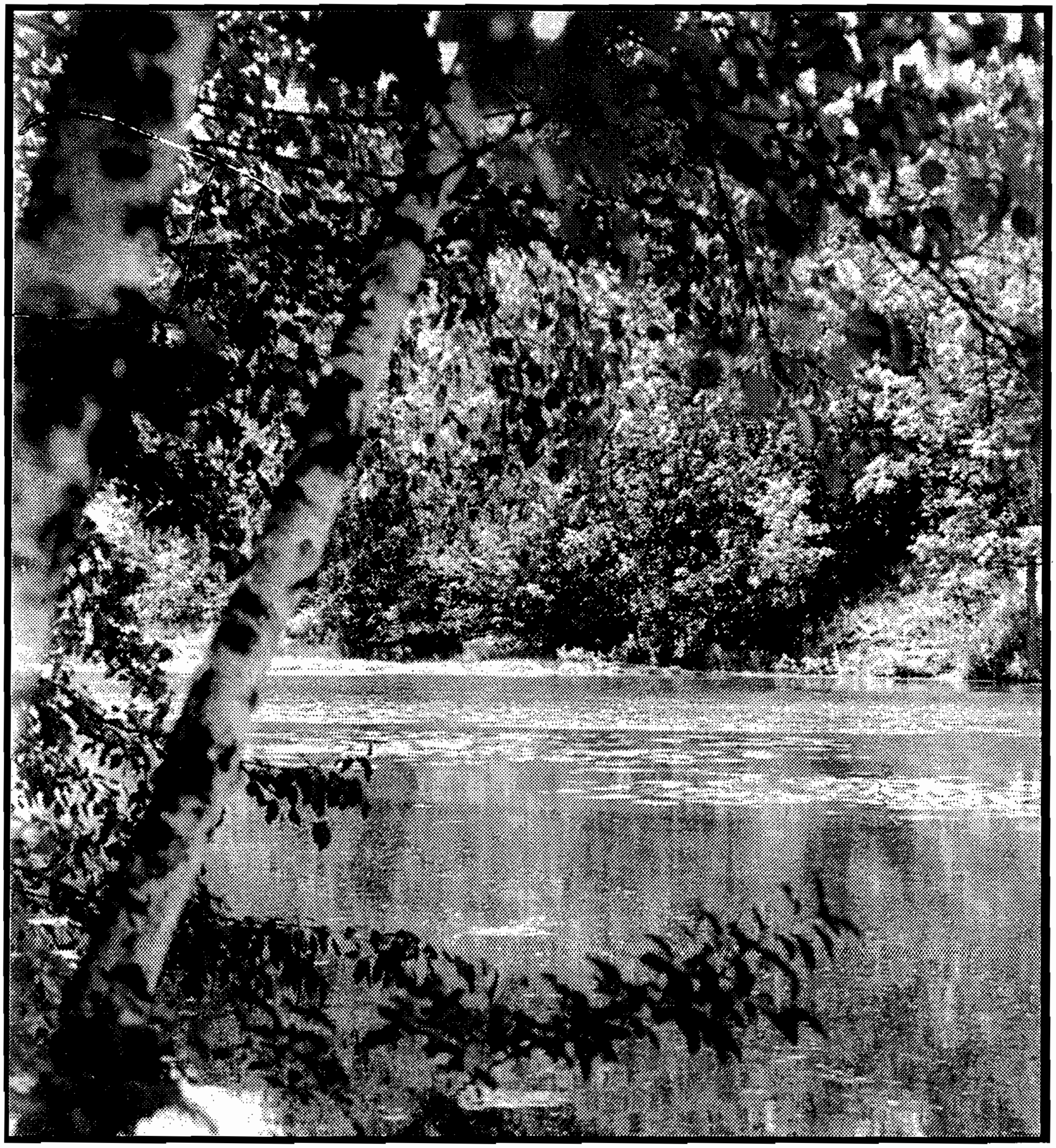
Stewart Lake Restoration and Watershed Management Plan



Prepared by Staff to Dane County Regional Planning Commission

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STEWART LAKE RESTORATION AND WATERSHED MANAGEMENT PLAN

Executive Summary

The water quality of Stewart Lake has deteriorated over the last two decades due to rainfall and snowmelt washing pollutants off surrounding roadways and urban and agricultural lands into the lake. As a result, the recreational use potential and aesthetics of the lake have been degraded. Because of these concerns, a management plan was prepared to provide guidance on stormwater pollution control and lake rehabilitation practices.

Major findings and water quality problems revealed in the plan include:

- Stewart Lake suffers from sedimentation and extensive filamentous algal growth, principally near its southern shore. The lake changes by mid-summer from a moderate fertility to a high fertility (eutrophic) condition. The primary cause of the water quality problems is stormwater runoff carrying high concentrations of suspended sediment and nutrients (phosphorus) into the lake. The internal recycling of phosphorus from bottom sediments in the lake also may induce algal growth.

- Gully erosion near CTH JG and Deer Trail Lane, as well as sediment discharges from agricultural land in the western part of the watershed (east of Hickory Road), are a priority concern and should be mitigated to protect Stewart Lake from further water quality deterioration.

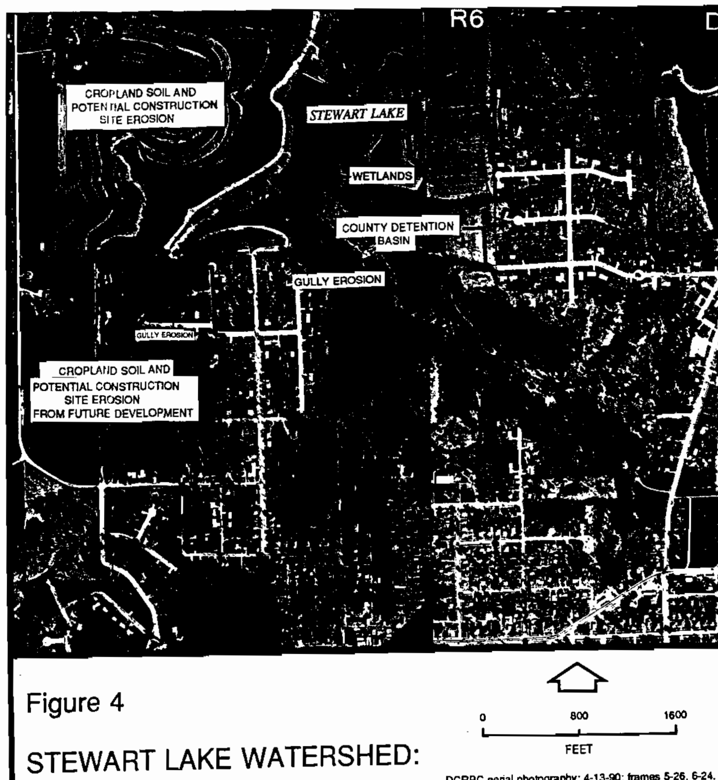

Figure 4

STEWART LAKE WATERSHED:

Areas of Management Concern

DCRPC aerial photography: 4-13-90; frames 5-26, 6-24. Note: photo is not geometrically correct and reflects scale distortion typical of unrectified vertical photography.

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Priority management recommendations include:

1. Stormwater conveyance and gully stabilization measures near CTH JG and Deer Trail Lane should be implemented by Dane County and the Village of Mount Horeb.

2. Construction erosion control *and stormwater management practices* for *planned* development south of Deer Trail Lane should be pursued by the Village. Additional erosion control measures should be evaluated for existing agricultural land (approx. 12 acres) in this area.

3. An experimental project of applying barley straw to inhibit filamentous algal growth in Stewart Lake should be considered by the County Parks Department. Alternatively, County lake management personnel and equipment should be mobilized to attempt to remove filamentous algae when nuisance conditions are observed in mid-summer.

4. Partial lake dredging eventually should be conducted to restore the lake's depth, reexpose springs, improve fish habitat and limit phosphorus recycling. Dredging should not be pursued until sediment discharges to the lake are adequately controlled.

STEWART LAKE RESTORATION AND WATERSHED MANAGEMENT PLAN

INTRODUCTION AND BACKGROUND

Stewart Lake is a six-acre impoundment located north of the Village of Mount Horeb. The impoundment has a maximum depth of 12 feet and was formed in the late 1930s when a new dam was constructed to replace one built earlier in this century. The lake is in Stewart County Park (named after former County Board Chairman Frank Stewart) and is the only nearby water recreation area for local residents. The lake's fishery consists of panfish, bass and stocked rainbow trout. Figure 1 shows the location of the lake's watershed within Dane County.

This plan arises out of concerns over declining water quality conditions (e.g., sedimentation and severe algal blooms) in Stewart Lake, and the need to evaluate watershed management and lake protection and rehabilitation practices. Documented concerns about deteriorating lake conditions date back to the mid-1970s (see Appendix). The Dane County Water Quality Plan (DCRPC, 1990) recommends that the Village of Mount Horeb develop an overall stormwater management plan incorporating water quality protection measures. It also proposes that Dane County develop a lake protection and restoration strategy for Stewart Lake. Dane County was awarded two lake management planning grants from the DNR in 1992-1993 to determine in-lake water quality conditions, monitor phosphorus and sediment loads to the lake, survey lake bottom sediments, and develop a lake restoration plan. The U.S. Geological Survey was then subcontracted to perform monitoring work from April 1992 through September 1993. Based on this monitoring information and other data collected from field investigations and computer models, a lake restoration and watershed management plan was prepared by the Dane County Regional Planning Commission.

The first part of this plan provides general management objectives, the technical approach to evaluating stormwater and pollutant discharges to Stewart Lake, and a description of the watershed. The second part of the plan describes watershed management problems, current and projected stormwater flows/pollutant loads, lake water quality conditions and alternative management strategies. Lake and watershed management recommendations are then presented.

Objectives

A principal objective of the plan is to provide a strategy to protect and improve the quality and recreational uses of Stewart Lake. This may be attained by:

1) **expanding the implementation of erosion and stormwater pollutant control practices to minimize water quality impacts from urban and agricultural land uses;**
2) **controlling drainage and gully erosion problems;**
3) **pursuing in-lake management practices (e.g., filamentous algae and sediment removal); and**
4) **increasing public awareness and individual actions through information/education activities.**

Technical Approach

The Stewart Lake Watershed was divided into subbasins for hydrologic and water quality analyses. The computational models used for these analyses include the Soil Conservation Service (SCS) TR-55 model and the Wisconsin Department of Natural Resources (DNR) Source Loading and Management Model (SLAMM). TR-55 was used in hydrologic evaluations and SLAMM was used in estimating urban stormwater pollutant loads. A description of these two models is contained in a predecessor report to this document entitled *Stewart Lake Watershed Protection and Management Plan* (DCRPC, 1993).

Land use and hydrologic information needed for the models was compiled according to subbasin for existing (1990) conditions and for future long-term or ultimate development conditions. Such information included slopes, soil type, hydrologic soil classifications, vegetative cover, land use type, drainage system characteristics and TR-55 curve numbers. Hydrologic or flow estimates are based on modeling 2-, 10- and 100-year, 24-hour storm events. Stormwater pollution estimates are based on total annual loads. In addition to existing and future conditions, modeling was done for alternative management practice scenarios to illustrate effects on stormwater flows and pollutant loads.

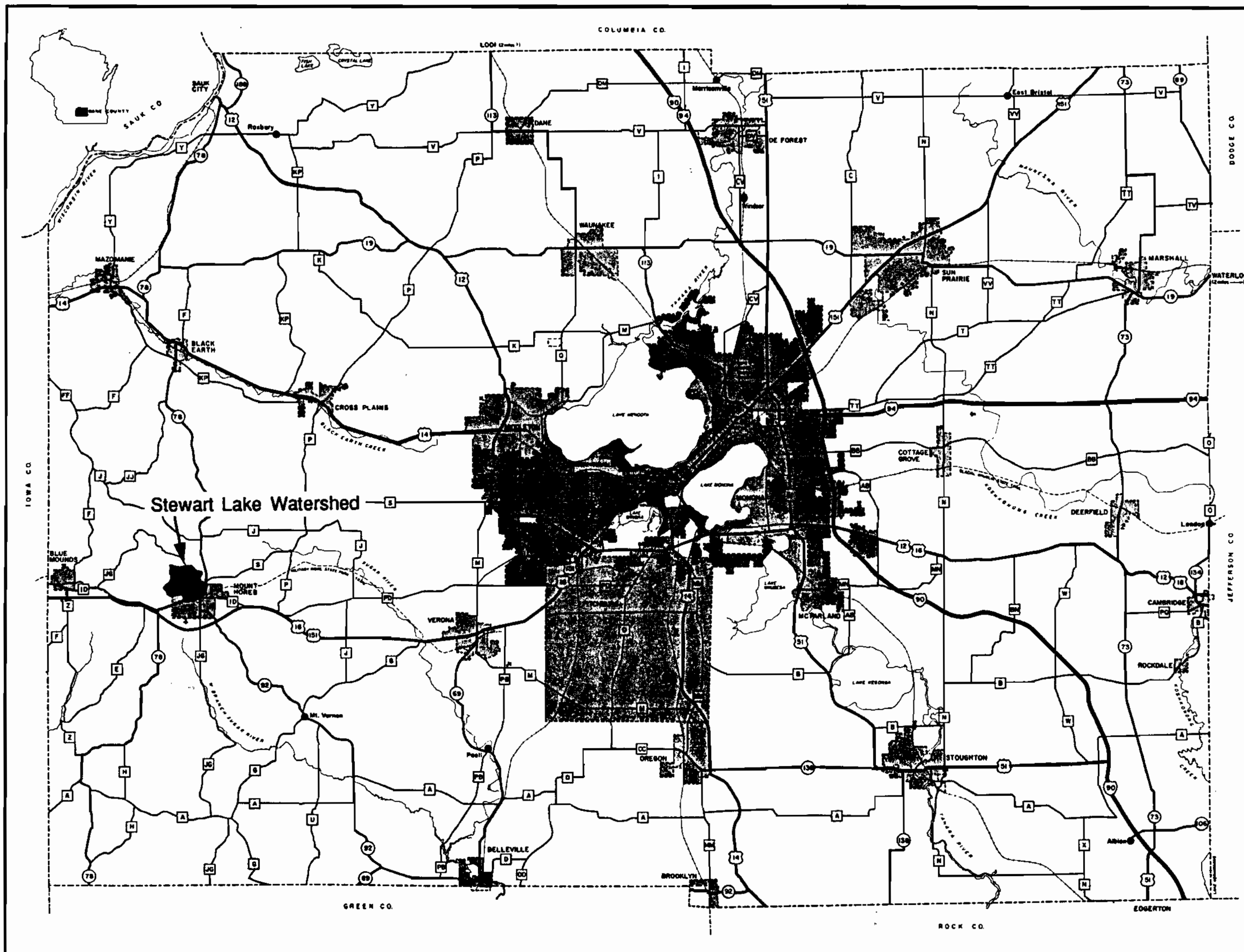


FIG. 1
Stewart Lake Watershed

WATERSHED DESCRIPTION

Land Uses

The Stewart Lake Watershed covers an area of approximately 480 acres (0.75 square miles) on the north side of the Village of Mount Horeb. About 75 percent (368 acres) of the watershed is within the Village of Mount Horeb Urban Service Area (see Figure 2). Much of the watershed in the northern part of the Village already has been developed for urban uses. Most of this development is residential, although there also are some downtown commercial and institutional land uses along State Highway 78.

Significant tracts of agricultural land are found on the west side of the watershed, where residential development can be expected in the long term. In addition, large tracts of vacant land exist along steep slopes and valley bottoms. This land is expected to become permanently protected from development through acquisition for the expansion of Stewart County Park. A comparison of 1990 and long-term land use forecasts is displayed in Table 1.

TABLE 1
STEWART LAKE WATERSHED
1990 AND LONG-TERM LAND USE ACREAGES

Land Use Description[1]	1990	Long-Range
Residential	139	237
Paved Streets	22	35
Commercial/Institutional	6	11
Park and Recreation	125	176
Agricultural, Pasture & Woodland	178	12
Water	6	6

[1]For detailed land use classification and maps, see DCRPC, 1993.

As Table 1 indicates, the watershed is projected to have a 70 percent increase in residential land use (from 139 to 237 acres). Correspondingly, agricultural acreage will be reduced. Although most of the agricultural land will be lost to urban development, some agricultural, pasture and wooded land will be acquired to expand Stewart Park.

The urban development, agricultural and construction activities which have occurred in the watershed have increased stormwater runoff and caused significant loadings of sediment and other pollutants to enter Stewart Lake. Future development is likely to cause similar adverse impacts unless proper management practices are implemented.

Geology and Soils

The Stewart Lake Watershed is in the "Driftless" (unglaciated) region of southwestern Wisconsin. Consequently, the topography is hilly with steep valley walls, rock ledge outcroppings, and well-developed drainage patterns. Most of the steep slopes (commonly over 12%) near Stewart Lake are in conservancy land uses and tree-covered.

The dominant upland soils in the watershed are the Dunbarton and Edmund silt loam series. These are shallow soils on uplands, formed from thin loess and clayey residuum. The soils overlay fractured dolomite bedrock at a depth of only 10 to 20 inches. The available water capacity for these soils is low and permeability is moderately slow. The TR-55 hydrologic classification of these soils is "D."

