SYLVAN LAKES RESTORATION PROJECT

DIAGNOSTIC - FEASIBILITY STUDY

SEPTEMBER 1983

BURLINGTON TOWNSHIP, NJ

F.X. BROWNE ASSOCIATES, INC.

220 SOUTH BROAD STREET

LANSDALE, PA 19446

DRAFT REPORT

DIAGNOSTIC FEASIBILITY STUDY
FOR THE
SYLVAN LAKES RESTORATION PROJECT

NEW JERSEY DEPARTMENT OF ENVIRONMENTAL PROTECTION
TRENTON, NEW JERSEY

SEPTEMBER 1983

SUBMITTED BY

BURLINGTON TOWNSHIP
NEW JERSEY

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1.0 Conclusions

Diagnostic Water Quality Study

1. Water quality data indicate that Sylvan Lakes are eutrophic. Concentrations of nutrients and chlorophyll a are high in both lakes.

2. Upper Sylvan Lake macrophytes significantly influence water quality. The macrophytes provide a route for transmission of nutrients from the sediments to the water column. Lower Sylvan Lake also has macrophyte problems, however phytoplankton populations are higher than in Upper Sylvan Lake and thus affect water quality.

3. The volumes and mean depths of unconsolidated sediments in Sylvan Lakes are listed below:

	Upper Sylvan Lake	Lower Sylvan Lake
Volume, cubic yards	10,436	44,068
Mean depth, feet	1.62	1.97

4. Phosphorus loads to Upper and Lower Sylvan Lakes are similar and are approximately 0.59-0.72 kilogram/hectare/year. A 65% reduction in phosphorus load will be necessary to reduce loads below critical levels.

5. Dredging of sediments can be expected to significantly improve water quality.

Lake Restoration Feasibility Study

1. Construction of a detention basin for removal of watershed nutrient and sediment inputs can significantly improve water quality in Upper Sylvan Lake. If a detention basin, as shown in Figure 6, is constructed and sediments are dredged from Upper Sylvan Lake, water quality conditions are expected to change from eutrohpic to mesotrophic conditions. The preliminary cost estimate for this detention basin is $13,000.

2. Construction of a detention basin in the west arm of Lower Sylvan Lake, as shown in Figure 7, can reduce nutrient loads to Lower Sylvan Lake, but cannot change the trophic status of the lake. The preliminary cost estimate for this detention basin is $28,500.

3. Future urban development will negatively affect water quality in Sylvan Lakes. The effects of development can be controlled through the use of detention basins or infiltration basins that optimize phosphorus removal. A detailed set of guidelines to be followed to optimize phosphorus sedimentation in detention basins will be provided during the Step 4 Engineering Design.

4. A dilution and aeration system can provide significant reductions in the average total phosphorus concentration in Sylvan Lakes. Excess iron in groundwater dilution water can precipitate in-lake phosphorus under aerobic conditions. The aeration system ensures that the phosphorus iron complex does not diffuse back into the water column. This system is an innovative lake restoration alternative, and would cost approximately $6,800 for Upper Sylvan Lake and $22,000 for both lakes.

5. The preliminary cost estimates for mechanical and hydraulic dredging of nutrient rich sediments from Sylvan Lakes is given below:

Hydraulic dredging, land application to farmlands	$200,000
Mechanical dredging, truck to landfill and use as cover material	$280,000

2.0 Recommendations

1. Reductions in watershed phosphorus loads will be necessary to restore water quality in Sylvan Lakes. The dilution and aeration system, an innovative lake restoration system, is recommended for Upper Sylvan Lake. Should the system perform as expected, the system should be installed in Lower Sylvan Lakes.

2. Future urban development non-point source pollution should be controlled with detention basins and infiltration basins. These basins should be designed to optimize settling and phosphorus removal.

3. Macrophyte densities reductions will be necessary to reduce translocations of sediment nutrients to the water column. Hydraulic dredging and sediment application to farmland is recommended to reduce macrophyte problems, reduce sediment accumulations, improve water quality, and improve aesthetic conditions in Sylvan Lakes.

