. Most of the stream channels within the watershed have been dredged at least once.

Today, approximately 70 percent of the watershed is used for agriculture. Farmers in the area primarily raise cash crops, such as corn, soy beans, wheat, and alfalfa. Although they do not typically plow in the fall, conservation tillage is not yet widely used despite the fact that much of this agricultural land is highly erodible. The watershed is dominated by loam and sandy loam soils, but some organic soils are scattered about, primarily along drainageways.

The City of Mason is located near the downstream end of Sycamore Creek. The city has no major industries that discharge process wastewater to the stream, but it does have a municipal plant that provides advanced wastewater treatment for a population of 6019. The Mason Wastewater Treatment Plant (WWTP) is designed to treat 1.5 million gallons per day. Sycamore Creek's drought flow is only 1.3 cubic feet per second at the point of wastewater discharge so that downstream from this point the stream is considered effluent-dominated.

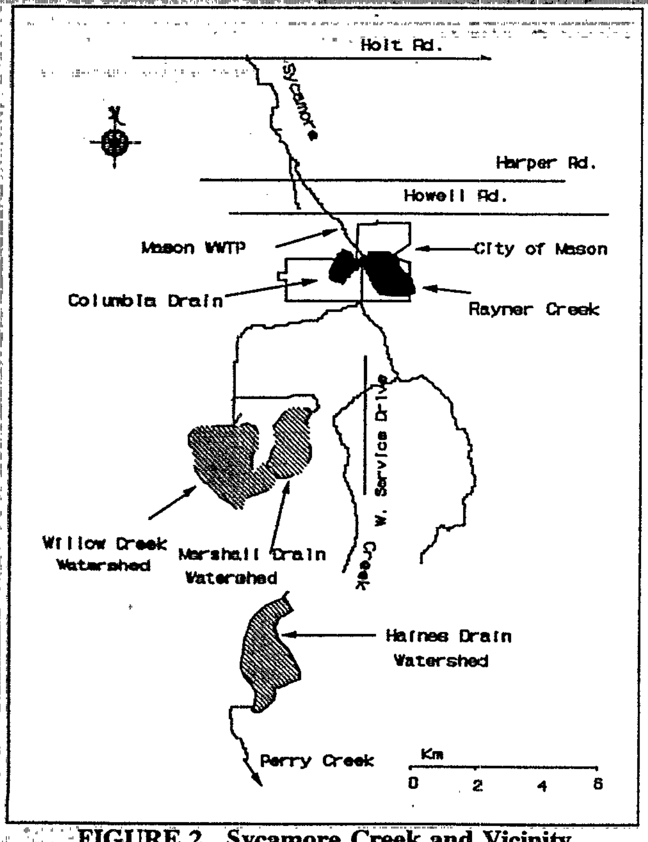

FIGURE 2. Sycamore Creek and Vicinity

Several Federal and State agencies are coordinating their efforts in the Sycamore Creek watershed to improve its water quality and protect designated uses. Sycamore Creek must meet Michigan's Water Quality Standards for the support of warm-water fish, other indigenous aquatic life and wildlife, total body contact recreation, and navigation, and for use as an industrial and agricultural water supply. As Michigan's United States Department of Agriculture (USDA) water quality nonpoint source (NPS) hydrologic unit project, the creek benefits from an intensive educational program, technical assistance, and cost sharing to implement best management practices (BMPs) within the watershed. In addition, the Ingham Soil Conservation District has a §205(J) grant from USEPA to provide technical assistance to farmers in the watershed; the USDA Agricultural Stabilization and Conservation Service has received $300,000 in special Agricultural Conservation Program cost share money for Sycamore Creek; and the Ingham County Department of Public Health has a §319 grant from USEPA to study groundwater in the watershed.

ASSESSING AND CHARACTERIZING THE PROBLEM

Targeting and Prioritizing

Sycamore Creek, which is listed on Michigan's §303(d) list, was targeted for intensive watershed analysis because its water quality problems are representative of many streams that drain primarily agricultural land in southern Michigan. Feedback on the success of NPS management measures in this watershed can therefore be applied to similar streams throughout the region.

Monitoring

Biological surveys (Clark, 1990), conducted to help characterize problems in the Sycamore Creek watershed and to serve as a baseline for documentation of future improvement, revealed that intolerant fish species were absent and that macroinvertebrate diversity and abundance in Sycamore Creek were low. This evidence that the creek's aquatic community is stressed and unhealthy, that designated uses are impaired, and that the DO standard is being violated, was supported by channel surveys, continuous DO monitoring, and DO modeling.