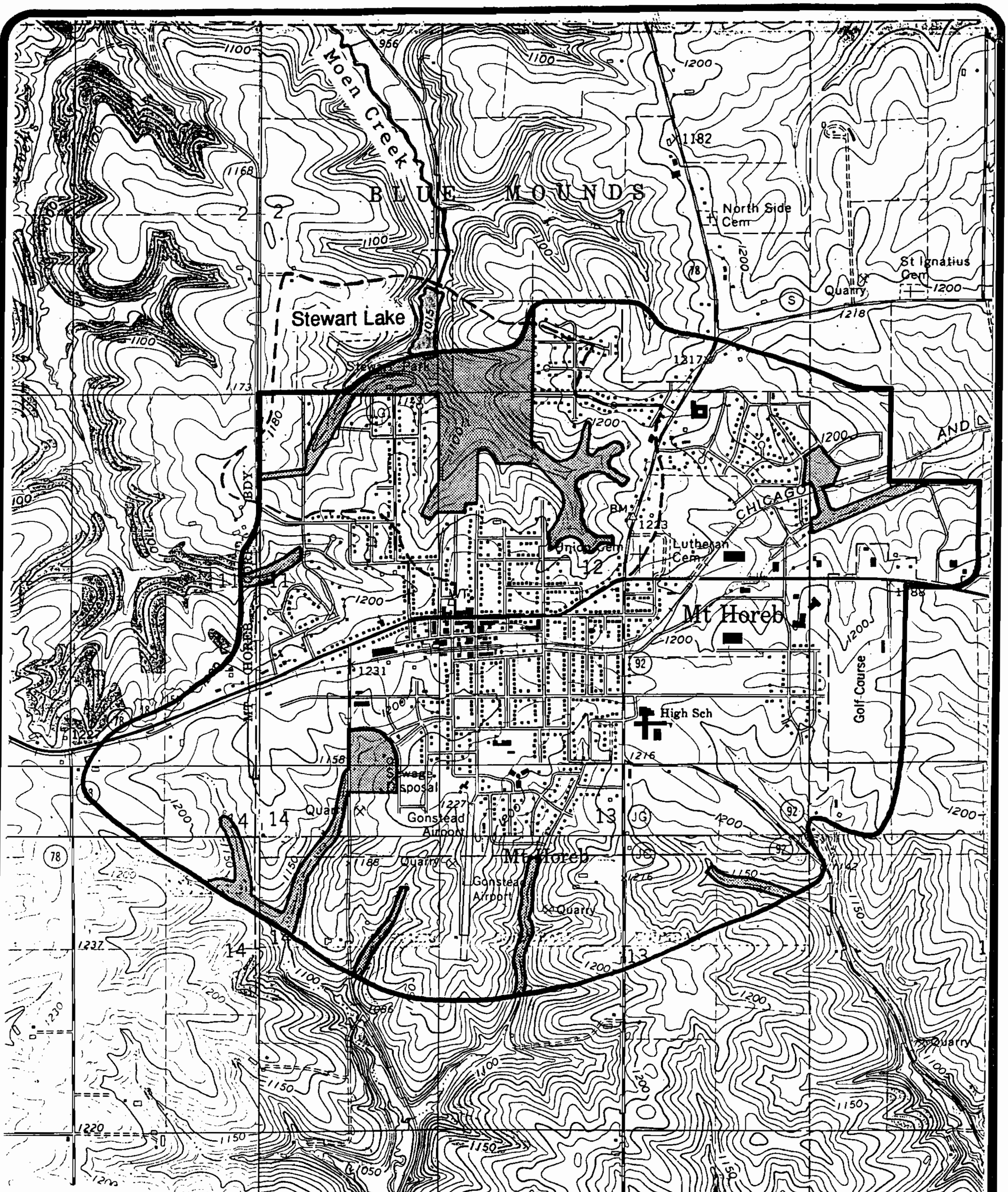


FIGURE 2

MT. HOREB URBAN SERVICE AREA

Environmental Corridor

--- Stewart Lake Watershed Boundary

N

OCT. 81
11/87
1"=2000'

In valley bottoms, soils in Seaton, Elvers and Chaseburg series predominate. These are moderately deep to deep soils formed in locally derived, water-deposited, silty material. The Elvers series is underlain by thick deposits of peat and muck. These soils have a moderate to moderately slow permeability and a seasonally high water table (within three feet of the surface for Seaton and Chaseburg, and within one foot for Elvers). Their hydrologic classification is "B."

Subbasin Delineation and Data

Subbasins were delineated in order to provide flexibility in locating and modeling potential management practices along natural drainage routes to Stewart Lake. A total of five subbasins were delineated. Figure 3 shows the subbasins and the hydrologic character of the watershed, including a map of the Village storm sewers (information on storm sewers is based on construction and historic maps; all sewers have not been field verified.) Each subbasin is comprised of all the upstream areas which contribute stormwater to it. Subbasin 3, for example, covers areas A, B, and C combined. Land use, TR-55 curve numbers and average slope for each subbasin are presented in DCRPC, 1993.

IDENTIFICATION OF WATERSHED PROBLEMS AND POTENTIAL MANAGEMENT APPROACHES

Public concerns have been expressed over declining water quality conditions in Stewart Lake. However, prior to this plan, no recent measurements have been made to quantify or document the lake's condition. Dane County and Village of Mt. Horeb staff also have observed water quality (sedimentation) and gully erosion impacts that have resulted from stormwater runoff. As a result, agency staff meetings and field investigations of the Stewart Lake Watershed were conducted in late 1992 through 1994 to identify specific problem areas and potential management solutions. (Detailed minutes of those meetings are included in DCRPC, 1993).

Of principal concern in the watershed are concentrated stormwater flow problems resulting from steep slopes and surrounding land use, such as paved streets. These factors are responsible for quickly conveying water downgradient to Stewart Lake during rainfall and snowmelt events. This stormwater has sufficient energy to erode and transmit significant amounts of soil and associated pollutants to the lake and its adjacent wetlands.

Stormwater discharges have caused gully erosion problems on hillsides, particularly those immediately south of the lake. Another area where problems from stormwater flows are anticipated is on the northeast side of the watershed at the end of Blue View Drive. To mitigate peak flows from frequently occurring rainfall events, Dane County has funded the construction of a detention basin near this site. It is not judged to be practical or cost-effective, however, to pursue multiple detention basins near the end of every hillside street that conveys water to Stewart Lake, particularly since there are long flow distances between the lake and several of these streets where some sediment deposition may occur.

Agricultural soil erosion from farm fields west and south of Stewart Lake is also contributing to sedimentation problems. In 1987, contour strip-cropping and two grass waterways were installed on these fields to reduce erosion and sediment delivery to the lake.

Also suspected of contributing to lake sedimentation problems is uncontrolled erosion from construction sites, although this has not been well-documented. Residential development has been occurring and is expected to continue within the watershed, particularly southwest of the lake between County Highway JG and Hickory Road. The Village of Mount Horeb enacted a construction site erosion control ordinance in February 1991 to help address this water quality concern.

Accidental events can also impact the lake. For instance, during the summer of 1992 a wastewater overflow occurred due to a break in a sanitary sewer line near the lake. This type of overflow can severely impair lake water quality. In June 1993, the Village of Mt. Horeb installed a secondary generator for its sanitary sewer lift stations to help avert wastewater overflows.

Figure 4 displays existing and potential areas of management concern in the Stewart Lake Watershed as revealed through field investigations. Stormwater discharge and pollutant monitoring, which was conducted by the U.S. Geological Survey, also assisted in identifying source areas contributing to erosion and pollution problems.

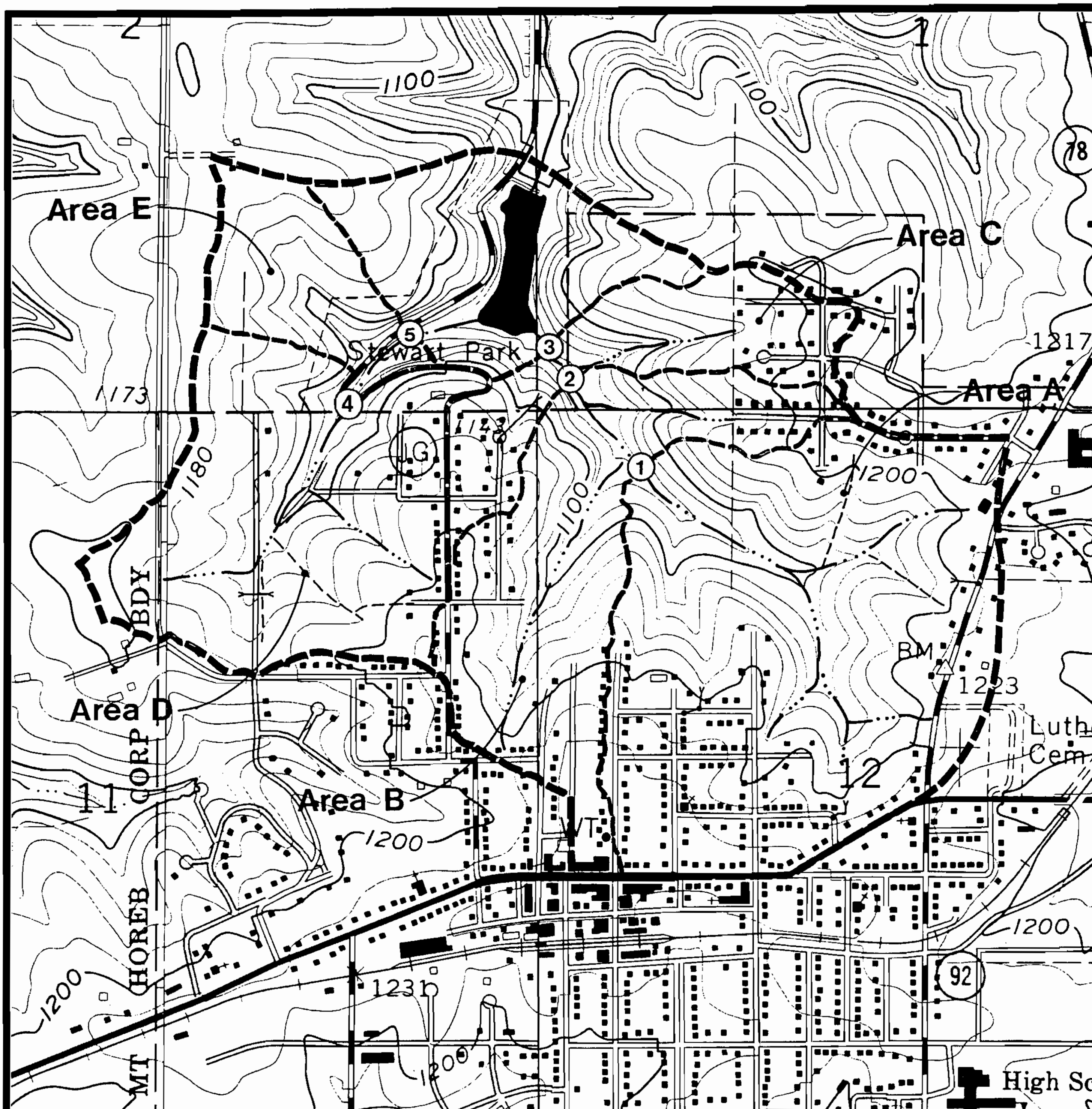
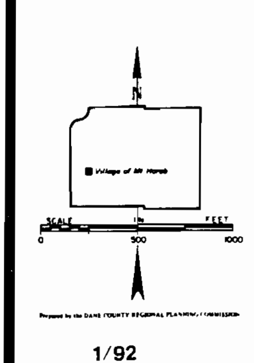


FIGURE 3
STORM DRAINAGE SYSTEM
STEWART LAKE WATERSHED

- Storm Sewer
- Watershed Boundary
- Sub-Basin Boundary, Analysis Point, & Number
- Intermittent Streams
- Perennial Streams
- Greenway Drainage



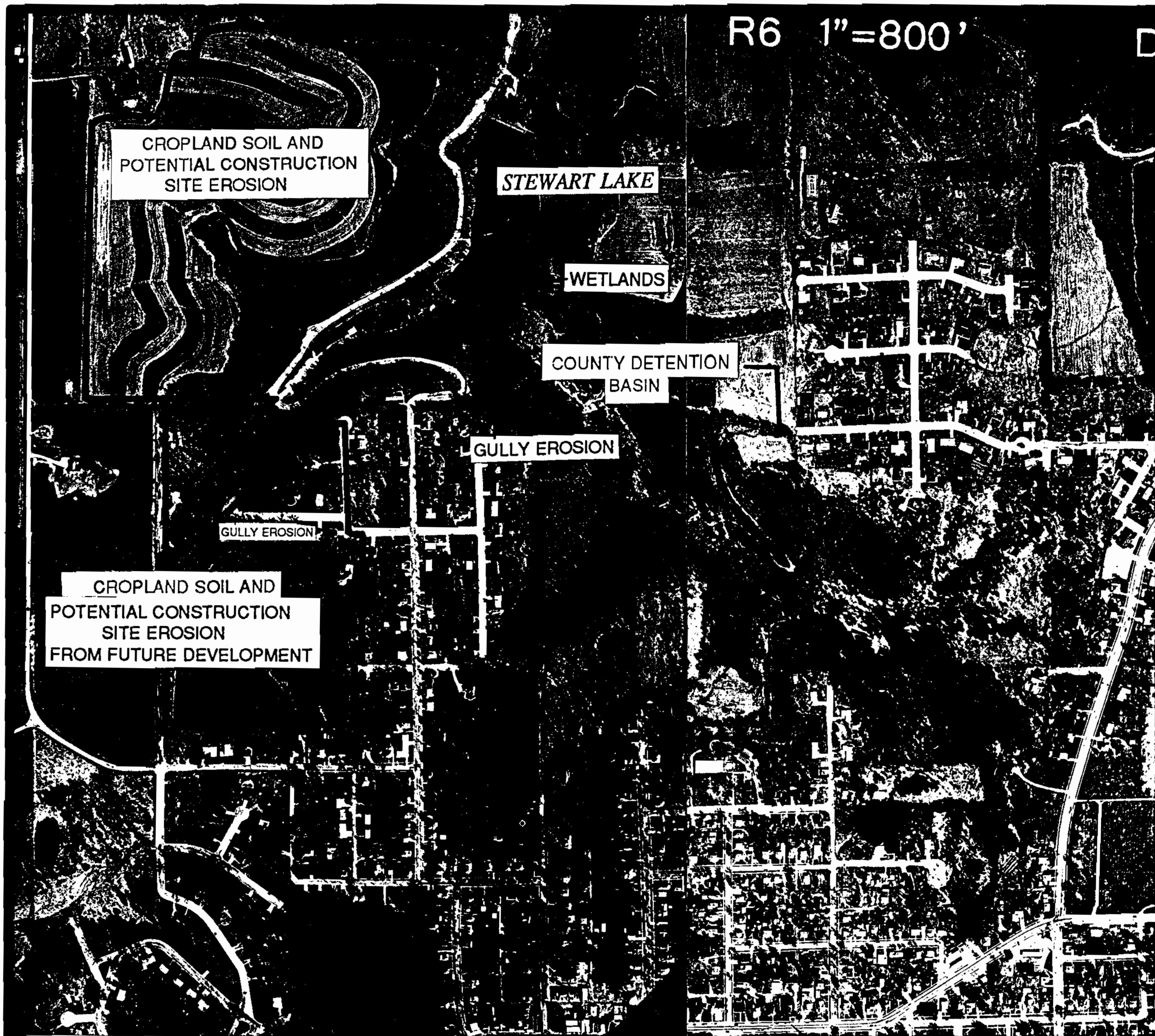
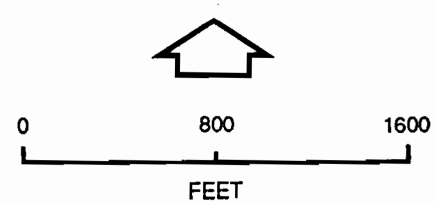


Figure 4

STEWART LAKE WATERSHED:

Areas of Management Concern



DCRPC aerial photography: 4-13-90; frames 5-26, 6-24.
Note: photo is not geometrically correct and reflects scale distortion typical of unrectified vertical photography.

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EXISTING AND FUTURE STORMWATER FLOWS AND POLLUTANT LOADS

Modeled Peak Flows

Hydrologic (TR-55) modeling was done for each subbasin in the Stewart Lake Watershed to determine peak stormwater discharges for existing (1990) and future development conditions. Table 2 displays modeling results.

TABLE 2
STEWART LAKE WATERSHED
PEAK DISCHARGES FOR 1990 AND LONG-RANGE LAND USE

Subbasin (See Figure 3)	Peak Discharge For 1990 Land Use			Peak Discharge For Long-Range Land Use			Percent Change
	2-Year, 24-Hour Event (cfs)	10-Year, 24-Hour Event (cfs)	100-Year, 24-Hour Event (cfs)	2-Year, 24-Hour Event (cfs)	10-Year, 24-Hour Event (cfs)	100-Year, 24-Hour Event (cfs)	
Subbasin 1 (includes Area A)	198	368	670	231	417	736	
Subbasin 2 (includes Areas A, B)	276	513	931	304	557	1,000	
Subbasin 3 (includes Areas A, B, C)	309	571	1,041	331	605	1,088	+7% +6% +5%
Subbasin 4 (includes Area D)	134	251	456	177	312	538	
Subbasin 5 (includes Areas D, E)	161	301	545	226	395	687	+40% +31% +26%

NOTE: Estimates derived from SCS Technical Release No. 55. Assumes No Structural Controls for 1990 and Long-Range Land Use.