3.0 Watershed Inventory and Population Analysis

3.1 Land Use

Existing land use in the Sylvan Lakes watersheds was determined by evaluation of USGS topographical maps, 1980 aerial photographs, and the Burlington Township Storm Drainage Study (Alaimo Engineers, 1980). Watershed boundaries were determined by an investigation of the sources listed above in addition to field verification of certain storm drainage patterns by the Burlington Township Engineer (personal communication, B. Wojtkowiak, 1983). Existing and future land use data for Upper and Lower Sylvan Lakes are presented in Tables 1 and 2, respectively. Land use maps for existing and projected future conditions are presented in Figures 1 and 2, respectively. Density criteria for urban areas are listed below:

High density urban:	Existing commercial areas and apartment complexes
Medium density urban:	more than 1 house/acre up to 4 houses/acre
Low density urban:	1 house/acre or less

The percent of urban development in the Upper Sylvan Lake watershed is 67%, while 44% of the Lower Sylvan Lake watershed is urbanized. The history of Sylvan Lakes extends back to the late 1800's. Agricultural activities dominated the area until World War I. Urban development occurred around Upper Sylvan Lake after World War II. More recent development occurred in the western portion of the Lower Sylvan Lake watershed during the late 1950's.

The Township Master Plan calls for 90-94% urban development in the Sylvan Lakes watershed. Most of the planned development will be medium density residential.

3.2 Population

Existing land use in the Sylvan Lakes watersheds was determined by evaluation of 1980 Census data and USGS topographical maps. The future population was estimated by assuming that the population per dwelling unit was 2.91 and that housing density would conform to the Township Master Plan.

Existing and future population estimates are given below:

Watershed	Existing Population	Future Population
Upper Sylvan Lake	207	370
Lower Sylvan Lake	1225	4000
Total	1432	4370

Table 1

Lower Sylvan Lake Land Use

	Current		Future	
	Acres	%	Acres	%
High Density Urban	30	6.6	30.0	6.6
Medium Density Urban	71	15.5	330.1	72.2
Low Density Urban	101.8	22.3	54.0	11.8
Pasture	34.8	7.6		
Orchard	10.4	2.3		
Cropland	51.0	11.1		
Forest	158.0	34.6	42.9	9.4
Total	457	100%	457	100%

Table 2

Upper Sylvan Lake Land Use

	Current		Future	
	Acres	%	Acres	%
High Density Urban	4.6	8.3	4.6	8.3
Medium Density Urban	19.8	35.7	31.9	57.5
Low Density Urban	12.9	23.2	15.6	28.1
Pasture	6.5	11.7		
Orchard				
Cropland				
Forest	11.7	21.1	3.4	6.1
Total	55.5	100%	55.5	100%