The Surface Water Quality Division of the Michigan Department of Natural Resources (MDNR) measured channel dimensions and sediment depth at 49 sites in the watershed using a survey rod and hand level. MDNR also made observations of bank erosion and riparian vegetation at most sites. Based on these observations, active channel erosion at each site was classified as high, moderate, or low.

MDNR conducted continuous DO monitoring at eight locations using recording electrode style monitors. Monitoring lasted from 6 to 103 days for each location.

Cause-and-effect synoptic DO surveys were conducted twice with sampling at nine locations in the creek during summer low flows to provide data to calibrate a low-flow DO model. These samples and a 24-hour composite sample of effluent from the Mason WWTP were analyzed for DO, biochemical oxygen demand (BOD), ammonia, solids, and nutrients. Stream flow measurements were made with a current meter, and an ethylene gas tracer was used to determine a reaeration rate coefficient for Sycamore Creek.

A special monitoring program was conducted during 1990 and 1991 to collect sediment and nutrient loading data for this watershed analysis. Three agricultural subwatersheds—Marshall Drain, Willow Creek, and Haines Drain—were sampled from March, after the snowmelt, until the appearance of a crop canopy in July. Marshall Drain and Willow Creek are within the Sycamore Creek drainage. Haines Drain is adjacent and was monitored to provide a control watershed that would allow a paired analysis for determining the effectiveness of NPS control strategies. Its soil, slope, and land use characteristics are similar to those of the Sycamore Creek watershed. Water quality samples were collected by hand two times each month during baseflow and by using automatic samplers at 1- to 4-hour intervals during runoff events . Flow was continuously measured during the monitoring season.

Two urban subwatersheds (Rayner Creek and Columbia Drain) were also monitored during two summer storms using an automatic sampler at 1/2- to 4-hour intervals. These watersheds were monitored to assist with the identification of urban pollution sources.

Modeling Dissolved Oxygen

MDNR used a quasi steady state DO model (O'Connor and DiToro, 1970) to predict DO concentrations in the creek during drought conditions. They sought to determine whether the DO standard would be met under the most severe circumstances and to determine the relative importance of oxygen-consuming factors during a drought. The model was calibrated by adjusting the plant respiration and photosynthesis terms to obtain the best match with the synoptic DO data. It was also calibrated to match continuous DO data collected at one location during the 1988 drought. Plant respiration and SOD were estimated in this second calibration as a single term and then separated assuming no net oxygen production by plants.

Preliminary Conclusions

The channel survey documented severe sedimentation throughout the watershed. Average sediment depth was 0.3 meter of primarily fine sand and silt. The survey also revealed that the most active stream bank erosion was occurring along wooded banks where herbaceous plants were sparse. Ninety percent of the stations where no active erosion was noted were nonwooded. Nonwooded sites usually had thick sod stabilizing the bank.

Seven of the DO monitoring sites were upstream of Mason's WWTP, and all but one recorded DO concentrations less than the minimum 5 mg/l standard. The DO standard was violated at these stations 53 out of 153 days. Three sites upstream of the WWTP, but downstream from a marsh, violated the DO standard on every day they were monitored. The other three sites that violated the standard, located upstream of both the WWTP and the marsh, did so only on days of surface runoff or during drought conditions. Downstream of the WWTP, the measured DO was less than 5 mg/l on only 1 out of 103 days and a large runoff event occurred on that day. These data indicated that nonpoint sources were contributing more to the oxygen demand in the stream than point sources.

DO modeling showed that most of Sycamore Creek is not expected to meet the DO standard under drought flow conditions. The daily minimum DO expected at drought flow is 0.0 mg/l at West Service Drive Creek, 4.4 mg/l at Cemetery Bridge, 4.5 mg/l at Howell Road, and 3.9 mg/l at Harper Road. The primary DO sink under drought conditions was shown to be SOD followed by aquatic plant respiration (Figure 3). The segment downstream of the marsh (represented by the station at West Service Drive Creek) is expected to have DO concentrations less than the standard, even under average summer flow, because of very high SOD in the marsh.