There are two principal drainage areas to Stewart Lake--Subbasin 3 to the southeast and Subbasin 5 to the southwest. Subbasin 3 is 290 acres and is about twice the size of Subbasin 5 (132 acres). Correspondingly, 1990 peak stormwater discharges for Subbasin 3 are nearly double the 1990 discharges for Subbasin 5 for all rainfall-runoff events. Peak discharges in 1990 for Subbasin 3 range from 309 cfs for the two-year, 24-hour event to 1,041 cfs for the 100-year, 24-hour event. Peak discharges in Subbasin 5 range from 161 cfs to 545 cfs for these same events. Approximately two-thirds of the total stormwater discharge to Stewart Lake currently originates from Subbasin 3.

Future urban development is expected to occur primarily in Subbasin 5, and this will increase the volume and peak rate of stormwater runoff from this drainage area. The peak discharge in Subbasin 5 for the two-year, 24-hour event increases 40 percent from 161 cfs in 1990 to 226 cfs for the long-range development condition. This future discharge also will represent 40 percent of the total, future two-year discharge to Stewart Lake. Increased stormwater flows from frequently occurring rainfall events may heighten gully erosion concerns in this subbasin.

Since limited development is expected to take place in Subbasin 3, future stormwater discharges from this drainage area will increase only 5 to 7 percent from 1990 conditions. Consequently, this subbasin can be considered hydrologically stable, although existing drainage and gully erosion problems could still be exacerbated by large storm events which may "blow out" channels that have bare soils or only woody vegetation.

Modeled Pollutant Loads

Urban and agricultural pollutant loadings to Stewart Lake were estimated from the Wisconsin DNR's Source Loading and Management Model (SLAMM) and from the Universal Soil Loss Equation (USLE). In addition, potential pollutant loadings from construction site erosion on developing lands were estimated from building construction data and an annual soil erosion rate that is commonly cited for construction sites. A total pollutant load was then determined by compiling loads from each of these types of land use.

Urban Lands

For urban land uses, annual suspended sediment, total phosphorus and heavy metal (i.e., zinc) loadings were determined for each subbasin for 1990 and long-range land use conditions (see Table 3). Most urban land in the Stewart Lake Watershed is found in Subbasin 3, and this drainage area is responsible for nearly 90 percent of the total 1990 urban pollutant (sediment, phosphorus and zinc) load to the lake.

As a result of projected urbanization, the greatest increase in future pollutant loads will be in Subbasin 5. However, zinc, suspended sediment and phosphorus loads from this subbasin will still be only 28 to 35 percent of the total future urban loads to the lake.

TABLE 3
STEWART LAKE WATERSHED
ANNUAL URBAN POLLUTANT LOADINGS FOR 1990 AND LONG-RANGE LAND USE

Subbasin (See Figure 3)	1990 Land Use			Long-Range Land Use			Percent Change		
	Suspended Sediment (Tons)[1]	Total Phosphorus (Lbs)[1]	Zinc (Lbs)[1]	Suspended Sediment (Tons)[1]	Total Phosphorus (Lbs)[1]	Zinc (Lbs)[1]			
Subbasin 1 (includes Area A)	7	36	11	9	47	17			
Subbasin 2 (includes Areas A, B)	11	55	16	14	69	23			
Subbasin 3 (includes Areas A, B, C)	12	65	19	15	78	26	+25%	+20%	+37%
Subbasin 4 (includes Area D)	2	8	2	5	31	8			
Subbasin 5 (includes Areas D, E)	2	8	2	8	42	10	+300%	+425%	+400%
TOTAL FOR ALL SUBBASINS	**14**	**73**	**21**	**23**	**120**	**36**	**+64%**	**+64%**	**+71%**

[1]SLAMM results reflect multiplication of a delivery ratio of .75 since some pollutant deposition is likely to occur because much of the urban area is not storm sewered or paved. Also, figures do not include loadings from construction site erosion and agricultural lands, though there is no agricultural land in Subbasins 1, 2 & 3 for the Long-Range Land Use Scenario.

NOTE: Estimates derived from SLAMM Pollutant Coefficients.

Construction Site Erosion From Developing Lands

Most vacant land in the Stewart Lake Watershed that is likely to be developed is located in Subbasin 5. Soil erosion from this land as a result of future construction activities can be a significant source of water pollution. The DNR has estimated that soil erosion from construction sites can equal and even exceed 30 tons/acre/year, which is considerably higher than average soil loss rates from agricultural lands. The 30 tons/acre rate represents a condition where there are no management controls, and actual soil loss from construction sites can be substantially lower if there is vigorous enforcement of a local construction site erosion control ordinance.

In comparing April 1980 and 1990 aerial photographs, it appears that 28 homes were built in the Stewart Lake Watershed during this time period. Thus, about three homes per year were constructed, principally on low- to medium-density lots, about one-third acre in size. At this rate of construction, approximately one acre of land was being developed annually for residential uses. Using the commonly cited DNR construction site erosion rate (30 tons/ acre), an annual load of 30 tons of suspended sediment may have been generated. This represents about twice the annual suspended sediment load determined for all urban areas in the Stewart Lake Watershed in 1990, as displayed in Table 3.

Within Subbasin 5, there are about 25 acres of land between County Highway JG and Hickory Road that is within Mount Horeb's Urban Service Area Boundary and may be developed in the future. Twenty acres of land to the west between Hickory Road and Bergum Road also is within the urban service area boundary. However, this land has been divided into large (e.g., five-acre) lots and thus limited residential development is expected. Long-range land use forecasts (beyond the year 2010) indicate that approximately 100 acres of land in the entire watershed could ultimately be developed, primarily for residential uses. Based on this forecast and historic building rates, an average of one to two acres of land may be developed annually in the watershed and subject to construction site erosion. Of particular concern is the agricultural land immediately west of Stewart Lake. Because of its close proximity, construction site erosion from this land could severely degrade lake water quality.

Agricultural Lands

Drainage from agricultural lands to Stewart Lake occurs principally from one farm in the northwest part of the watershed (see Fig. 4). South and west of the lake, there are 71 acres of cropland, most of which drain to a channel that goes under County Highway JG. The channel then crosses County Park property and outlets near the lake.

In 1987, a conservation plan was developed for this farm, and contour strip-cropping and grass waterways were installed to control soil erosion. With these management practices in place, predicted annual soil loss (according to the Universal Soil Loss Equation) is now 2.35 tons/acre, which matches the "tolerable" soil loss rate needed to maintain agricultural productivity on these fields.

The amount of soil eroding from this cropland that actually reaches Stewart Lake has not been determined, although a crude estimate can be made by multiplying the soil erosion rate by a standard sediment delivery ratio. Sediment delivery ratios are influenced in large part by a watershed's size and degree of channelization. For small and well-channelized watersheds, such as Stewart Lake's, most eroded material is likely to be delivered to a receiving water body. In viewing textbook charts (Barfield, et al., 1983) on drainage areas versus sediment delivery ratios, and relief-length (channelization) ratios versus sediment delivery ratios, a delivery ratio of over 50 percent to nearly 100 percent is likely from the agricultural fields west of Stewart Lake. Consequently, if a delivery ratio of 0.75 is assumed (halfway between 50 and 100%) and is multiplied by the average soil erosion rate (2.35 tons/acre/year) as well as the cropland acreage (71), a total annual sediment load can be determined. This estimated sediment load is 125 tons/year.

Sediment loads will be substantially lower in the future if agricultural land is taken out of production. Based on long-range land use forecasts, only about five acres of agricultural land eventually may exist in Subbasin 5, and the associated sediment load would be ten tons/year, which is only eight percent of the 1990 load.

Total phosphorus loads also can be estimated by multiplying a common nutrient runoff coefficient (0.5 pounds/ acre/year) for agricultural land by the total cropland acreage (71 in 1990). The resulting phosphorus load is 36 pounds per year.

Cumulative Pollutant Loads From All Land Uses

Table 4 displays total pollutant loads to Stewart Lake for 1990 and future, long-term conditions as compiled from urban, developing and agricultural land uses. Future conditions and loadings **do not** assume additional stormwater management controls than existed in 1990.

In 1990, over 70 percent of the total sediment load to the lake was estimated to originate from agricultural land. However, in the long term, as agricultural land is converted to low- to medium-density residential development, cumulative sediment loadings will be substantially lower (reduced by 60%). In contrast, urban land uses are responsible for most of the current phosphorus and nearly all of the heavy metal (zinc) loads to the lake. These pollutant loads will increase in the future as more urban development takes place. Phosphorus loads are of particular concern because this nutrient promotes algal and rooted aquatic plant growth.

TABLE 4
STEWART LAKE WATERSHED
TOTAL ANNUAL POLLUTANT LOADINGS FOR 1990 AND LONG-RANGE LAND USES

Type of Land Use	1990 Condition			Long-Term Condition			Percent Change
	Sediment (Tons)	Total Phosphorus (Lbs.)	Zinc (Lbs.)	Sediment (Tons)	Total Phosphorus (Lbs.)	Zinc (Lbs.)	
Urban	14	73	21	23	120	36	
Developing[1]	30	Neg.	Neg.	30	Neg.	Neg.	
Agricultural	125	36	Neg.	10	3	Neg.	
TOTALS	**169**	**109**	**21**	**63**	**123**	**36**	**-63% +13% +71%**

[1]Assumes there is not stringent erosion control. Sediment loads can be substantially lower if there is vigorous enforcement of local erosion control ordinance.
Neg. = Negligible.

Storm Event Monitoring Results

In addition to the modeled pollutant loadings, actual field monitoring of flow, suspended-sediment and phosphorus concentrations was conducted by the U.S. Geological Survey on several drainageways in the Stewart Lake Watershed during selected runoff events in 1993. This was done to help verify important source areas in the watershed that may be responsible for a large amount of the pollutant loadings to the lake. Monitoring took place principally from March through September, and results for two runoff events are exhibited in Table 5. Figure 5 displays the locations of monitoring sites. In addition, a comparison of results for the two major tributaries to the lake is presented in Table 6. Highest total phosphorus concentrations generally are consistent with the highest measured suspended-sediment levels.

TABLE 5 STEWART LAKE WATERSHED USGS TRIBUTARY MONITORING RESULTS: 1993							
		Runoff Event of March 29, 1993[2]			Runoff Event of July 9, 1993[3]		
Map No.[1]	Site Location	Suspended Sediment Concentration (mg/l)	Total Phosphorus Concentration (mg/l)	Flow (cfs)	Suspended Sediment Concentration (mg/l)	Total Phosphorus Concentration (mg/l)	Flow (cfs)
1	Top of Trib. by Third St.	535	1.29	0.80 (E)	7,290	3.88	9.0 (E)
2	Main Channel Below Site 1	54	0.43	3.7	NR	NR	NR
3	Middle of Trib.	11	0.38	0.50 (E)	NR	NR	NR
4	Top of Trib. by Blue View Dr.	33	0.60	0.15 (E)	1,700	1.82	0.2 (E)
5	Bottom of Trib.	48	0.30	0.05 (E)	6,800	3.34	1.0 (E)
6	Top of Trib. by Nordic Tr.	21	0.68	0.10 (E)	2,880	2.32	0.5 (E)
7	Bottom of Trib.	47	0.17	0.30 (E)	NR	NR	NR
8	Top of Trib. by Park View Dr.	348	0.56	0.35	NR	NR	NR
9	Bottom of Trib.	88	0.47	0.20 (E)	NR	NR	NR
10	Top of Trib. by CTH JG	28	0.56	0.03 (E)	526	0.47	1.0 (E)
11	Bottom of Trib.	1,320	2.00	0.01 (E)	421,000	86.0	0.5 (E)
12	Main Trib. @ SE end of lake	278	0.52	6.8	8,100	6.82	2.6 (E)
13	SW Trib. @ CTH JG	1,120	1.46	4.6	1,110	1.84	10.0 (E)
14	NW Trib. @ CTH JG	239	0.46	1.1	NR	NR	NR
15	Moen Creek @ Lake Outlet	42[4]	0.36	10.0	NR	NR	NR

Note: (E) = Field Estimate; NR = Not Recorded.

[1]See Figure 5.
[2]Sampling not done simultaneously at all sites, although all samples were collected between 2:08 p.m. and 4:49 p.m.
[3]All samples collected at 1:15 a.m., except for Site 12, where sample was collected at 1:30 a.m.
[4]Sample collected at 5:50 p.m.

TABLE 6 COMPARISON OF RUNOFF EVENT MONITORING RESULTS TWO PRINCIPAL TRIBUTARIES OF STEWART LAKE[1]					
Monitoring Site[2]	Date	Time	Discharge (cfs)	Suspended Sediment Concentration (mg/l)	Total Phosphorus Concentration (mg/l)
12	July 17, 1993	1240	2.3 (E)	5280	3.94
13	July 17, 1993	1240	4.0 (E)	1930	NR
12	July 25, 1993	0320	2.5 (E)	982	1.18
12	July 25, 1993	0350	6.3 (E)	1570	1.80
13	July 25, 1993	0315	2.0 (E)	864	1.04
13	July 25, 1993	0330	3.5 (E)	1040	1.22
12	September 14, 1993	0010	2.8 (E)	1910	2.06
13	September 14, 1993	0005	4.0 (E)	4000	4.52

Note: (E) = Estimate; NR = Not Recorded.
[1]Where samples were collected at approximately the same time.
[2]See Figure 5.

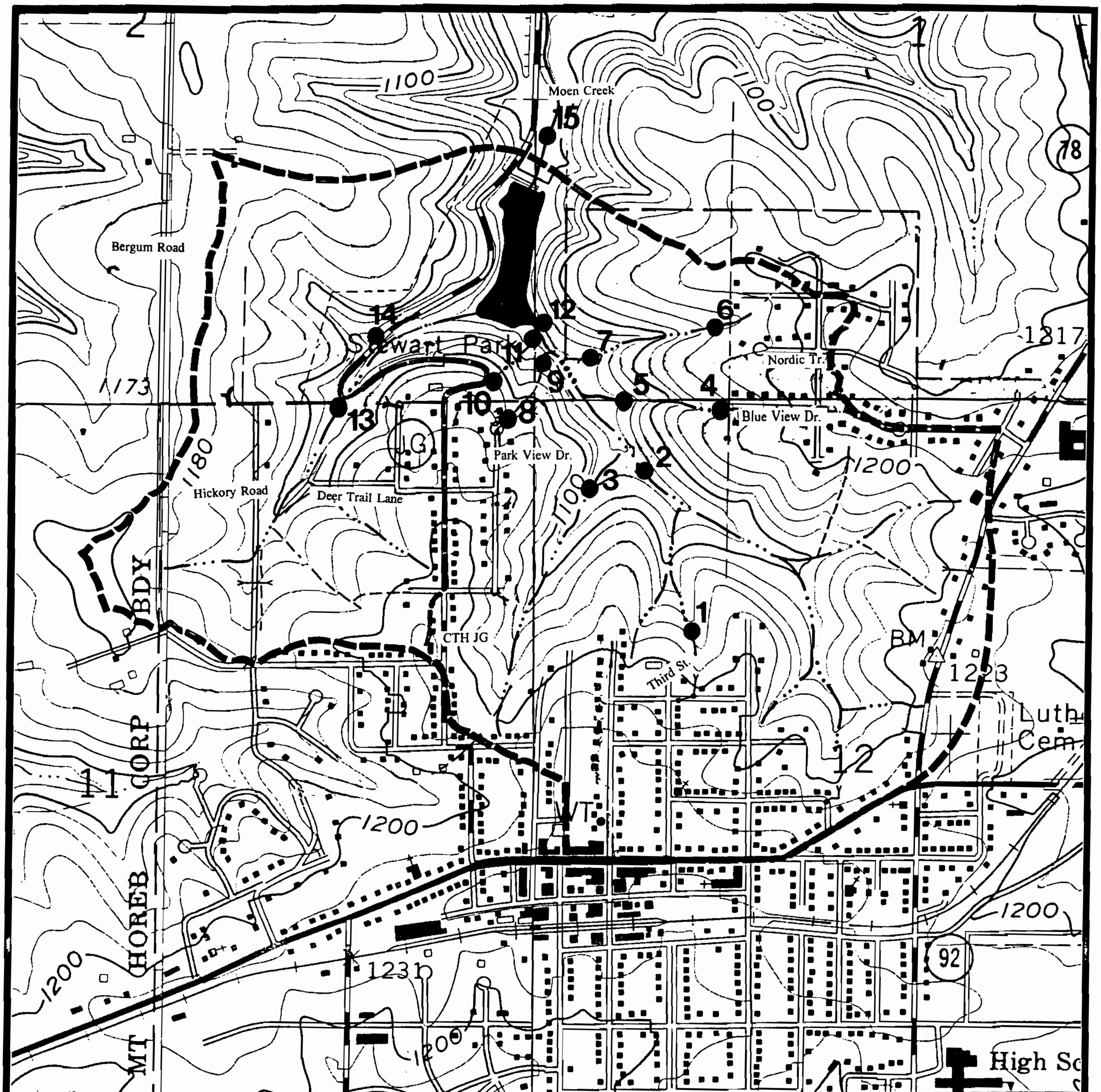
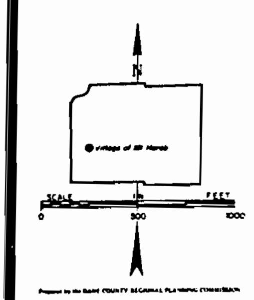


FIGURE 5

Storm Event Monitoring Sites
STEWART LAKE WATERSHED

Watershed Boundary
Monitoring Sites & Number
Intermittent Streams
Perennial Streams
Greenway Drainage



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Monitoring results highlight the pollutant problem associated with gully erosion in the watershed. Site 11, which is the bottom of the unstabilized gully off CTH JG, had an extremely high concentration of suspended-sediment during the July 9 runoff event as compared to other tributaries in the watershed. Even though the estimated flow from site 11 was relatively modest (0.5 to 1.0 cfs), the sediment load from this tributary can have a major influence on the total pollutant load measured at the outlet of Subbasin 3.