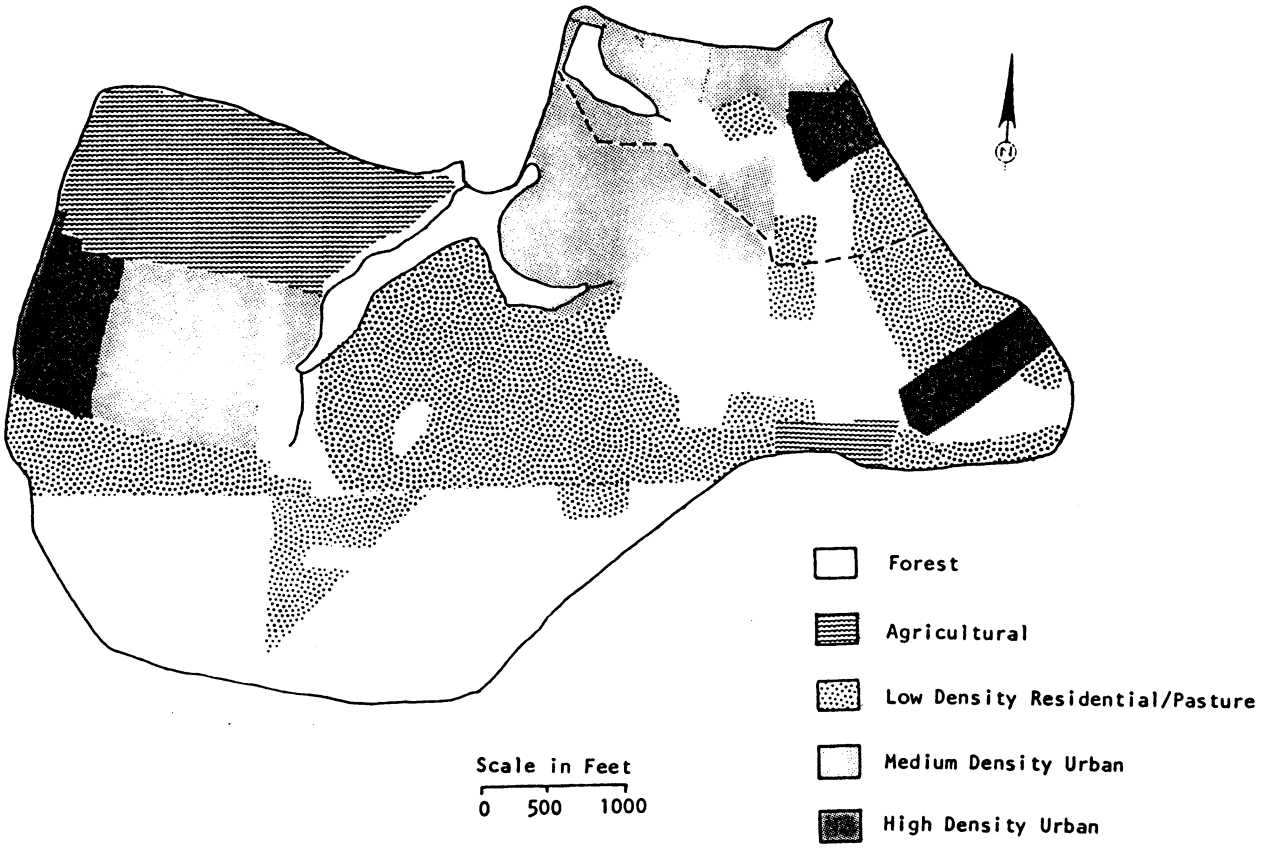

Figure 1. Existing Land Use in the Sylvan Lakes Watershed

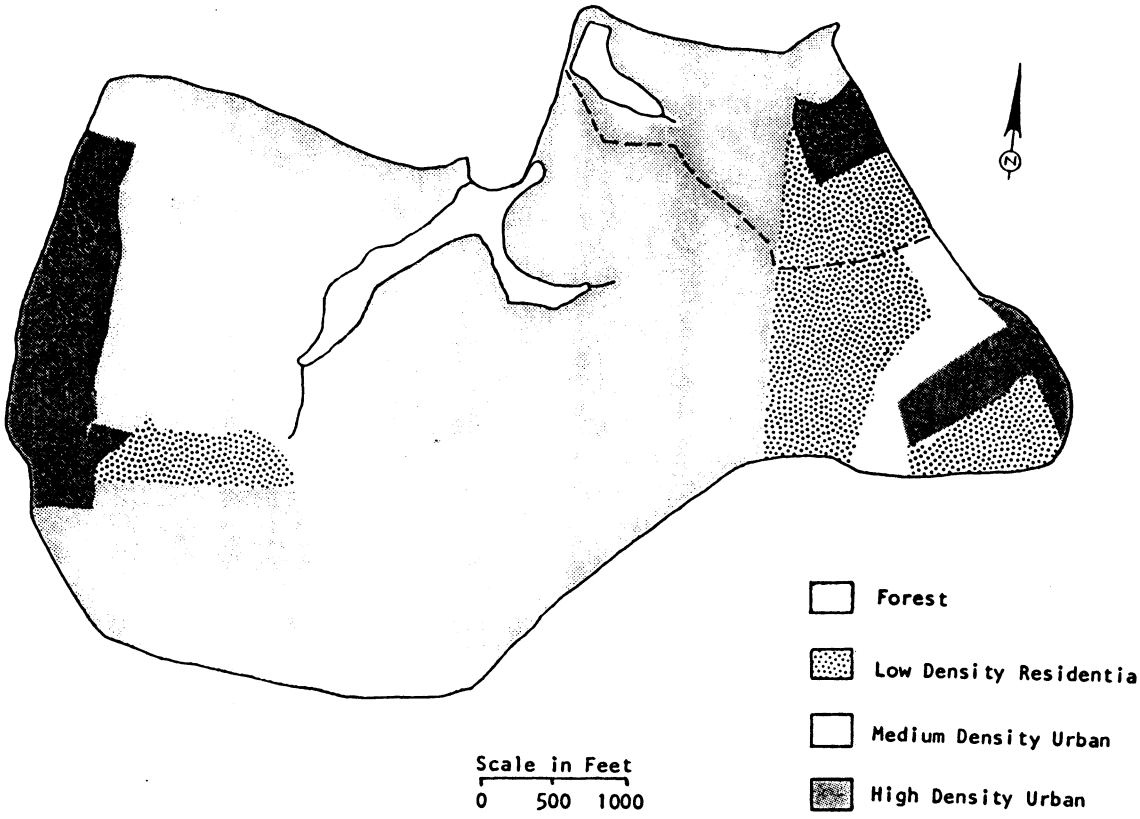

Figure 2. Projected Future Land Use in the Sylvan Lakes Watershed According to the Master Plan

4.0 Sylvan Lakes Analysis

4.1 General Characteristics

The physical characteristics of Sylvan Lakes are presented below:

	Upper Sylvan Lake	Lower Sylvan Lake
Surface Area, acres	4.0	13.9
Volume, cubic feet	1.23×10^6	3.94×10^6
Mean Depth, feet	7.06	6.51
Maximum Depth, feet	14.7	14.1
Mean Hydraulic Residence Time, days	74	27
Volume of unconsolidated sediment, cubic yards	10,436	44,068
Mean Depth of unconsolidated sediments, feet	1.62	1.97

Further details regarding the sediment data may be found in Section 4.4. A map of the lakes with locations of lake monitoring stations is presented in Figure 3. Upper and Lower Sylvan Lakes are interconnected with a culvert. Upper Sylvan Lake generally flows into Lower Sylvan Lake, however, occasional high water levels in Lower Sylvan Lake will cause a flow reversal. Lower Sylvan Lake is dendritic with three arms extending from the deepest portion of the lake.

4.2 Lake Water Quality

A listing of data collected by NJDEP during 1982 is presented in Table 3. Samples were collected from three stations in Lower Sylvan Lake six times and from one station in Upper Sylvan Lake five times. Samples were analyzed for the following parameters:

Total Phosphorus	Dissolved Oxygen (0.5 m and bottom)
Dissolved Ortho-phosphate	Temperature (0.5 m and bottom)
Ammonia	Secchi Disk Depth
Nitrate	Chlorophyll *a*
Total Kjeldahl Nitrogen	pH
Total Suspended Solids	Alkalinity

Herbicides applications were discontinued for the duration of the monitoring period to ensure a natural biological response to nutrient inputs.

Total phosphorus concentrations in Upper Sylvan Lake were consistently low (0.037 mg/l TP as P) during the summer period, while total phosphorus concentrations in Lower Sylvan Lake were higher (0.065 mg/l) with a maximum concentration of 0.101 mg/l observed during the summer. Both lakes had similar total phosphorus concentrations of approximately 0.06 mg/l in October.