The habitat observed to be destroyed by sediment and the DO monitoring and modeling results show that sediment is the pollutant most responsible for impairment of Sycamore Creek. As a result, MDNR decided that reducing suspended solids loads to the creek would be the most appropriate way to decrease SOD and the nutrient loads that may be stimulating aquatic plant growth.

THE WATERSHED ANALYSIS

The pollutant load associated with each monitored runoff period in the urban and agricultural subwate. heds was calculated from the interval method (Richards and Holloway, 1987) according to the equation

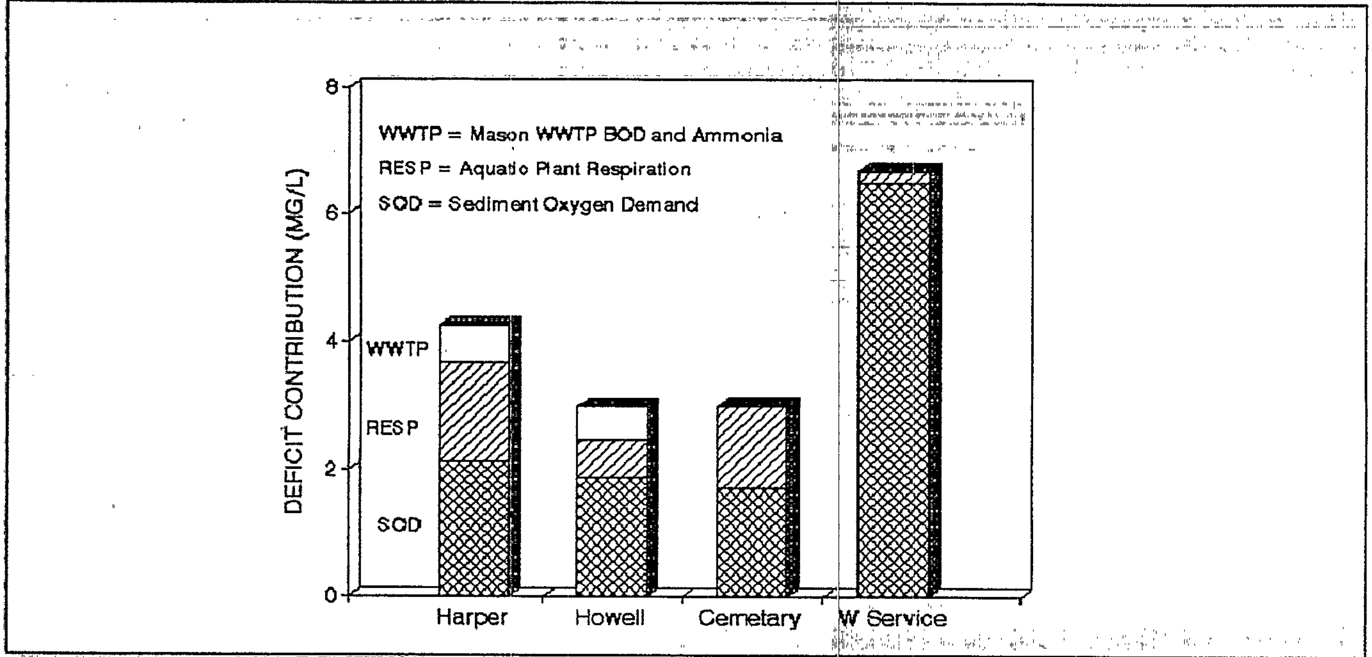

FIGURE 3. Relative contribution of DO sinks to the DO deficit

$$L = \Sigma\, c_i * q_i * t_i * k$$

where

- L = storm load (kg);
- c = pollutant concentration (mg/l);
- q = instantaneous flow associated with the sample (l/sec);
- t = time increment for the interval (minutes); and
- k = unit conversion constant (0.00006).

The calculated loads did not include bedload.

Estimating Sediment Loads from Agricultural Areas

Since MDNR's intention was to develop load reduction strategies, it was necessary to estimate the load term as the annual average load of pollutants to the stream from various sources. Site-specific monitoring data are the best means of estimating annual average pollutant loads when data are available. Since site-specific monitoring data were available for this project, estimates were made from these data.