Monitoring results also suggest the significance of Subbasin 4 in contributing sediment to the lake. While this subbasin is about one-third the size of Subbasin 3 (95 acres versus 290), its tributary had instantaneous sediment concentrations and flows that were of similar magnitude to that of the principal tributary at the outlet of Subbasin 3. (It should be noted, however, that monitoring of the two sites was not usually done simultaneously, and Subbasin 3 has a longer time of concentration than Subbasin 4, thus the times of peak discharge and pollutant concentration for each subbasin will be different.)

In addition to storm event monitoring, the USGS estimated the average annual quantity of sediment entering Stewart Lake based on 1941 and 1993 lake bed survey maps and sediment core information. Sediment volume and density data were calculated, and an average sediment loading rate of 283 tons/year (over a 52-year period) was determined. This figure is about 100 tons higher than the annual loading estimate derived from model simulations for 1990 land use conditions (see Table 4). The model results, though, do not reflect historic land use conditions (i.e., prior to the implementation of soil conservation practices) or account for sediment delivery from gully erosion; thus the discrepancy between the two estimates may be supportable, particularly if Stewart Lake has a high sediment-trapping efficiency, which appears to be valid.

LAKE WATER QUALITY CONDITIONS

The U.S. Geological Survey also measured the water quality of Stewart Lake in 1992 and 1993. The lake's fertility (trophic) status was determined based on secchi disk (water clarity), total phosphorus and Chlorophyll-a monitoring. (This was done in accordance with an index established by Carlson, 1977.) A summary of trophic state measurements is presented in Figure 6. This is followed by an illustration of the three trophic categories that are associated with different levels of the measured parameters. In addition to these data, depth profiles of dissolved oxygen, water temperature, specific conductivity, and pH were made by the USGS on a monthly basis. Profiles are presented in Appendix A, along with other detailed monitoring data.

Total phosphorus concentrations also have been summarized on a mean monthly basis. These values are presented in Table 7 below and can be compared with specific levels of lake fertility as established by Vollenweider (1968).

TABLE 7
STEWART LAKE MEAN MONTHLY TOTAL PHOSPHORUS CONCENTRATIONS FROM WEEKLY SAMPLING[1] DURING 1992 AND 1993

	May	June	July	August	September	October[2]
Mean concentration (μg/l)	15	16	29	34	34	19
Number of Samples	5	8	10[3]	8	8	5
Standard Deviation	4	5	10	11	6	6

[1]Samples collected at a depth of 1.5 feet by U.S. Geological Survey.
[2]Sampling conducted in 1992 only.
[3]Three of the 10 samples considered outliers and not included in determining the mean.

Note: Total P concentration of: 0-10 μg/l = Oligotrophic condition (low fertility); 10-30 μg/l = Mesotrophic condition (moderate fertility); >30 μg/l = Eutrophic condition (high fertility and nuisance plant conditions). As established by Vollenweider, 1968.

TROPHIC STATE INDICES
STEWART LAKE AT MT. HOREB, WI.
DANE COUNTY

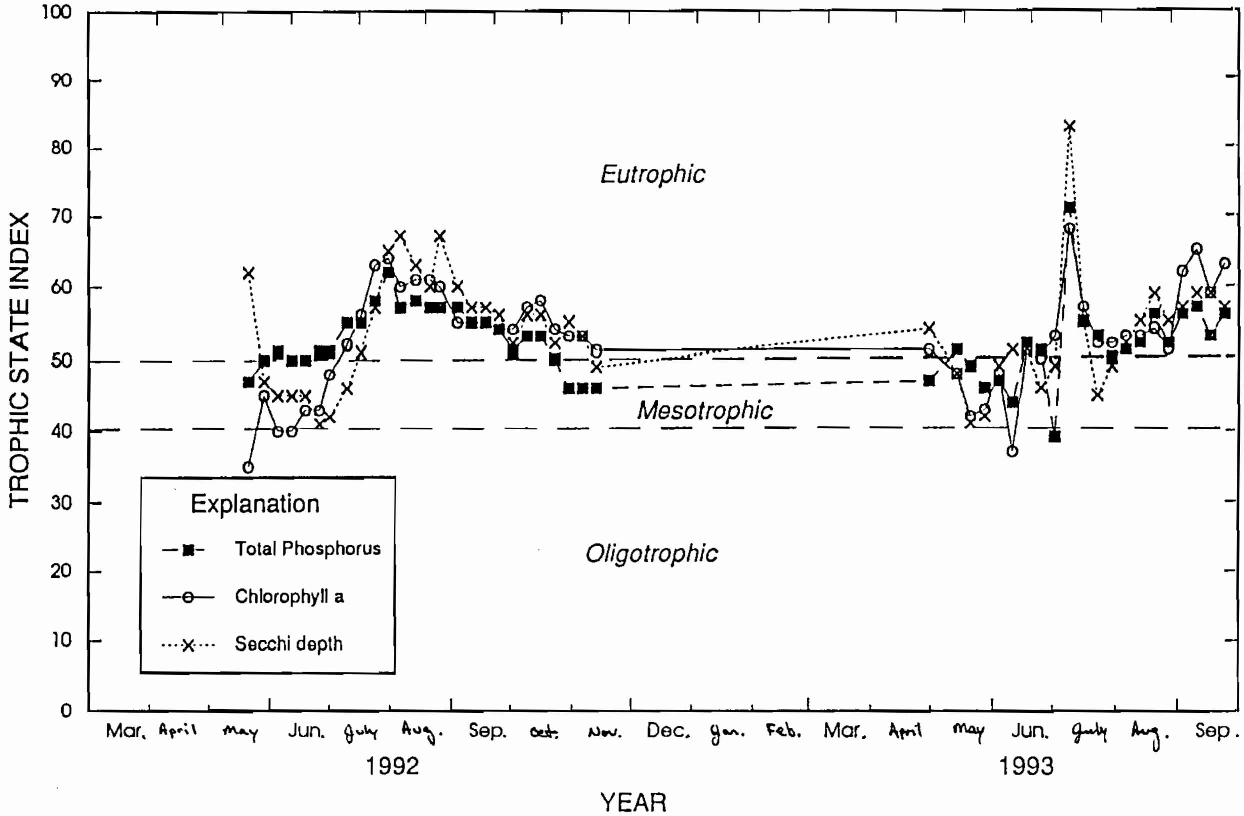
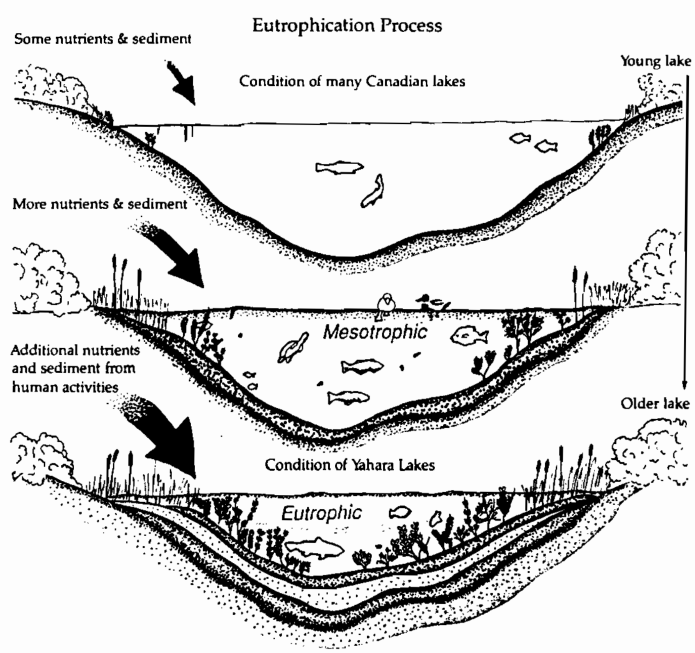


Figure 6. Trophic state indices.



Monitoring results generally indicate that fertility conditions are not problematic (or are acceptable from a recreational use and aesthetic perspective) in Stewart Lake until about July, when the lake changes from a mesotrophic to a eutrophic condition. This fertility level is maintained through September. Elevated phosphorus concentrations during this time period promote nuisance filamentous algal growth as displayed by photos in Appendix B. Algae are prevalent at the southern end of the lake where water depths are shallow (see Figure 7). Abundant rooted aquatic plant growth was not prevalent or a perceived problem, probably because there is not an extensive littoral zone in the lake and there is limited light penetration due to algal growth and/or lake turbidity.

In July and August 1993 sharp declines in dissolved oxygen concentrations were recorded in Stewart Lake between a depth of six and nine feet, with anoxic conditions evident below nine feet (see Appendix A). This depletion of oxygen near the lake bottom may induce the cycling of phosphorus from bottom sediments into overlying water, as well as stress the lake's cold water (rainbow trout) fishery. Fishkills have not been reported, however, even during the winter when low dissolved oxygen levels can again be problematic in shallow impoundments (Stewart, 1994).

High water temperatures (above 75° F) also can stress a trout fishery. The highest water temperature recorded in Stewart Lake over the 1992-93 monthly sampling period occurred on August 27, 1993. The temperature was 25.5° C (78° F) at a depth of 1.5 feet, though at a depth of six feet the temperature was only 20°C (68° F).

Lake Sediment Monitoring Results

Based on an evaluation of two lake bed survey maps prepared in 1993 by the USGS and in 1941 by the engineering firm of Mead & Hunt, the location and thickness of sediment deposits in Stewart Lake have been identified (see Figure 8). (The two maps were not able to be directly compared, however, because certain areas of the lake were not inventoried as part of the early survey.) Based on available information, sediment deposits are thickest (5 to 6 feet) at the southeastern end of the lake near its principal inlet. Part of this area has become completely filled in. The estimated volume of sediment that has accumulated in the lake from 1942 to 1993 is 490,000 cubic feet (18,150 cubic yards). While this is a significant amount, the total area of the lake that has more than three feet of accumulated sediment is in the range of 10 percent (not including the unknown area at the southwest end of the lake) to 17 percent (assuming all of the area at the southwest end of the lake is covered with more than three feet of sediment). In addition, there are about 1.15 acres at the southern end of the lake where water depths are shallower than three feet. This represents only 17 percent of the total lake area, which is a low figure compared to other Wisconsin impoundments, where the total lake area under three feet commonly exceeds 50% (Marshall, 1988).

Eight sediment core samples were analyzed from Stewart Lake in 1993. Density and particle size measurements were made (see Appendix A). The average dry density of the samples is 60 lbs/cubic feet. Using this density number and the sediment volume figure, the weight of sediment accumulated in the lake over a 52-year period is estimated to be 14,700 tons. The particle-size analyses indicated that most (90%) of this sediment is finer than sand (i.e., less than 0.062 mm). Approximately 20% to 30% of the sediment is clay (less than .002 mm).

One of the sediment cores (#1) was analyzed for pollutants, which included 16 pesticides, as well as zinc and lead. DDD, DDE and PCBs were detected, but at very low levels, below standards of environmental concern. Zinc and lead concentrations were within EPA criteria for "unpolluted" sediment conditions. Additional sediment analyses for other potential contaminants and phosphorus may be needed if sediment removal (dredging) is pursued as a lake restoration option.

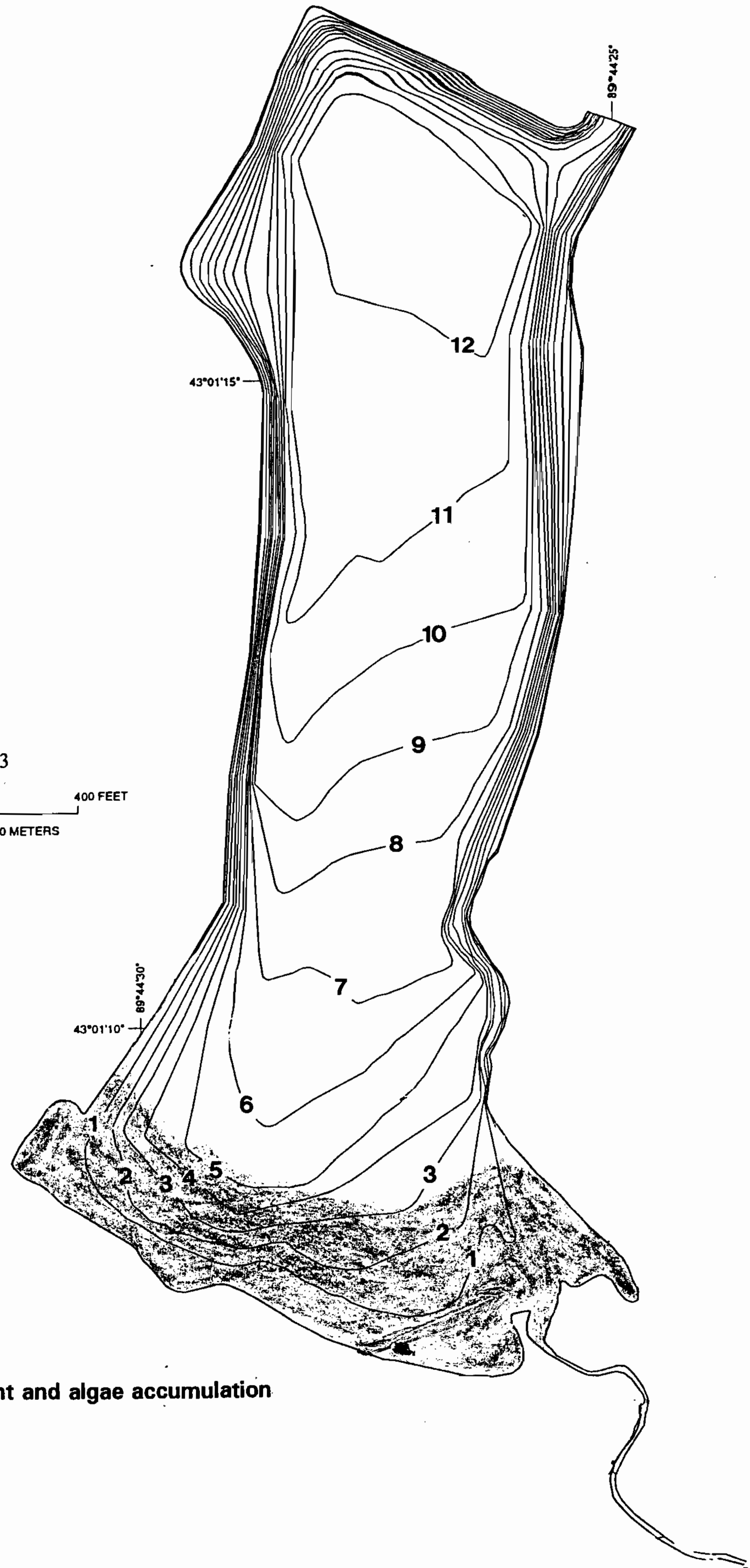


Figure 7

STEWART LAKE

– 2 – Water Depth Contours (in feet)
derived from USGS Lake Bed Survey in 1993

0 100 200 300 400 FEET
0 50 100 METERS

N

Area of sediment and algae accumulation

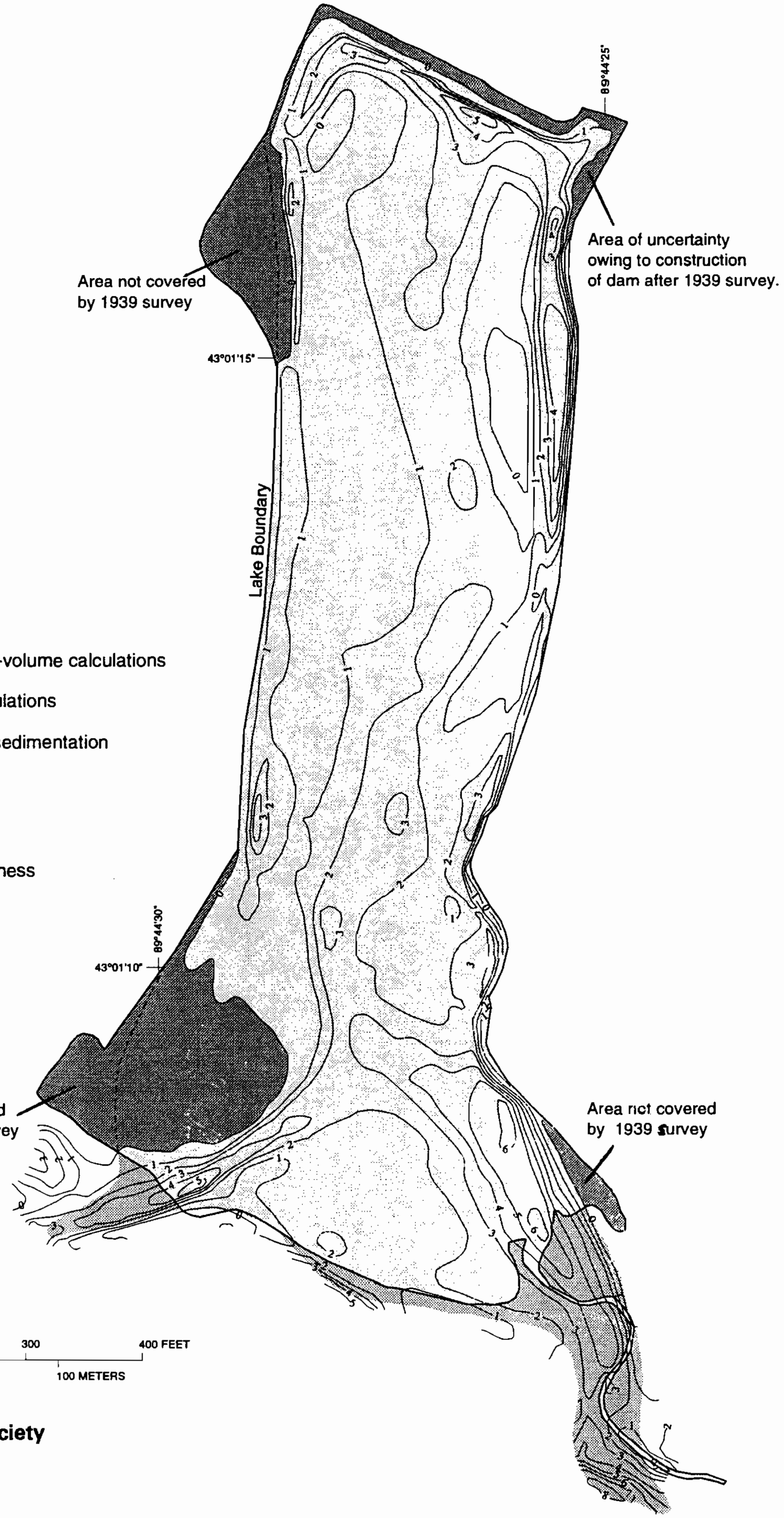
Figure 8

STEWART LAKE

Thickness of sediment accumulation from 1940-93

EXPLANATION

- Areas not included in sediment-volume calculations
- Interior of lake included in calculations
- Lake area completely filled by sedimentation since 1940.
- —— Lake Boundary in 1993
- - - - Lake Boundary in 1940
- –2– Line of constant sediment thickness