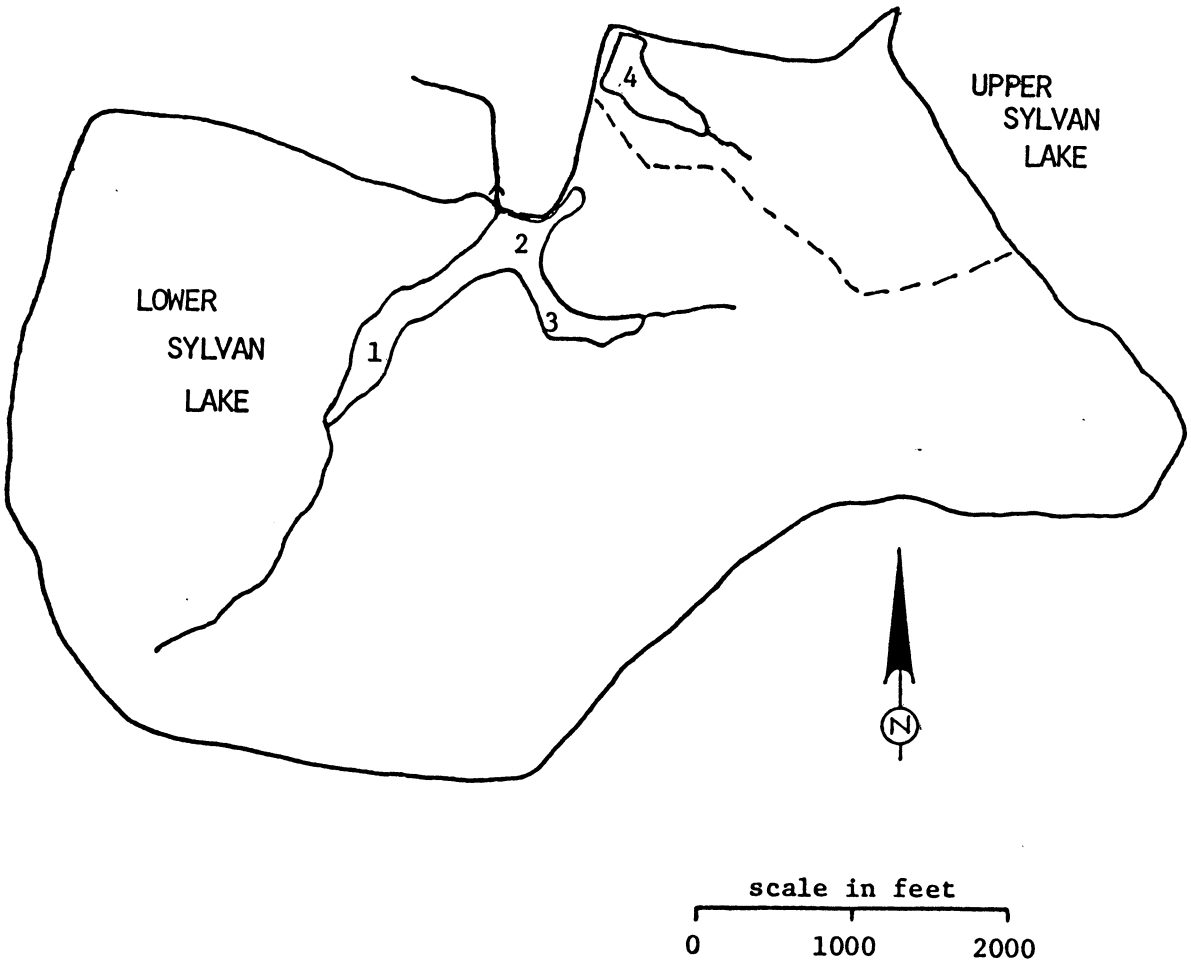

Figure 3. Sylvan Lakes Watersheds and Lake Sampling Locations

Table 3

Sylvan Lakes Water Quality Data

Date (1983)	TP mg/l	PO4 mg/l	NH3 mg/l	NO3 mg/l	TKN mg/l	TN mg/l	TSS mg/l	chl a ug/l	TIN/PO4	Secchi Depth m.	Sat. D.O. mg/l	Surface D.O. mg/l	Bottom D.O. mg/l	Surface Temp. C	Bottom Temp. C	pH	Alkalinity mg/l
LOWER SYLVAN																	
Sta. 1																	
3/3	0.039	0.010	0.05	0.87	0.55	1.42	6.0		92.0	1.7	11.8	12.7		8.0		7.4	
6/10	0.039	0.026	0.13	0.28	0.99	1.27	2.0	36.8	15.8	1.5	8.7	12.0	1.0	22.0	17.0	8.7	33.0
7/01	0.082	0.020	0.16	0.30	1.19	1.49	5.0	25.2	23.0	0.9	8.6	8.3	5.8	23.0	19.0	6.8	
8/05	0.101	0.016	0.13	0.05	1.03	1.08	12.0	68.4	11.3	0.9	8.1	12.5	0.5	26.0	22.0	9.0	
9/15	0.082	0.010	0.14	0.30	1.68	1.98	4.0	177.4	44.0	0.5	8.7	6.7	0.7	22.3	22.0	7.1	
10/07	0.068	0.010	0.14	0.30	0.73	1.03		41.3	44.0	1.2	9.1	9.1	6.7	20.0	19.0	7.3	38.0
Sta. 2																	
3/3	0.059	0.010	0.05	0.87	0.55	1.42	3.0		92.0	1.8	11.8	11.6		7.5		7.6	
6/10	0.039	0.026	0.09	0.30	0.76	1.06	1.0	57.9	15.0	1.2	8.8	11.6	2.5	21.5	19.0	8.4	33.0
7/01	0.082	0.013	0.15	0.35	0.79	1.14	9.0	17.3	38.5	0.9	8.6	9.1	0.8	23.0	22.0	7.0	
8/05	0.059	0.010	0.09	0.07	0.94	1.01	11.0	51.5	16.0	0.8	8.1	12.4	1.2	26.0	24.0	8.4	
9/15	0.082	0.091	0.07	0.05	2.13	2.18	6.0	79.9	1.3	0.4	8.5	14.8	0.3	22.7	22.0	9.2	
10/07	0.049	0.010	0.19	0.17	0.96	1.13		31.5	36.0	1.1	8.9	10.0	0.3	20.9	20.0	7.5	41.0
Sta. 3																	
3/3	0.020	0.010	0.05	0.85	0.30	1.15	7.0		90.0	1.6	11.8	11.6		8.5		7.5	