For each agricultural watershed, pollutant loads during baseflow were estimated by multiplying the average baseflow pollutant concentration by the total annual flow for baseflow days in a 12-month period that began October 1989. Total annual flow for baseflow days was determined by correlating a United States Geological Survey (USGS) gage at Holt Road for days when both locations were at baseflow conditions. For runoff periods, a linear regression model was derived from the runoff data to predict individual storm loads from the peak daily average flow at the USGS gage. These regression models were used to calculate suspended solids loads from each of the three agricultural subwatersheds for the 61 significant storms recorded at the USGS gage during the available 6-year period of record. This period of record included water years 1976-1980 and water year 1990. A significant storm was defined as one that produced a peak daily average flow of at least 2 m^3/sec at the Holt gage, with a peak flow at least 1.4 m^3/sec or 50 percent greater than the flow prior to the storm and with at least 1 day of flow recession preceding the event.

The regression models for storm runoff loads in the agricultural watersheds were developed for storms with peak daily average flows of 2 to 12.2 m^3/sec. Of the 61 storms in the 6-year record at the gage, 53 fell within this range and only 8 were larger. The regression models had R^2 values of 0.94, 0.75, and 0.70 for Marshall Drain, Haines Drain, and Willow Creek, respectively. The total average annual load predicted for the three subwatersheds, including storm and base flow, was 81 metric tons/year.

The average areal suspended solids loading rate for the three agricultural subwatersheds—Marshall Drain, Willow Creek, and Haines Drain—was assumed to be representative of the nonurban portion of the Sycamore Creek watershed upstream of Harper Road. This assumption was valid because these subwatersheds have soil and land use characteristics that are similar to those of the larger Sycamore Creek watershed upstream of Harper Road. They are also subject to the same regional farming practices. Combined, these three subwatersheds drain 9.5 km^2.

Estimating Sediment Loads from Eroding Banks

Annual average channel erosion for actively eroding banks was determined by multiplying the bank height at the location of erosion, the length of the eroding portion, the lateral recession rate, and the density of the soil in the eroding banks. Length and height were estimated from channel survey data collected by MDNR in 1989. The lateral recession rate for a 3.6-kilometer length of the Willow Creek channel with organic soils was determined by comparing 1989 channel cross section measurements with design criteria for the channel when it was last dredged in 1952. For other actively eroding banks, the lateral bank recession rate was assumed to be the same as that of Willow Creek if the soil was organic, and half this rate for banks with loamy soil.

The fraction of the eroded soil that would travel as bedload was subtracted from the channel erosion estimates. This allowed direct comparison with the agricultural and urban load estimates that were based on measurements that did not include bedload. For organic soils, the coarse sand fraction of the bank soil was estimated by collecting a composite soil sample from the stream bank and separating the components gravimetrically by shaking the sample in a bottle with water and observing the thickness of the sand layer after settling. Particle size distributions in the Ingham County Soil Survey (USDA, 1989) were used to estimate the fraction of loamy soil that would travel as bedload.

In Willow Creek, erosion of organic soil on the streambank contributed to the suspended solids loads measured in that watershed. In addition to measured loads, organic aggregates from stream banks were also observed to be traveling semisuspended near the stream bottom. No active bank erosion was occurring in either Marshall Drain or Haines Drain, and therefore measured loads originated only from upland areas in these watersheds. The contribution of channel erosion to measured suspended solids load in Willow Creek was estimated by analyzing COD, turbidity, and suspended solids measurements. Samples from Willow Creek that contained primarily organic sediment from the stream banks could be identified by turbidity measurements less than 75 NTU and/or a ratio of COD to suspended solids that was greater than 0.35. Figure 4 shows the correlation between COD and suspended solids for low-turbidity samples. There is a good correlation because the source of organic solids in the stream bank is homogeneous. These samples were usually collected during the rise and peak of the storm hydrographs.

Estimating Sediment Loads from Urban Areas

An urban load estimation model (Driver and Tasker, 1988) was used to predict pollutant loads from the Mason urban area. The model used rainfall, drainage area, impervious area, population density, and mean January temperature to predict pollutant loads from individual storms. City sewer maps were used to delineate drainage boundaries, and drainage areas were then estimated by overlaying a grid and counting grid squares in the watershed. Aerial photographs were used to estimate impervious area, and the 1980 census provided population density values. The model was used to predict the suspended solids load for each of the storms monitored. While predicted loads agreed with measured loads for Columbia Drain, agreement with