N

0 100 200 300 400 FEET
0 50 100 METERS

Prepared by U.S. Geological Society

EVALUATION OF ALTERNATIVE WATERSHED MANAGEMENT STRATEGIES

Alternative management strategies are presented for water quality and gully erosion control concerns that have been identified in the Stewart Lake Watershed. Water quality management strategies were analyzed to illustrate pollutant reductions that might be expected from different levels of management practice implementation. The general cost-effectiveness of these strategies is also presented.

Table 8 indicates watershed management alternatives that were evaluated in accordance with the water quality and erosion control benefits they are likely to provide. The alternatives are associated with varying levels of management effort (i.e., low, moderate and high). Table 9 on page 22 summarizes the estimated pollutant reductions and costs associated with each management alternative.

TABLE 8
ALTERNATIVE WATERSHED MANAGEMENT CONTROLS

Management Level	Practice Description
1. No Action	No additional watershed management controls. Emphasis is placed on in-lake restoration practices.
2. Low Level of Effort	Improved housekeeping practices only.
3. Moderate Level of Effort	Improved housekeeping practices plus structural practice (sedimentation basin) in Subbasin 5. No gully erosion control.
4. High Level of Effort	Improved housekeeping practices plus stormwater filtration or wetland propagation in Subbasin 3. Acquisition of farmland in Subbasin 5. Gully erosion control.

No-Action Alternative

Declining water quality conditions have been observed in Stewart Lake and thus there is an impetus to improve management of the lake. One management option is to refrain from taking any action until more technical data are gathered or to place emphasis only on in-lake restoration practices, such as dredging, rather than expending additional effort and expenditures on stormwater management (i.e., lake protection) measures. However, without additional stormwater quality practices, current sediment loading rates to the lake are not likely to change until much of the agricultural land (which is the largest source of sediment) in the watershed is converted to another use. This is not expected to occur in the near future. Thus it is probable that the effectiveness of in-lake management practices (dredging) will be significantly shortened in the absence of further watershed management controls.

Low Level of Effort - Improved "Housekeeping" Practices Only

Examples of urban housekeeping practices pertinent to stormwater quality management include: aggressive street and parking lot sweeping; timely leaf collection services; vigorous construction site erosion control; judicious use of road deicers; downspout redirection to vegetated surfaces; and public information/education efforts on proper fertilizer and pesticide use as well as pet waste control. These types of practices are relatively inexpensive compared to structural stormwater management measures, and they can have an effect in reducing stormwater pollutants from urban areas.

A summary of the type and level of housekeeping practices provided by the Village of Mount Horeb is provided in Appendix C. If desired, additional attention could be placed on some of these activities within those areas of the Village draining to Stewart Lake. It is particularly important for the Village to stringently enforce its construction site erosion control ordinance. Without enforcement, annual sediment losses from construction sites can exceed that from all urban areas in the watershed, as displayed in Table 4. With stringent ordinance enforcement, sediment losses may be about 50 to 75 percent lower than what is hypothetically shown in

Table 4. As a result, proper construction site erosion control practices can represent the most cost-effective approach to limiting pollution from areas that are being developed.

Regular street cleaning (e.g., once/week) in existing residential and commercial areas may reduce phosphorus, sediment and, to a lesser extent, heavy metal pollutant loadings compared to no cleaning. However, when compared to the Village's current street cleaning efforts (twice/week on main streets and monthly on residential streets) relatively minor additional pollutant reductions (0-10%) would be expected. Therefore, it is difficult to justify increasing street cleaning beyond about one pass every month or every two weeks in most residential areas. Aggressive early spring cleanup and late fall leaf removal efforts for all urban land uses are most important to pursue from a pollutant control standpoint and thus should be encouraged.

As part of housekeeping practices, public information/education efforts can be emphasized to promote citizen actions that will help reduce water pollution. These actions include careful use of fertilizers and pesticides, keeping leaves and yard waste out of streets and storm sewers, and properly disposing of pet waste. Tips on what should and shouldn't be done can be included in the Village's local newspaper, a Village newsletter or some other media source. The Dane County Lakes and Watershed Commission can provide assistance to the Village on possible public information/education activities. The Commission has publications which can be distributed or serve as examples regarding the types of messages the Village may wish to convey to its residents.

Moderate Level of Effort - Housekeeping Practices Plus
Structural Practice (Sedimentation Basin)
No Gully Erosion Control

In addition to improved housekeeping practices, structural management measures often need to be installed in urban areas to substantially control or reduce stormwater pollutant loadings. These measures often consist of stormwater infiltration or detention basins, which have a long storage time to allow for the settling or filtering of pollutants before water flows to a receiving water body. Depending on the type and size of structure, pollutant reductions of 30 to 90 percent can be achieved.

In the Stewart Lake Watershed, a dry detention basin has been constructed by the County to reduce water velocities and gully erosion from a small drainage area off Blue View Drive. The detention basin, though, does not have a long storage time, and thus may not substantially reduce pollutants in the street runoff. Larger detention basins with longer storage times are often needed to provide significant water quality benefits. These types of structural basins are not always feasible, particularly in highly urbanized areas, because they can require a large amount of land and be expensive to install as well as costly to maintain.

Most of the predicted sediment loading in the Stewart Lake Watershed is not from urban areas but rather from agricultural lands (see Table 4). Thus, from a sediment loading standpoint it would not be effective to pursue a structural practice in the urban part of the watershed (e.g., Subbasin 3) without first addressing sediment loadings from agricultural fields (located in Subbasin 5). Soil conservation practices (grass waterways and contour strips) have been installed to reduce soil erosion from these fields; yet the practices still do not appear sufficient to protect Stewart Lake from receiving large quantities of sediment.

An agricultural sedimentation basin could be installed to further reduce pollutant loadings, provided there are suitable site conditions and a willingness by the landowner to build such a structure. If there is a proposal for some of the farmland within the current urban service area to be developed, then an urban sedimentation basin should be considered. Sedimentation basins are typically designed to have a removal efficiency of 50 to 75 percent. Based on the cropland acreage in Subbasin 5 and an average ten-year design storm, at least a one-half-acre basin would need to be constructed. The estimated cost for such a structure would be $10,000 to $30,000, perhaps even higher if site constraints elevate construction bids. Also, these costs do not reflect annual operation and maintenance (O&M) expenses, which are typically in the range of three to five percent of capital costs. Thus, for this sedimentation basin, annual O&M costs would be about $500 to $1,500.

While housekeeping and structural water quality management practices can reduce pollutant loadings to the lake, they do not address gully erosion problems that have been identified in the watershed (see Figure 4). One approach is to withhold from taking any corrective action unless conditions worsen, since expensive structural stormwater conveyance systems, such as storm sewers or paved chutes, may need to be installed to control problem sites. However, without any action soil erosion from these gullies will continue. There are also concerns that with future urbanization stormwater discharges in Subbasin 5 may increase by over 40 percent for frequently occurring rainfall events, which may induce additional gully erosion.

High Level of Effort - Housekeeping Practices, Wetland Propagation, Land Acquisition and Gully Erosion Control

While a structural practice may alleviate sediment loadings from agricultural fields west of Stewart Lake, other pollutant loadings (i.e., phosphorus and heavy metals) that originate principally from urban areas south of the lake (in Subbasin 3) will continue without further management measures. A structural practice such as a wet detention basin could be evaluated in Subbasin 3 to reduce nutrient and metal loadings, although it may not be desirable from a county park use and maintenance perspective. (Based on the size of the contributing drainage area, the detention basin would probably need to be at least one acre in size and would have a phosphorus-trapping efficiency of approximately 25 to 45 percent and a sediment-trapping efficiency of 50 to 90 percent.)

A less expensive alternative to a structural practice, though also less effective, is to establish additional vegetation, such as wetland plant species, which could provide some pollutant adsorption and nutrient uptake from runoff within Subbasin 3. In general, there is a lack of information or experience on creating wetlands for stormwater pollution control. From information that has been gathered, constructed wetlands can have sediment removal efficiencies of 30-90 percent and nutrient removal efficiencies of 0-40 percent, though research findings regarding the nutrient-uptake capabilities of wetland vegetation are mixed. Much of this uptake is seasonal, and nutrients may be released upon the death and decay of plant material in the fall. Thus, in some constructed wetland systems, plants are harvested annually in order to remove pollutants from the system. The average cost to establish wetland vegetation is $1,000 to $3,000/acre, and to optimize pollutant removal, the surface area of wetlands should generally constitute two to three percent of the total area of the contributing drainage basin (Schueler, 1987).

In the Stewart Lake Watershed, there are approximately 1.5 acres of wetland immediately south of the lake. The wetland represents about 0.5 percent of the total subbasin drainage area. During stormwater runoff, this wetland may provide some sediment and nutrient removal functions, which could be enhanced by establishing more wetland vegetation. If feasible, vegetation should be propagated within the main drainage channel leading to the lake, since this channel conveys most of the sediment, phosphorus and heavy metal loadings generated from urban areas in the watershed. An experimental project at creating additional wetland vegetation for stormwater pollutant control could be evaluated in cooperation with researchers from the University of Wisconsin.

Another experimental approach to controlling pollutant (i.e., sediment, nutrients and heavy metal) discharges to Stewart Lake is to establish a membrane or fiber filter within the stormwater drainage network (either near the stream outlet in Subbasin 3 or near the culvert under CTH JG in Subbasin 4). Such a filter already has been designed by the U.S. Forest Products Laboratory, and implemented at a storm sewer outfall in the City of Monona at Interlake Park. The effectiveness of that filter is currently being monitored, and if results prove promising, a similar practice should be considered for the Stewart Lake Watershed.

A alternative approach to structural practices for mitigating pollutant loads is to change land uses that are having a major impact on water quality conditions. While most of the watershed is either developed or permanently owned as parkland, the opportunity to acquire undeveloped agricultural land, which is currently contributing much of the sediment load to the lake, could be explored. Part of this land is located outside of the Village of Mount Horeb's Urban Service Area and thus is not planned to be developed in the near future. (Long-term forecasts, however, indicate this land may be developed for residential uses.)

If acquired, the land would function as an upland buffer area to Stewart Park and would be converted from crop production to permanent vegetative cover. This land also could be used as a site for a stormwater management practice if needed later to control runoff from upgradient development. Since the site would probably not be suitable for public access, a conservation easement may be more appropriate than fee simple acquisition. The estimated cost for this agricultural land is likely to be in the range of $1,500 to $3,000/acre. Significant water quality benefits could be achieved by acquiring either part or all of the land. For example, if half of the 64 acres of cropland west of the lake were acquired, this would cut predicted soil losses by about 50 percent, roughly matching the trapping efficiency of a sedimentation basin.

As indicated earlier, there are also gully erosion areas in the watershed that are of management concern. Two prominent sites are located south of Stewart Lake east of CTH JG and Park View Drive. Another problem area is at the end of Deer Trail Lane. Boulders have been placed in the gully off Park View Drive to limit further erosion; however, even with this practice, some erosion from undercutting has been observed. To resolve existing problems, stormwater conveyance structures (storm sewer pipes or paved chutes) or slope stabilization measures (e.g., polymer applications) should be instituted. Conveyance structures are expensive and illustrate the need for good storm drainage planning as part of overall site and roadway designs for urban developments.

The gully off Park View Drive is about 300 feet long and has a drainage area of 8.5 acres. The gully adjacent to the horseshoe curve on CTH JG extends over 100 feet and has a drainage area of about 2.5 acres. An experimental stabilization compound (polyacrylomite) could be applied to these gullies to limit further erosion. This substance is currently being tested at the Dane County Landfill as a slope stabilization measure. Alternatively, corrugated metal pipes could be installed to convey water downhill from CTH JG and Park View Drive. A pipe from CTH JG could be connected to the Park View Drive drainage pipe (about 200 feet away) in order to direct flow to a central area upstream of Stewart Lake. Based on contributing drainage areas, estimated pipe sizes would be at least 21 and 36 inches in diameter. Their associated capital costs are estimated to be about $45/lineal foot and $90/lineal foot, respectively. An outlet protection structure (energy dissipator) would also need to be installed to prevent scour and outlet erosion. This structure would probably be a concrete or riprap apron, possibly costing $5,000 to $10,000.

Summary of Alternatives

A summarization of the projected pollutant reductions, loadings and preliminary cost estimates associated with each alternative management strategy is shown on Table 9.

TABLE 9
SUMMARY OF POLLUTANT REDUCTIONS AND COSTS FOR ALTERNATIVE MANAGEMENT STRATEGIES

Management Alternative	Potential Pollutant Reduction	Annual Predicted Loading With Management Strategy[1]			Average Cost Estimate
		Sediment[2] (tons)	Phosphorus (lbs.)	Zinc (lbs.)	
No Action	0%	169	109	21	No watershed management costs. Only costs are for in-lake restoration practices.
Low Level (Housekeeping Practices Only)	50% control of construction site erosion. 10% control of phosphorus and sediment from street sweeping and other practices.	153	102	19	$1,000-$1,500 added annual costs for aggressive street cleanup in watershed. $1,000-$2,000 annually for public information/ education activities.
Moderate Level (Sedimentation Basin - No Gully Erosion Control)	Additional 50% control of sediment and 25% control of phosphorus from cropland.	91	93	19	$10,000-$30,000 capital cost for sedimentation basin. Annual O&M cost of $500-$1,500.
High Level (Wetland Propagation/ Stormwater Filter Land Acquisition - Gully Erosion Control - No Sedimentation Basin)	Additional 15% control of urban phosphorus load by wetland vegetation and 50% control of sediment and phosphorus from partial farmland acquisition (32 acres).	87	74	13	$20,000-$30,000 for Wetland Propagation Project ($5,000 for design and $15,000-$25,000 for landscaping and plantings). $48,000-$96,000 for partial land acquisition (32 acres x $1,500-$3,000/acre). $40,000-$50,000 capital costs for structural gully erosion control. Nominal cost for polymer application.

[1]Based on 1990 condition.
[2]Does not reflect contribution from gully erosion.

LAKE RESTORATION STRATEGIES

The principal water quality problems affecting Stewart Lake are excessive sedimentation and nuisance filamentous algal blooms, both occurring predominantly at the southern, shallow end of the lake. The blooms affect the aesthetics and recreational (fishing) use of the impoundment. Accumulated sediment has reduced the lake's volume (actually filling in part of the lake) and may be covering up important spring areas. (Historical field inventories have revealed at least four or five springs in the lake.)

Based on the lake and watershed monitoring information that has been collected, two important management questions should be raised: Can sufficient nutrient and sediment control be accomplished to protect the lake from further deterioration; and what in-lake practices can be used to accelerate the lake's recovery?