6/10	0.029	0.010	0.08	0.34	0.49	0.83	8.0		42.0	1.8	8.7	11.0	6.8	22.0	15.0	8.5	32.0
7/01	0.049	0.042	0.16	0.23	0.67	0.90	2.0	16.9	9.3	0.8	8.3	8.7	8.5	24.5	19.0	6.9	
8/05	0.049	0.010	0.09	0.05	0.85	0.90	11.0	59.4	14.0	0.9	8.1	12.0	0.5	26.0	20.0	9.1	
9/15	0.082	0.059	0.07	0.05	2.16	2.21	4.0	122.3	2.0	0.4	8.7	12.8	1.0	22.4	17.0	9.5	
10/07	0.068	0.010	0.14	0.11	1.10	1.21		19.7	25.0	1.1	9.1	9.5	3.8	20.0		7.7	43.0
Means:	0.060	0.022	0.110	0.31	0.99	1.30	6.07	57.54	33.95	1.07	9.13	10.91	2.69	20.35	19.79	7.98	36.67
UPPER SYLVAN																	
6/10	0.029	0.010	0.05	0.05	0.56	0.61	3.0	19.2	10.0	1.5	8.7	10.2	0.3	22.0	15.0	7.8	43.0
7/01	0.049	0.010	0.14	0.05	0.49	0.54	11.0	12.9	19.0	1.3	8.4	8.0	0.3	24.0	20.0	7.2	
8/05	0.039	0.010	0.1	0.05	0.55	0.60	8.0	25.0	15.0	1.2	8.0	9.1	0.4	27.0	20.0	7.8	
9/15	0.029	0.010	0.07	0.05	0.25	0.30	7.0	40.1	12.0	1.5	8.6	6.4	0.5	23.0	20.0	7.2	
10/07	0.058	0.049	0.16	0.05	0.47	0.52		3.1	4.3	2.4	8.9	7.0	0.2	21.0	19.0	7.2	53.0
Means:	0.041	0.018	0.104	0.050	0.464	0.51	7.25	20.05	12.1	1.6	8.5	8.1	0.3	23.4	18.8	7.4	48.0

Legend

TP = Total Phosphorus as P

PO_4 = Orthophosphate Phosphorus as P

NH_3 = Ammonia Nitrogen

NO_3 = Nitrite plus Nitrate Nitrogen

TKN = Total Kjeldahl Nitrogen

chl a = Chlorophyll a

TIN = NH_3 plus NO_3

D.O. = Dissolved Oxygen

Ortho-phosphate concentrations were undetectable in Upper Sylvan Lake until turnover, while ortho-phosphate concentrations were more variable in Lower Sylvan Lake. The ortho-phosphate concentration in Lower Sylvan Lake varied from 0.091 mg/l PO_4-P to less than detectable levels.