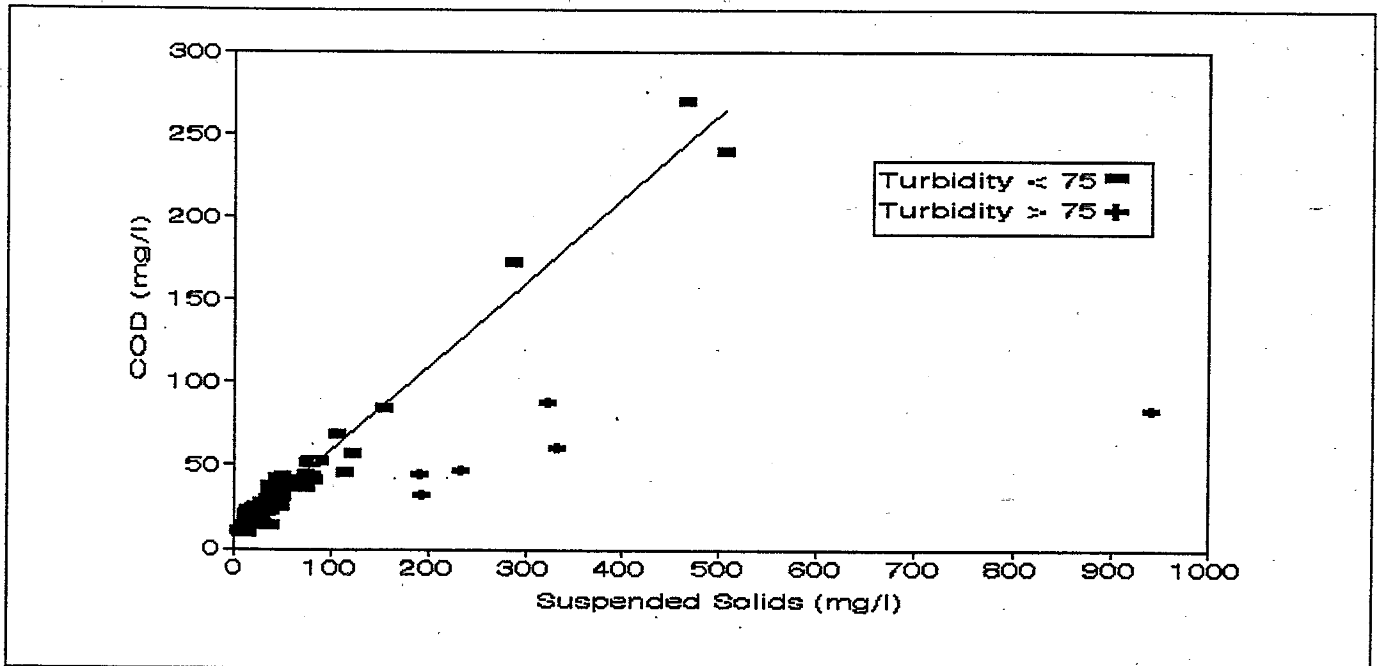

FIGURE 4. Relationship between chemical oxygen demand and suspended solids for Willow Creek runoff samples

measured loads for Rayner Creek was reasonable but not as good.

The model was calibrated by adjusting the bias correction coefficient until model predictions matched measured values. A +290 percent adjustment was made for Rayner Creek, and a -20 percent adjustment was needed for Columbia Drain.

The calibrated model predicted suspended solids loads for rainfall events between April and October for 1976 through 1980 and 1990. Modelers determined the amount of rainfall for each day within this period from precipitation data at Eaton Rapids, which is approximately 19 km southwest of Mason. The model was not used to calculate loads during winter (November-March) because of the possibility that precipitation during this season might include snow, which does not run off immediately. Instead, winter loads were estimated to be 60 percent of summer loads. Modelers assumed that the average areal loading rate from the modeled watersheds was representative of the that portion of the city served by storm sewers.

Annual average suspended solids loads from point sources were calculated from self-monitoring data. A worst-case estimate of the maximum possible load of suspended solids from septic tanks was calculated for a 14.6-square kilometer subwatershed and extrapolated, based on area, to the entire watershed. One-half of the homes without documented on-site treatment were assumed to be directly discharging to the stream or to have a direct link to the stream via underground drains. Septic tanks were assumed to remove 50 percent of the solids.