To help answer these questions, a phosphorus loading model developed by Vollenweider (1975) was used to predict future trophic state (fertility) conditions based on assumed changes in external (stormwater) phosphorus loadings. Vollenweider classifies as "dangerous" the rate at which receiving waters would become or remain eutrophic (nutrient rich). Vollenweider's model for evaluating external phosphorus loading to a lake is based on the ratio of mean lake depth to hydraulic residence time and phosphorus loading per unit of lake-surface area (see Figure 9). However, the model does not consider internal phosphorus loading (phosphorus released from bottom sediments). Internal loading can be very significant, accounting for 50 percent or more of the total phosphorus input to a lake (Cooke et al., 1993). This level of internal loading also may occur in Stewart Lake, though it has not been able to be estimated from the limited monitoring data that were collected as part of this study.

As Figure 9 displays, Stewart Lake is likely to remain eutrophic even if external phosphorus loadings are reduced 30 percent, which is the goal associated with a high level of stormwater management control (see Table 9). The effect of internal phosphorus loading is not reflected in Figure 9, and such loading will hinder major improvements in lake fertility conditions. However, improvements can still take place and further water quality deterioration abated if there is some control of both internal and external phosphorus loadings. Improved conditions can occur because lake fertility is responsive to nutrient levels in more of a continuum than a threshold manner (as may be incorrectly inferred from the loading models). By controlling phosphorus, sediment loadings to the lake also will be mitigated, which will help prevent further habitat damage.

Various lake restoration techniques exist to address lake quality problems (USEPA, 1988). Most practices emphasize either algal biomass control or macrophyte (rooted plant) control. Some practices can provide multiple benefits. Table 10 provides a listing of available restoration measures and their relative applicability to address conditions found in Stewart Lake.

It is apparent from Table 10 that sediment removal (dredging) would provide the greatest benefit to Stewart Lake, since it could address several lake quality concerns: habitat impairment; internal phosphorus cycling inducing algal growth; threat of rooted weed growth in the littoral zone; and potential spring flow suppression from sediment accumulation. No other restoration practice is capable of addressing all of these issues.

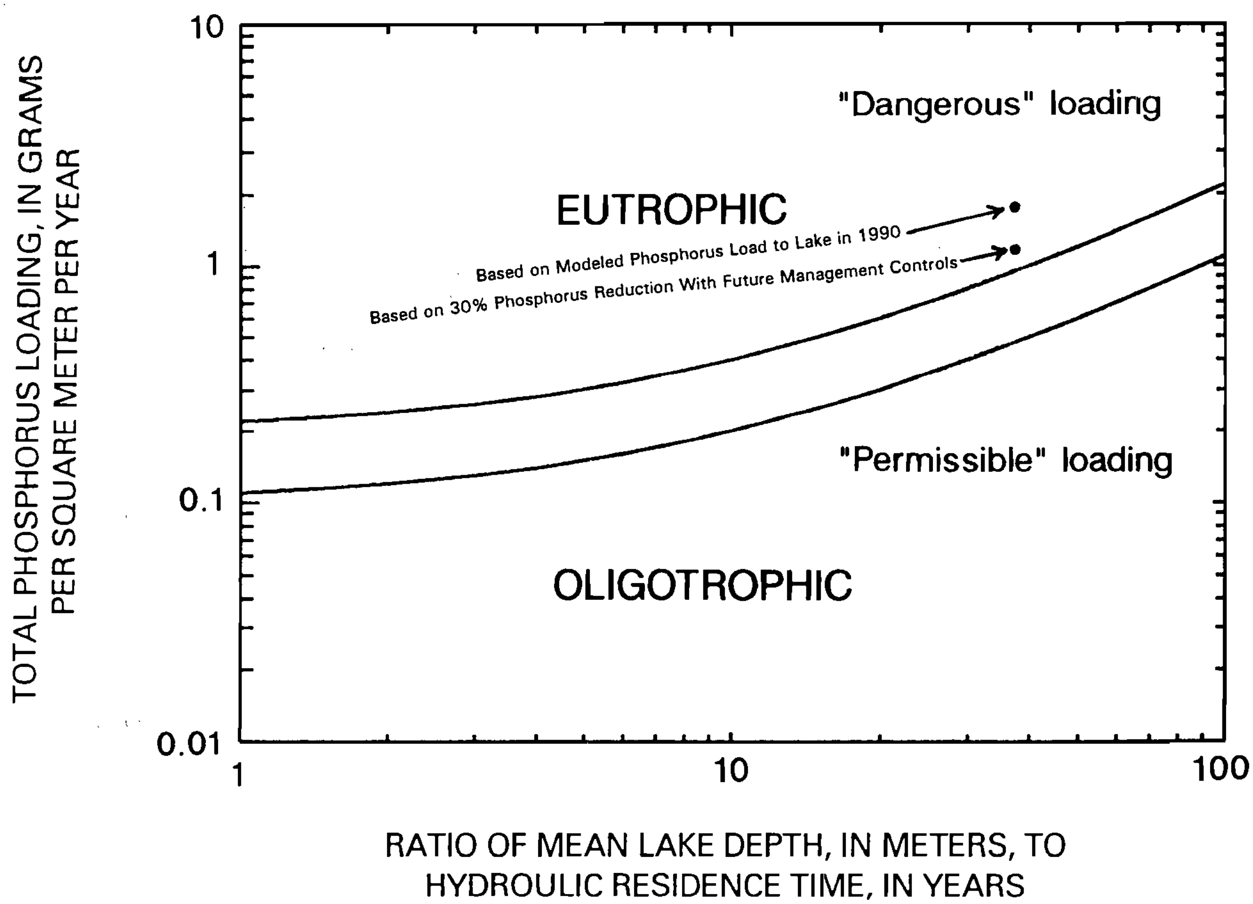


Figure 9. Phosphorus loading classification for Stewart Lake Based on Vollenweider model.

TABLE 10
IN-LAKE RESTORATION TECHNIQUES AND APPLICABILITY TO STEWART LAKE[1]

Practice	Principle	Applicability
Alum Treatment to Precipitate and Inactivate Phosphorus	The continuous, internal release of phosphorus can impair water quality improvement. By adding aluminum salts to a lake and its sediments, the internal cycling of phosphorus can be reduced since aluminum binds with phosphorus. With a limited supply of available phosphorus, nuisance algal growth is less likely to occur.	Phosphorus cycling from sediments may be significant in Stewart Lake. While alum treatment may reduce algal growth, rooted aquatic plants could proliferate in the years following treatment due to increased light penetration. External sources of nutrients have to be controlled in order for this practice to be effective. In a small lake with a short hydraulic residence time, alum may be easily dispersed from bottom sediments, making it ineffective.
Sediment Removal - Dredging	Another method to control the release of algae-stimulating nutrients from a lake is to remove layers of highly enriched bottom sediments. Dredging also reduces rooted aquatic plant densities and increases a lake's depth/volume.	Dredging of selected shallow areas of Stewart Lake could address multiple management issues. Dredging would recover some of the lake's original volume and depth. It could re-expose springs that may be covered with sediment and reduce rooted weed and algal growth through substrate removal and curtailment of internal phosphorus cycling. Long-term benefits could be achieved, but costs are high and an adequate disposal site for spoils has to be identified.
Dilution and Flushing	Dilution is the addition of nutrient-poor water. Flushing involves the addition of large volumes of water to wash out algal cells.	The source of additional, large volumes of water is not readily available. Capital costs for pumps and engineering work would be high. Increased volumes of water released downstream could have negative effects on riparian lands.
Artificial Circulation	This technique is used to prevent or eliminate thermal stratification through mixing of compressed air injected from a pipe at the lake's bottom. Dissolved oxygen levels will improve and algal growth may be controlled.	Significant thermal stratification doesn't occur in Stewart Lake to justify this practice. Also, lake turbidity could increase.
Hypolimnetic Aeration	Dissolved oxygen concentrations at the bottom (hypolimnion) of a lake are increased without destratifying the lake. This is usually accomplished with an airlift device which brings cold hypolimnetic water to the surface, where gases are exchanged, and then returns it to the lake bottom.	Not applicable since Stewart Lake is not considered thermally stratified.
Sediment Oxidation	Nitrate-nitrogen is added to bottom sediments to promote the oxidation (breakdown) of organic matter and denitrification, which reduces phosphorus release from the sediments.	There is limited documentation on the effectiveness of sediment oxidation; thus, it does not have a strong confidence rating. Internal release of phosphorus must be activated by iron redox reactions rather than high pH and temperature. This has not been substantiated for Stewart Lake.
Addition of Algicides/Herbicides	Nuisance aquatic plants are poisoned with chemicals (e.g., Diquat and copper sulfate). Plants are left to die and decompose. A rapid reduction in vegetation can occur for weeks to months, though new plants will regrow, sometimes to densities greater than before.	Copper sulfate could be used to control algae, but treatments do not provide any restorative benefits. Multiple applications per year may be required and there is no carry-over to the following year. General county policy is to avoid the use of herbicides to control aquatic plants.
Food Chain Manipulation	Large numbers of predator fish are introduced to eat smaller, planktivorous fish in a lake. With less planktivorous fish, fewer microscopic animals (zooplankton) are consumed and their population expands. With greater quantities of zooplankton, algae may become less abundant since they are the zooplanktons' food source.	The number and type of fish species in Stewart Lake are not suitable for this management approach. Also, it is experimental and has a poor confidence rating.
Hypolimnetic Withdrawal	Nutrient-rich, oxygen-free water is removed through a deep outlet in a dam or by a siphon, thereby increasing hypolimnetic oxygen levels. This may reduce the impact of sediment-released nutrients on surface water algae.	This practice is not applicable since Stewart Lake is not considered thermally stratified.
Water level Drawdown	By exposing sediments to prolonged freezing and drying, certain plants (roots and seeds) can be destroyed. Other plant species, however, are either unaffected or enhanced. Drawdown also provides an opportunity to repair dams and docks, improve fish management, remove sediment, and install sediment covers to control plant growth.	Drawdown doesn't address the control of algae, only rooted aquatic plants which are not a principal management issue for Stewart Lake. Drawdown could be used to assist with dredging operations, however.
Weed Harvesting	Nuisance rooted plants are cut and removed. Unlike herbicide applications where plants die, decompose and release nutrients and organic matter, harvesting may have some restorative value in lakes with dense plant growth and low external nutrient loading because plant material is physically removed.	The small size and quantity of rooted weeds in Stewart Lake probably do not warrant harvesting with county barge equipment. However, county cutters could be used to remove filamentous algae or selective weeding from shoreline areas with hand tools could be considered.
Biological/Natural Chemical Controls to Reduce Weeds and Algae	Plant-eating or plant pathogenic organisms are introduced to control nuisance aquatic vegetation. The use of grass carp, for example, has been effective in reducing nuisance vegetation in some states; however, there are uncertainties about effective stocking rates. Rotting barley straw has been found to produce a chemical that inhibits algal growth.	Biological controls do not address algae. Experimental approach with only a fair confidence rating for macrophyte control. Wisconsin prohibits the introduction of biological controls (Adm. Code NR 19.27). Barley straw use is applicable for small ponds, such as Stewart Lake.
Shading and Sediment Covers	The use of dyes and coverings on a lake's surface limit plant growth by blocking sunlight. Plastic sheets applied to bottom sediments pose a physical barrier to plant growth.	Sediment covers do not address algal problems. Screening materials are expensive for use over large areas. There is limited documentation on the use and effectiveness of dyes or other methods of lake surface shading.

[1]Derived from: U.S. Environmental Protection Agency (1988); Cooke et al., (1993).

Sediment Removal — Dredging

Dredging is the only lake management technique available to restore impoundments to their original volume. There are several critical elements associated with dredging projects. These include the following: 1) determination of sediment sources; 2) characterization of the sediment; 3) determination of sediment removal areas and depth; 4) environmental problems associated with sediment removal; 5) sediment removal methods; 6) selection of feasible access and sediment disposal areas; 7) water inflow and outflow; 8) long-term impacts on lake levels; and 9) cost considerations. One or more of these considerations may quickly render dredging impractical or too expensive to pursue (Marshall, 1988).

The characterization and sources of sediment in Stewart Lake is discussed elsewhere in this report (see page 16 and Appendix A). Sedimentation and shallow water depths are principally a concern within about a 1.8-acre area in and near the southern part of the lake. The amount of sediment that has accumulated in this area is estimated to be 6,000 to 9,000 cubic yards. (A more precise estimate cannot be made since the sediment thickness in the southwest corner of the lake has not been determined, thus a certain thickness assumption had to be applied to this part of the lake.) From limited sediment analyses that have been done, bottom sediments appear to be relatively clean and should not complicate or limit disposal options. Based on typical contractor dredging costs for small impoundments ($3-$7 per cubic yard or $15,000 to $25,000 per acre), the cost to remove most of the accumulated sediment at the southern end of the lake would be approximately $20,000 to $60,000.

Sediment is usually removed by mechanical (e.g., grab bucket) or hydraulic (e.g., cutter-head suction) dredges. The principal advantage of mechanical dredging is that sediment can be removed at in situ density, and dewatering is typically not necessary for the excavated material prior to removal from the dredging site. However, mechanical dredging is not as precise and controlled as hydraulic dredging and will tend to leave a pock-marked bed with rougher final bed contours (Fitzpatrick, 1994). (Smooth bottom contours, though, may not be important for Stewart Lake.) Dragline dredges, used in sand and gravel mining, also can be efficient in underwater excavating. These dredges have a long working reach of up to 150 to 200 feet, but they also have precision limitations (Fitzpatrick, 1994).

In some instances, water from impoundments can be drawn down and bulldozers and scrapers used to excavate sediment. This approach should be considered for Stewart Lake since water can be drained from the lake and equipment access is available from county park property. (Note: Stewart Lake has been drained in the past as part of early fish management efforts by the Wisconsin Conservation Department, and planning for a future lake drawdown would need to be done in consultation with Wisconsin DNR staff.) Dredge spoils could be transported by lined and covered dump trucks to a suitable disposal site, such as on county-owned property or nearby farmland with owner permission.

While dredging will reduce the amount of sediment-laden phosphorus at the lake bottom, which otherwise would be available for recycling and fostering algal growth, remaining phosphorus in the sediment and lake water will not be tied up or precipitated. Thus internal recycling will still occur and the level of phosphorus and algal control that can be attained with dredging is probably more uncertain than with other lake management practices (e.g., alum and algicide treatments).

Most environmental concerns associated with dredging center around the resuspension of sediment (turbidity) and attached nutrients during their removal. While sediment and nutrient enrichment can disrupt the biological community of a lake, in most cases the effects are short term and negligible (Cooke et al., 1993). Another concern about dredging is that it may destroy the benthic population of fish food organisms and gamefish spawning areas. If a lake basin is dredged completely, two to three years may be required to reestablish the benthic fauna (Carline & Brynildson, 1977). If portions of the bottom are left undredged, reestablishment may be almost immediate (Collett et al., 1981). In any case, the effect of dredging on benthic communities appears to be short-lived and generally acceptable relative to the longer-term benefits derived (Cooke et al., 1993). However, lake drawdown accompanied by bulldozer operation is probably more destructive of the benthic community than conventional dredging methods.

In summary, dredging is a proven, effective practice that can provide long-term ecological benefits. While there are no ongoing operation and maintenance costs associated with dredging, it does have a high capital cost, particularly if a suitable spoils disposal site is not readily available. Also, since much of Stewart Lake is still relatively deep (≈ 80% of the lake is greater than three feet), there is probably not an immediate need to pursue this practice, and it should not be carried out until external sediment loadings are controlled.

Other Lake Management Techniques

Lake Drawdown

Lake drawdowns can be used to expose bottom sediments to the atmosphere for drying and destroying aquatic plants. When this occurs, sediments that are high in organic matter can compact, deepening an impoundment (Marshall, 1988). However, the probable effectiveness of simply drawing down lake levels to increase water depths in Stewart Lake is low, because the organic content of the bottom sediments is low while the inorganic or silt content is high.

Alum and Herbicide Treatments

There are other lake management practices, such as alum and herbicide treatments, that can address the most noticeable problem facing Stewart Lake—nuisance filamentous algal growth. A significant advantage of alum and algicide (e.g., copper sulfate) treatments is that they are substantially less expensive to carry out than dredging, though they need to be performed periodically to provide long-term benefits. Also, alum and algicides represent more direct methods of controlling internal phosphorus cycling and/or algal populations (see Table 10).

These practices, though, do not address bottom sediment removal, and thus they are not of assistance in restoring the lake's original volume and improving existing fish habitat conditions, including potentially enhancing spring flow which could benefit the lake's cold water (trout) fishery. In addition, treating plants with herbicides without removing them can lead to oxygenation depletion and nutrient release due to plant decomposition and subsequent regrowth (Engel, 1990). It is also questionable how effective alum treatments may be in a shallow impoundment with a short water residence time, such as Stewart Lake, since extensive wave action could disperse the alum floc on the lake bottom.

Mechanical Plant Removal

With the exception of algicide applications, filamentous algae are very difficult to directly control. If not attached to densely growing plants, filamentous algae are not effectively removed by conventional plant harvesting equipment. However, harvesters can be adapted with front flares, smaller mesh, pontoons and floating booms to help contain algae (Winkleman & Lathrop, 1993). Small boats or cutters equipped with a "plow" also could be used to push algae to shore for pickup and disposal.

Dane County currently has two weed cutters and selected harvesters that can cut in water 18 inches or less in depth. An attempt to remove algae in Stewart Lake by using this equipment could be made by the Dane County Public Works Department in early to mid-July when nuisance conditions become prevalent. Equipment effectiveness can be evaluated, and mechanical adaptations or alternatives considered if there are impediments to algae removal.

Experimental Techniques — Barley Straw Applications

Lake researchers have found that rotting barley straw produces a natural chemical that inhibits the growth of several planktonic and filamentous algae, without adverse environmental side effects (Welch, et al., 1990). They are recommending that barley straw be applied to a lake or pond twice a year: once in the autumn and once again in the spring before algal growth begins, at about one-third ounce of straw per one-and-one-third cubic yards of water. Wisconsin DNR staff have noted that barley straw has been used in Wisconsin, with mixed results being observed for Traxler Pond near Janesville (Jim Leverance, personal communication).

CONCLUSIONS

1) Stewart Lake suffers from extensive filamentous algal growth and sedimentation, principally near its southern shore. Water quality deteriorates by mid-summer (July) from a mesotrophic (moderate fertility) to a eutrophic (high-fertility) condition.

2) The primary cause of the water quality problems is stormwater runoff carrying high concentrations of suspended sediment and nutrients into the lake. The internal release of phosphorus from bottom sediments also may be responsible for algal growth, though this has not been verified.

3) Gully erosion near CTH JG and Deer Trail Lane and sediment discharges from agricultural lands in the western part of the watershed (east of Hickory Road) are of priority concern and should be mitigated to protect Stewart Lake from further water quality deterioration. If stormwater runoff is not controlled, the effectiveness and longevity of any in-lake restoration practice will be diminished. Consequently, stormwater management measures should be pursued prior to in-lake restoration practices.

4) Of available lake restoration practices, dredging to remove sediment would provide the greatest resource benefits and be the longest-lasting, though it is also the most expensive.

5) County weed removal equipment can be employed and experimental practices (such as the application of barley straw) carried out to try to prevent and remove filamentous algal growth in order to provide immediate, though short-term, recreational use and aesthetic benefits.

RECOMMENDED WATERSHED AND LAKE IMPROVEMENT PROGRAM

The recommended program for the Stewart Lake Watershed is based upon an analysis of lake and watershed problems and an evaluation of alternative management strategies. It also should be recognized that the recommended program stems from a broader planning and policy context, as summarized below.

The framework for the control of stormwater pollution originating from urban, developing and agricultural lands is addressed on an areawide basis in the Dane County Water Quality Plan (DCRPC, 1990), Water Quality Implementation Plan (DCLWC, 1992) and the Dane County Soil Erosion Control Plan (DCLCC, 1988). In addition, recreational and open space needs are put forth in the County Park and Open Space Plan (DCPC, 1990). The recommendations contained in these plans provide overall guidance for management approaches to individual watersheds and urban drainage basins. The Stewart Lake Restoration and Watershed Management Plan represents a refinement and detailing of the countywide plans. As well as seeking integration with adopted county plans, recommendations in the Stewart Lake Plan should be incorporated into locally adopted plans and policies, such as the Village of Mount Horeb Development Plan (1981).

The recommended watershed improvement program addresses both stormwater quality and gully erosion control concerns. These concerns should be dealt with first before extensive lake restoration practices (e.g., dredging) are pursued. Otherwise, the effectiveness of lake improvement efforts will be jeopardized.

Stormwater Management and Gully Erosion Control

The principal stormwater management issue in the watershed is concentrated runoff problems originating from urban and agricultural land uses and steep topography. High stormwater flows can carry substantial amounts of pollutants to Stewart Lake and cause gully erosion.

Of the various management strategies evaluated, housekeeping practices, stormwater filtration/wetland propagation, and agricultural land acquisition (high level of effort) is the alternative most effective in reducing stormwater pollutant loads (see Table 6). This strategy will reduce soil erosion and cut current predicted sediment loads by over 50 percent, largely through partial conversion of farmland close to the lake to permanent vegetative cover (and with limited or no development in adjacent areas). Associated phosphorus and heavy metal (zinc) loadings will be reduced by 30 or more percent. This strategy has a somewhat higher cost than constructing and maintaining an agricultural sedimentation basin (moderate level of effort). Site constraints and the interests of the landowner, however, may preclude construction of such a structure. Alternatively, an urban sedimentation basin should be considered by the Village of Mt. Horeb for the area east of Hickory Road to control stormwater runoff from existing and future development.

The amount of soil erosion from existing gullies in the watershed has not been quantified, though it is significant enough to impair lake water quality and destabilize slope conditions. To reduce erosion and prevent enlargement of existing gullies, slope stabilization through polymer applications or structural stormwater conveyance systems (storm sewers or paved chutes) should be pursued for problem sites in the watershed (e.g., off the horseshoe curve on CTH JG and off Deer Trail Lane). **This should be a management priority.**

Land Use Management of Developing Lands

In addition to land acquisition, aggressive housekeeping practices and structural controls, emphasis should be placed on good *stormwater planning* as part of development proposals. Much of the current gully erosion problems in the watershed stem from the lack of storm drainage planning as part of urban development and roadway designs.

Limiting and controlling erosion and drainage during and after development should be a high priority in any development proposal. A thorough site analysis should precede all construction activities in the watershed. Areas most and least suited for development should be identified. Developments should then be designed to fit the natural terrain to the maximum extent possible. Streets, for example, should be aligned along contours rather than straight up and down hills. The amount of impervious area should be limited to the extent feasible to reduce water runoff, and overall land disturbance should be minimized by minimizing grading. The goal of site plans should be to preserve as much of the existing topography, vegetation and natural drainage system as possible.

Lake Restoration

The initial focus of lake management activities should be on preventing and removing nuisance filamentous algal growth to improve aesthetic and recreational use conditions in Stewart Lake. Immediate though short-term benefits would be provided. County lake management crews and equipment should be used initially to try to accomplish this work. Barley straw applications to inhibit algal growth can be attempted. The use of herbicides is another option to address algae problems, though this is counter to adopted county policy, and crews would still need to be used to collect and dispose of dead plant material.

Dredging represents the only lake management practice that could provide long-lasting ecological benefits by restoring the lake's volume and fish habitat. However, dredging should not be pursued until external sediment loadings to the lake are controlled.

Program Implementation Roles

(Bold type indicates high-priority activities)

Village of Mount Horeb

1. The Village should place additional emphasis on limiting peak rates and volumes of runoff from future development. To do this, the Village should require good stormwater drainage planning as part of any development proposal and provide explicit technical criteria by revising its local construction site erosion control ordinance to specify that runoff rates and volumes should not exceed pre-development conditions. The Village should continue to emphasize stringent enforcement of its ordinance, recognizing the detrimental water quality impacts to Stewart Lake that are likely to occur without proper erosion control measures. **Of particular concern is the developing drainage area east of Hickory Road, including Deer Trail Lane. Erosion control and stormwater quality management practices should be emphasized for this area.**

2. To further protect the lake, the Village also should not seek to expand its current urban service area boundary within the watershed, and through its extraterritorial plat review authority prohibit or limit development to low-density uses (i.e., one-acre or larger lots) of agricultural land west of the lake. Stormwater quality management practices (e.g., wet detention basin) should be required for any higher density development that might occur.

3. The Village should carry out thorough street cleaning practices in the early spring and late fall to control pollutant loads in the watershed. Other housekeeping practices that can provide water quality benefits, such as judicious use of road deicers, should also be pursued.

4. The Village should work with the Dane County Lakes and Watershed Commission in establishing public information/education activities to inform watershed residents of practices they can follow to limit water pollution.

Dane County

5. **The Dane County Land Conservation Department, in association with the County Highway Department and the Village of Mount Horeb, should analyze specific stormwater conveyance and**

the Legislature, the following activities, which are relevant to Stewart Lake, will be eligible for up to 50 percent state cost-share funding:

1) "The purchase of property which would substantially contribute to the protection or improvement of a lake's water quality or its natural ecosystem." (Partial farmland acquisition could qualify.)

2) "The restoration of a wetland or lands draining to a wetland which will substantially contribute to the protection/improvement of a lake's water quality or its natural ecosystem."

3) "The development of local regulations or ordinances, which will prevent degradation of a lake's water quality or its natural ecosystem" (e.g., strengthening and expanding the Village's erosion control ordinance).

4) "Diagnostic/feasibility studies, engineering or landscape design plans proposed as part of an overall lake improvement plan approved by the DNR" (e.g., dredging engineering work).

5) ". . .Watershed management and pollution prevention and control practices" (e.g., a sedimentation basin).

6) "Lake aeration and chemical, biological or physical lake treatment of sediments" (not currently recommended for Stewart Lake).

Activities **not** eligible for funding under revised Adm. Code NR 191 include: **dredging**; design, installation, operation or maintenance of sanitary sewers; **routine chemical treatments or mechanical harvesting of aquatic plants**; water safety patrols; and dam repair, operation or removal.

source control measures needed to solve existing gully erosion problems in the watershed. This includes reviewing the potential use of chemical (polymer) applications to stabilize slope conditions.

6. The Dane County Parks Commission/Department should explore the feasibility of acquiring some of the farmland west of Stewart Lake as an upland buffer or stormwater retention area to the lake and Stewart County Park. Land acquisition represents an effective approach to reducing sedimentation problems in Stewart Lake. If the land is not suitable for public access and use, a conservation easement may be more appropriate than fee simple acquisition. The County also should require land dedication or fees to install a stormwater quality management practice(s) if higher density development (e.g., < one-acre lots) is proposed for this area.

7. The Parks Department also should investigate wetland propagation and other stormwater filtration (e.g., fiber membrane) practices within the principal drainageway south of the lake to provide additional phosphorus control. An experimental project at wetland propagation for stormwater pollutant control could be conducted with assistance from researchers at the University of Wisconsin-Madison Institute for Environmental Studies, Extension, and/or Landscape Architecture Department. However, this should be of lower priority relative to other stormwater management measures, which have a proven level of reliability.

8. **An experimental project of applying barley straw to impair algal growth in the lake should be conducted in the spring and fall by the County Parks Department. The Parks and Public Works Departments also should mobilize lake management personnel and equipment to remove filamentous algae when nuisance conditions are observed in the summer.**

9. The Dane County Lakes and Watershed Division should work with the County Parks and Public Works Departments to evaluate the relative priority, time frame and approach to dredging Stewart Lake. This should be considered as part of the county's proposed overall dredging assessment study.

10. The Lakes and Watershed Division also should offer assistance to the Village and/or local interest groups in promoting citizen information/education activities that can help protect and monitor the water quality of Stewart Lake. An "adopt-a-lake" program could be initiated if sufficient citizen interest exists. For example, participants could organize watershed cleanup days, serve as local pollution watchdogs and/or monitor lake water clarity on an ongoing basis through secchi disk measurements.

Program Cost Estimates and Grant-Eligible Activities

Preliminary cost estimates for the recommended watershed improvement program are displayed in Table 9. Additional housekeeping and public information activities are anticipated to have an annual cost of about $1,000 to $2,000 each. A sedimentation basin is projected to have a capital cost of $10,000 to $30,000, which also represents the general cost range for the wetland propagation project. Partial farmland acquisition (fee simple) is estimated to cost $48,000 to $96,000 based on 32 acres of land at $1,500 to $3,000 per acre. The cost of a conservation easement also could approach this total. Capital expenditures for stormwater conveyance structures to control gully erosion are estimated to be $40,000 to $50,000, though polymer applications, if proven to be effective, would only have a nominal cost.

Lake restoration/management costs would result from dredging and the use of county weed cutting equipment. Contractual dredging costs are estimated to be $20,000 to $60,000. County costs for mobilizing lake management personnel to remove and prevent algal growth would be approximately $500 to $1,000 based on at least two field outings per year. This would be incorporated in the County's annual aquatic plant harvesting budget.

Funding to implement these management activities should be pursued from Dane County, the Village of Mt. Horeb and the Wisconsin Department of Natural Resources. The DNR is currently in the process of developing amendments to its Lake Protection Grants Program (Adm. Code NR 191). If the amendments are adopted by

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APPENDIX A

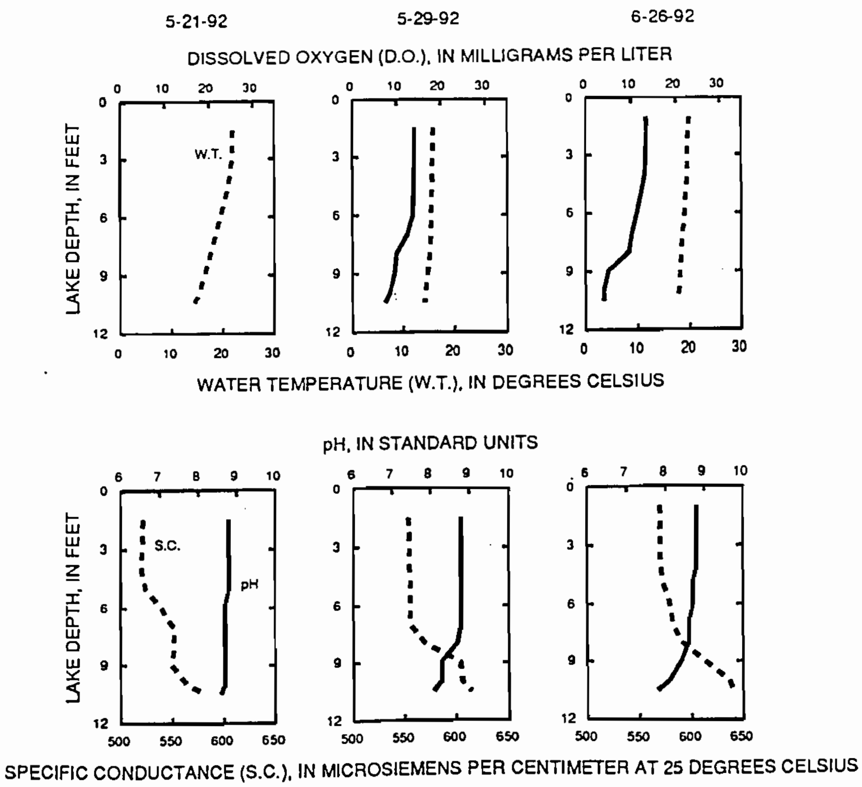
LAKE AND SEDIMENT MONITORING DATA

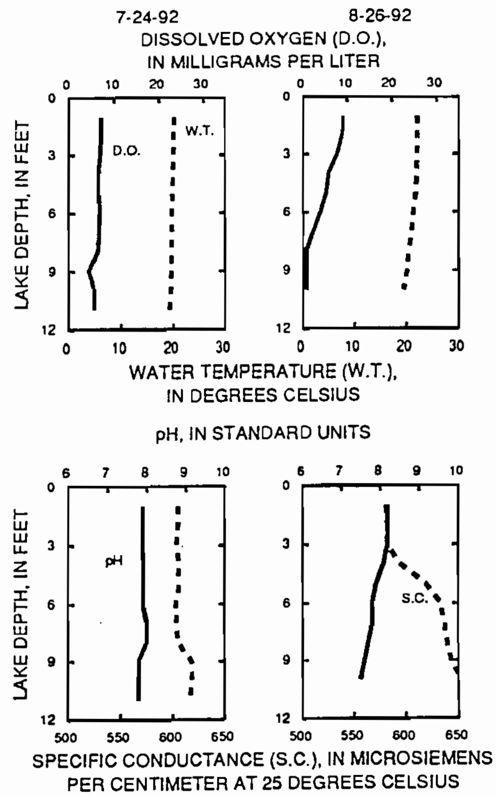
TABLE A-1
STEWART LAKE MONITORING DATA
Water Clarity and Water Quality Analyses and Their Associated Trophic State Indices (TSI)
1992-1993