ALLOCATING LOADS

Controlling suspended solids is most important if the quality of Sycamore Creek is to improve. Less sediment in the creek will improve fish and macroinvertebrate habitat; provide a firmer stream bottom that is more appealing for recreation; deepen the channel, thereby improving navigation potential; and increase oxygen concentrations by reducing SOD and aquatic plant respiration. Model simulations revealed that respiration by aquatic plants contributed significantly to the DO deficit at some locations in the creek. Aquatic plants depend on available nutrients to grow, and since most nutrients are transported to Sycamore Creek while adsorbed to suspended sediment, reducing sediment loadings will address this problem.

At this time, no models reliably predict the effects of reduced suspended solids load on habitat, aquatic life, or SOD. In the absence of more precise models to target efforts to reduce suspended solids loadings, MDNR considered the water quality goals, the pollutant reductions that are achievable with best management practices, and the level of pollutant reduction that is likely to result in a significant (i.e., detectable) response in the stream.

A proportional response by SOD rates to reductions in suspended solids load was considered to be reasonable in the absence of more precise models. Based on the assumption of a proportional response, Figure 3 shows that the suspended solids loading would have to be reduced by 52 percent to reduce DO levels sufficiently to meet the standard at all locations (except downstream of the marsh) during drought flow. Figure 3 shows that a 52 percent reduction in SOD would improve DO at Harper road by 1.1 milligrams per liter. Since the expected DO at Harper Road is 3.9 milligrams per liter, a 1.1 milligrams per liter improvement in DO would allow the DO standard to be met under drought conditions.

Final plans on how to achieve the needed reductions have not been made; however, for discussion purposes, Table 1 presents one possible allocation scheme to achieve the 52 percent reduction. This scheme includes reducing agricultural erosion by 56 percent, reducing stream bank erosion in organic soils by 100 percent, reducing stream bank erosion in loamy soils by 20 percent, and reducing urban sources of suspended solids by 30 percent.

Other reduction strategies are possible, but this strategy is reasonable and can be achieved by carefully targeting areas with high delivery ratios for erosion control measures. These areas include agricultural fields adjacent to the stream, construction sites that are adjacent to the stream or in an area served by storm sewers in the City of Mason, and the most severely eroding stream banks.

IMPLEMENTING POLLUTION CONTROLS

The necessary load reductions will be achieved, in part, by an ongoing USDA program that is intended to reduce erosion on agricultural land by 50 percent by targeting highly erodible areas. However, additional programs tocontrol suspended solids delivery to the stream will be needed to reduce overall loadings by 52 percent.

FOLLOW-UP

Monitoring

Follow-up monitoring is necessary to indicate whether the TMDL adequately protects water quality and the

TABLE 1. **Annual average load of suspended solids from various sources to Sycamore Creek upstream of Harper Road and the load reductions necessary to meet water quality standards**

Source of Suspended Solids	Annual Average Load (metric tons/year)	Load Reduction to Meet Water Quality Standards	Method of Calculation
Organic soil from stream banks	209	100%	change in channel volume over time
Loamy soil from stream banks	238	20%	field estimate
Nonurban (e.g., agricultural fields)	438	56%	regression model and monitoring data
Urban runoff	153	30%	calibrated regression model
Point sources	7.9	0%	self-monitoring data
Septic tanks	4.3	0%	worst-case estimate

aquatic community and to better quantify loads, verify models, and evaluate the effectiveness of controls. Monitoring of three agricultural subwatersheds using a paired sampling approach (Spooner et al., 1985) is being conducted to provide feedback on whether best management practices reduce sediment loads to the stream. Agricultural management practices are being documented by periodic site visits during the sampling season (approximately March-July). MDNR is storing these land use data in the form of input files for the Agricultural Nonpoint Source (AGNPS) model. The AGNPS model results are being compared to actual runoff data for each runoff event that is monitored. This is possible since recording rain gages are being operated in each subwatershed during the monitoring season.

Three years of data collection have been completed. Data from the first 2 years of monitoring were used to estimate loads from agricultural areas as described above. At this writing (December 1992), it appears promising that funding for an additional 6 years is forthcoming from USEPA under the §319 national monitoring program. The future monitoring data can be used to verify and refine the agricultural loading model described above.

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This case study was prepared by John Suppnick, Michigan Department of Natural Resources, in conjunction with USEPA Office of Wetlands, Oceans and Watersheds, Watershed Management Section. To obtain copies, contact your EPA Regional 303(d)/TMDL Coordinator.