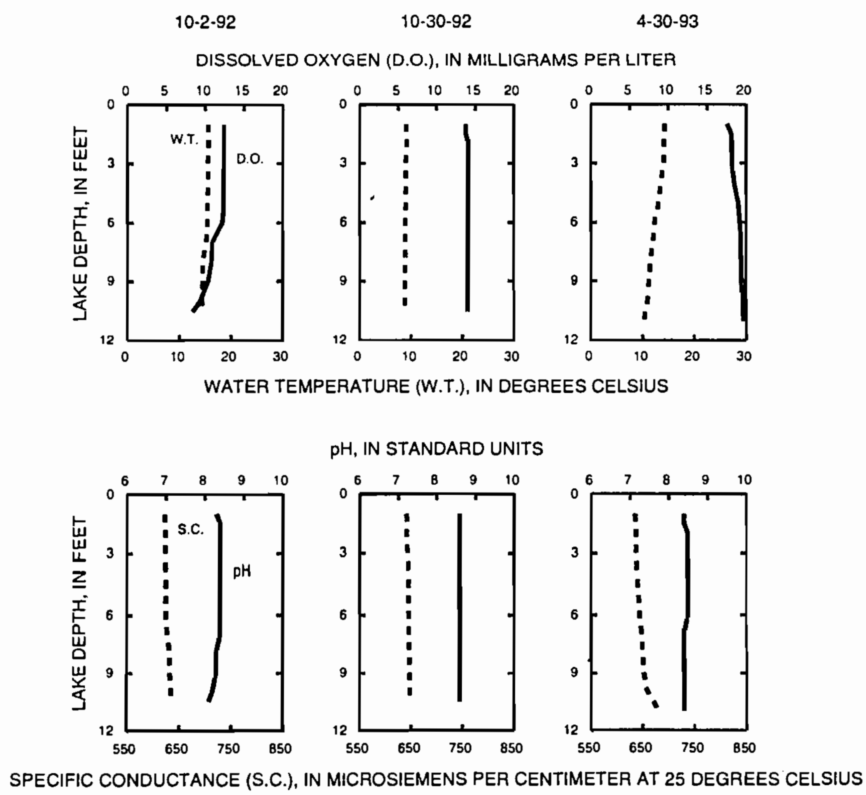
Date	Secchi Disk			Sampling Depth (feet)	Total Phosphorus			Chlorophyll a	
	Depth (meters)	Depth (feet)	TSI[1]		Conc. (mg/L)	Conc. (µg/L)	TSI[1]	Conc. (µg/L)	TSI[1]
5/21/92	0.9	3.0	62	1.5	0.012	12	47	1	35
5/29/92	2.4	7.9	47	1.5	0.017	17	50	4	45
6/5/92	2.9	9.5	45	1.5	0.018	18	51	2	40
6/12/92	2.8	9.2	45	1.5	0.017	17	50	2	40
6/19/92	2.8	9.2	45	1.5	0.017	17	50	3	43
6/26/92	3.7	12.1	41	1.5	0.019	19	51	3	45
7/1/92	3.4	11.2	42	1.5	0.020	20	51	6	48
7/10/92	2.7	8.9	46	1.5	0.030	30	55	10	52
7/17/92	1.9	6.2	51	1.5	0.034	34	55	16	56
7/24/92	1.2	3.9	57	1.5	0.048	48	58	40	63
7/31/92	0.7	2.3	65	1.5	0.076	76	62	49	64
8/6/92	0.6	2.0	67	1.5	0.042	42	57	28	60
8/14/92	0.8	2.6	63	1.5	0.049	49	58	30	61
8/21/92	1.0	3.3	60	1.5	0.039	39	57	31	61
8/26/92	0.6	2.0	67	1.5	0.044	44	57	28	60
9/4/92	1.0	3.3	60	1.5	0.040	40	57	15	55
9/11/92	1.2	3.9	57	1.5	0.032	32	55	14	55
9/18/92	1.2	3.9	57	1.5	0.032	32	55	14	55
9/25/92	1.3	4.3	56	1.5	0.029	29	54	13	54
10/2/92	1.7	5.6	52	1.5	0.019	19	51	11.95	54
10/9/92	1.3	4.3	56	1.5	0.024	24	53	19.7	57
10/16/92	1.3	4.3	56	1.5	0.026	26	53	20.5	58
10/23/92	1.8	5.9	52	1.5	0.016	16	50	12.9	54
10/30/92	1.4	4.6	55	1.5	0.010	10	46	11.4	53
11/6/92	1.6	5.2	53	1.5	0.010	10	46	10.5	53
11/13/92	2.1	6.9	49	1.5	0.010	10	46	8.2	51
4/30/93	1.5	4.9	54	1.5	0.011	11	47	8.68	51
5/14/93	2.3	7.5	48	1.5	0.020	20	51	6.02	48
5/21/93	3.8	12.5	41	1.5	0.015	15	49	2.54	42
5/28/93	3.6	11.8	42	1.5	0.010	10	46	3.08	43
6/4/93	2.1	6.9	49	1.5	0.011	11	47	5.96	48
6/11/93	1.9	6.2	51	1.5	0.008	8	44	1.42	37
6/18/93	1.9	6.2	51	1.5	0.023	23	52	8.31	51
6/25/93	2.6	8.5	46	1.5	0.018	18	51	7.14	50
7/2/93	2.2	7.2	49	1.5	<0.004	4	39	11.5	53
7/9/93	0.2	0.7	83	1.5	0.240	30	71	82.9	68
7/16/93	1.4	4.5	55	1.5	0.030	30	55	18.9	57
7/23/93	2.9	9.5	45	1.5	0.026	26	53	10.2	52
7/30/93	2.1	6.9	49	1.5	0.016	16	50	10.1	52
8/6/93	1.7	5.6	52	1.5	<0.020	20	51	11.1	53
8/13/93	1.4	4.6	55	1.5	0.023	23	52	10.4	53
8/20/93	1.1	3.6	59	1.5	0.036	36	56	13.2	54
8/27/93	1.4	4.6	55	1.5	0.022	22	52	8.3	51
9/3/93	1.2	3.9	57	1.5	0.037	37	56	35.4	62
9/10/93	1.1	3.6	59	1.5	0.039	39	57	52.3	65
9/17/93	1.1	3.6	59	1.5	0.024	24	53	24.5	59
9/24/93	1.2	3.9	57	1.5	0.038	38	56	43.1	63

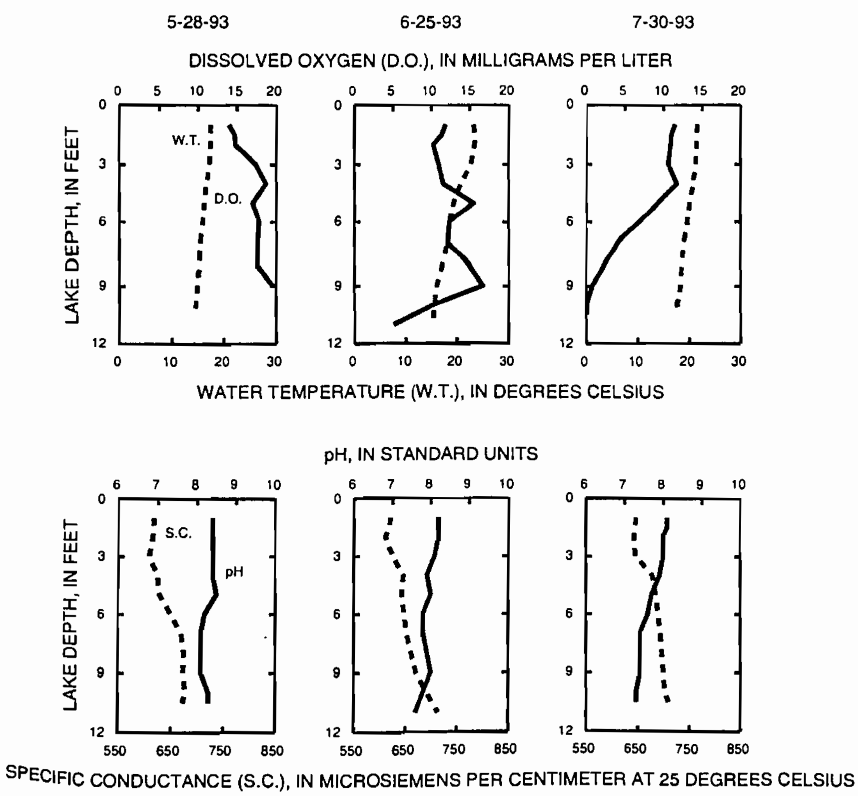
Note: Data collected by U.S. Geological Survey.
[1]TSI of <40 = Oligotrophic conditions; 40-50 = Mesotrophic conditions; > 50 = Eutrophic conditions. Based on Index developed by Carlson (1977).

STEWART LAKE DISSOLVED OXYGEN, WATER TEMPERATURE pH AND SPECIFIC CONDUCTIVITY PROFILES








5-28-93
6-25-93
7-30-93
DISSOLVED OXYGEN (D.O.), IN MILLIGRAMS PER LITER
0 5 10 15 20
W.T.
D.O.
LAKE DEPTH, IN FEET
0 3 6 9 12
0 10 20 30
WATER TEMPERATURE (W.T.), IN DEGREES CELSIUS
pH, IN STANDARD UNITS
6 7 8 9 10
S.C.
pH
550 650 750 850
SPECIFIC CONDUCTANCE (S.C.), IN MICROSIEMENS PER CENTIMETER AT 25 DEGREES CELSIUS

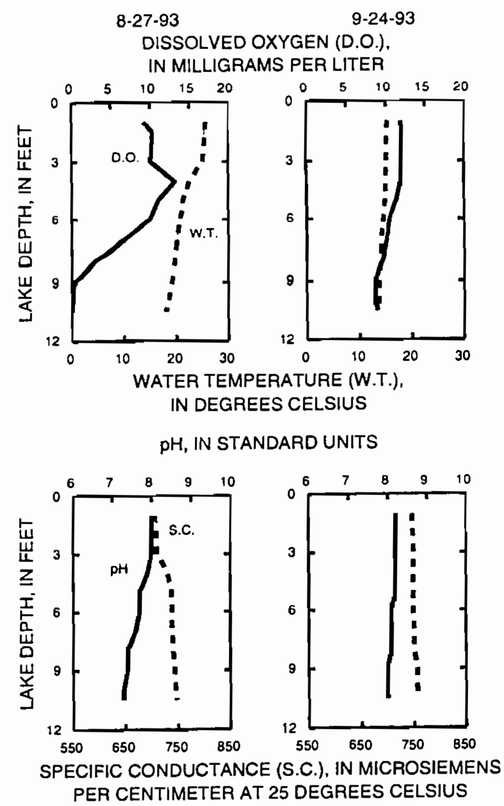

8-27-93
9-24-93
DISSOLVED OXYGEN (D.O.), IN MILLIGRAMS PER LITER
0 5 10 15 20
D.O.
W.T.
LAKE DEPTH, IN FEET
0 3 6 9 12
0 10 20 30
WATER TEMPERATURE (W.T.), IN DEGREES CELSIUS
pH, IN STANDARD UNITS
6 7 8 9 10
S.C.
pH
550 650 750 850
SPECIFIC CONDUCTANCE (S.C.), IN MICROSIEMENS PER CENTIMETER AT 25 DEGREES CELSIUS

TABLE A-2 DENSITY AND PARTICLE SIZE OF BED SEDIMENT IN STEWART LAKE			
Core[1]	Bulk Density (feet)	Particle Size (feet)	Density (lb/ft^3)
1	—	1.5 - 1.7	—
2	1.4 - 1.7	1.2 - 1.4	71.9
3	0.6 - 0.9	2.2 - 2.5	32.5
4	0.6 - 0.9	—	70.9
5	1.4 - 1.7	0.5 - 0.7	60.3
6	1.6 - 1.9	0.4 - 0.6	54.2
7	1.5 - 1.8	1.2 - 1.5	56.6
8	0.0 - 0.5	—	57.6
9	0.6 - 0.9	—	11.2[2]
10	—	0.3 - 0.6	—
11	1.3 - 1.6	0.7 - 1.0	76.1
		Average, excluding core #9	60.0

Note: All except core #8 were sampled with a 2.25-inch diameter core. Core #8 was sampled with a 2-inch diameter core.

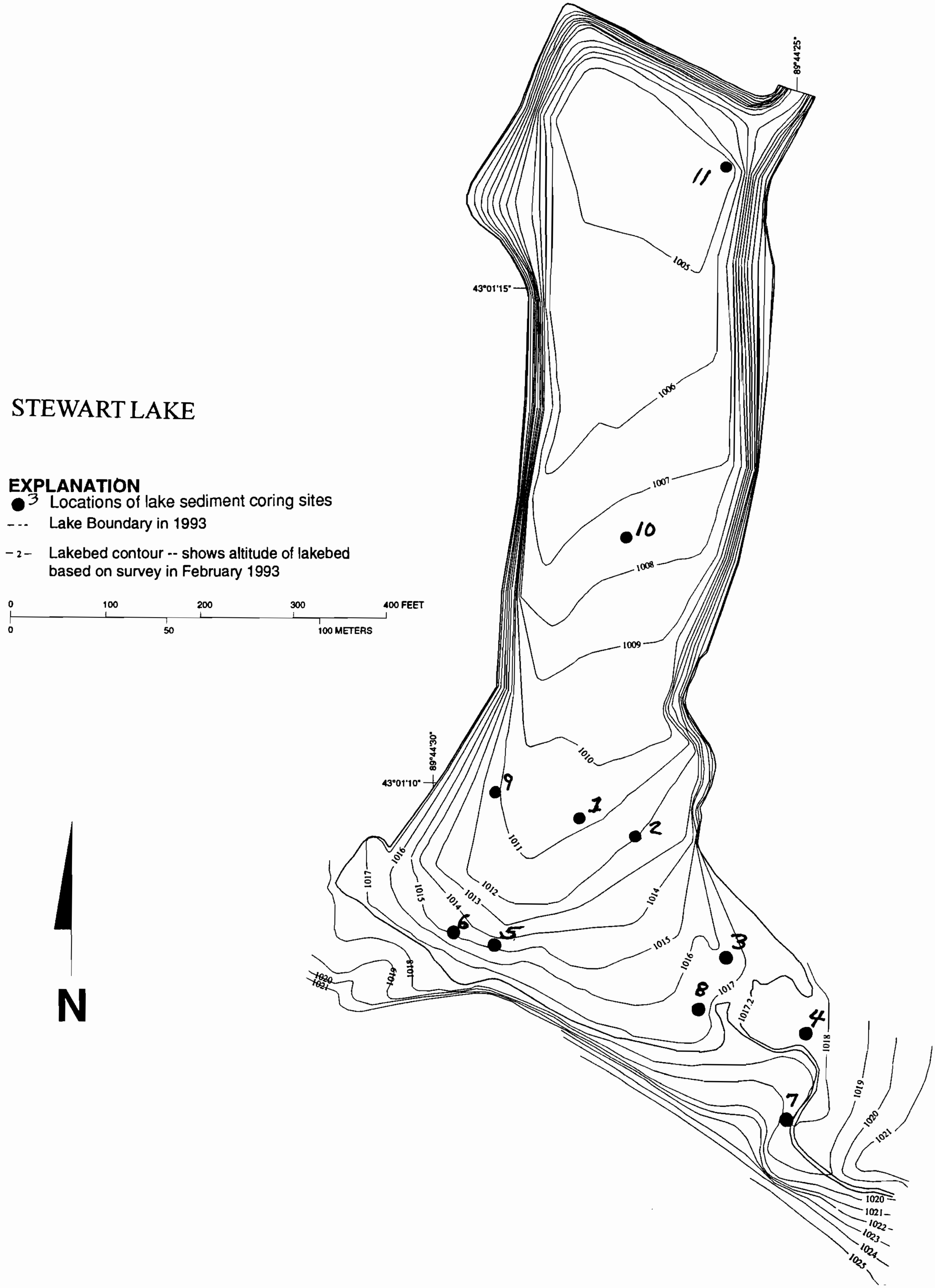
[1]See Map A-1 on following page.
[2]Material was peat.

TABLE A-3 LAKE BED SEDIMENT PARTICLE SIZE							
Core No.	Percentage Finer Than Indicated Particle Size						
	0.125 mm	0.062 mm	0.031 mm	0.016 mm	0.008 mm	0.004 mm	0.002 mm
1	—	100%	96%	71%	44%	38%	35%
2	100%	87	70	38	27	22	22
3	100	53	49	35	26	23	19
4	—	—	—	—	—	—	—
5	100	98	90	61	42	34	26
6	100	99	81	47	32	29	28
7	100	90	77	49	33	30	25
8	—	—	—	—	—	—	—
9	—	—	—	—	—	—	—
10	100	97	97	82	61	45	43
11	100	96	93	77	60	46	30

TABLE A-4
LAKE BED CHEMISTRY FROM CORE #1

Date	Lead, Recovered (UG/G as PB)	Zinc, Recovered (UG/G as ZN)	PCN, Total in Bottom Material (UG/KG)	Aldrin, Total (UG/KG)	Lindane, Total (UG/KG)	Chlordane, Total (UG/KG)	DDD, Total (UG/KG)	DDE, Total (UG/KG)	DDT, Total (UG/KG)	Endosulfan, Total (UG/KG)
3/5/93	20	80	<1.0	<0.1	<0.1	<1.0	0.3	0.9	<0.1	<0.1

Date	Endrin, Total (UG/KG)	Toxaphene, Total (UG/KG)	Heptachlor, Total (UG/KG)	Heptachlor Epoxide, Total (UG/KG)	Methoxychlor, Total (UG/KG)	PCB, Total (UG/KG)	Mirex, Total (UG/KG)	Perthane (UG/KG)	Dieldrin, Total (UG/KG)
3/5/93	<0.1	<10	<0.1	<0.1	<0.2	15	<0.1	<1.00	<0.1



Map A-1 Locations of lake sediment coring sites and altitude of Stewart Lake's bed in February 1993.

APPENDIX C

Village of Mt. Horeb
Urban Management Practice Survey
as of December 1992

Street Sweeping

Main streets are swept twice per week and residential streets monthly, or after heavy rains in low-lying areas. The Village uses its own Elgin brush sweeper.

Leaf and Yard Waste Services

Grass and leaf pick-up service is provided from the first of October to the end of November. Yard waste is picked up weekly on a year-round basis. Leaf burning is allowed, but a permit is required.

Deicing Practices

The Village uses a 50/50 mixture of sand and salt. In the winter of 1991-92, 705 tons of this mixture were used on 35 to 40 road miles. This amounts to 8.8 tons each of salt and sand per mile, which is a rate generally consistent with other Dane County municipalities. The Village dumps its snow on municipal property near Springdale Street and the Military Ridge State Bike Trail.

Stormwater Drainage System

Besides stormwater, the following discharges can be made to the stormwater drainage system: foundation drains; sump pumps; roof drains; and swimming pools. The Village has some catch basins for stormwater drainage, which are cleaned out in the spring and fall.

Construction Site Erosion Control

The Village enacted a construction site erosion control ordinance in February 1991. The ordinance does not address long-term stormwater management for new developments.