Moderate levels of ammonia around 0.1 mg/l were measured in both lakes. Undetectable levels of nitrate were found in Upper Sylvan Lake; in contrast, Lower Sylvan Lake nitrate levels were high (0.86 mg/l) in April with a gradual decrease to undetectable levels in August and subsequent increase in October. Organic nitrogen concentrations increased in Lower Sylvan Lake from 0.42 mg/l in March to 1.90 mg/l in September. Concentrations of organic nitrogen in Upper Sylvan Lake did not increase throughout the summer period but remained consistently low, around 0.37 mg/l.

Chlorophyll a concentrations and Secchi disk depths in the lakes are listed below:

	Upper Sylvan Lake	Lower Sylvan Lake
Average chlorophyll a (ug/l)	20.0	57.5
Maximum chlorophyll a (ug/l)	40.1	177.4
Spring Secchi disk depth (m)	1.5	1.5
Summer Secchi disk depth (m)	1.5	0.41

These data suggest that Upper Sylvan Lake is dominated by macrophytes, and that both phytoplankton and macrophytes significantly impact nutrient dynamics in Lower Sylvan Lake. The variations in ortho-phosphate in Lower Sylvan Lake are explained by growth and death cycles in phytoplankton populations. The undetectable summer ortho-phosphate and lower organic nitrogen concentrations in Upper Sylvan Lake occur because dissolved nutrients have been incorporated into macrophyte biomass. Organic nitrogen values in Lower Sylvan Lake are higher due to the fact that phytoplankton (which contain organic nitrogen) are suspended in the water column.

Transparency, as measured by Secchi disk, gradually decreases in Lower Sylvan Lake as chlorophyll a concentrations increase, while Upper Sylvan Lake has a rather constant level of transparency. Upper Sylvan Lake transparency levels are high because macrophytes utilize most available nutrients which prevents excessive levels of chlorophyll production.

Phytoplankton growth depends on a variety of nutrients including phosphorus, nitrogen, carbon, iron, manganese, and certain trace minerals. Acording to the law of the minimum, biological growth is limited by the substance that is present in minimal quantity with

respect to the needs of the organism. Nitrogen and phosphorus are usually the elements in least relative supply in most natural water systems. Depending on the species, algae require approximately 7 to 12 mg of nitrogen per 1 mg of phosphorus. Phytoplankton growth is phosphorus limited when the ratio of inorganic nitrogen to ortho-phosphate is greater than 12.0. Phytoplankton growth is nitrogen limited when the ratio is less than 7.0.

Ratios of nitrogen to phosphorus indicate phosphorus limitation in both lakes throughout most of the summer. This ratio decreased gradually during the summer until in September the ratio in Lower Sylvan Lake indicated nitrogen limitation. The N:P ratio in the main body of Lower Sylvan Lake, Station 2, was 1.3 in September. In Lower Sylvan Lake, a gradual decrease throughout the summer in nitrate concentration, concurrent with an increase in the chlorophyll concentration, also indicates that phytoplankton growth eventually becomes nitrogen limited by September. Thus, in Lower Sylvan Lake, late summer phytoplankton populations were limited by both nitrogen and phosphorus. The lowest N:P ratio in Upper Sylvan Lake was measured in October. This ratio was depressed due to an increase of ortho-phosphate. The ortho-phosphate increase was probably due to macrophyte decay.

Dissolved oxygen concentrations are consistently below 1.0 mg/l in the deeper areas of each lake during the summer period. The monitoring station in the East Arm of Lower Sylvan Lake is approximately 5 feet deep and accordingly takes longer to develop anoxia in bottom waters. Neither lake develops strong thermal gradients, although the absence of complete dissolved oxygen profiles prevents a substantive conclusion regarding the effects of thermal stratification on oxygen transport to the lake bottom. In Upper Sylvan Lake, dissolved oxygen concentrations at the lake bottom do not increase in October; this is probably due to a high oxygen demand resulting from macrophyte decay.

Trophic State

Selected parameters have been used to define the trophic state of a lake. There are three levels of trophic state. Oligitrophic lakes are water bodies with low concentrations of nutrients and algae, with dissolved oxygen present throughout the water column, and high transparency levels. Species diversity of algae, macrophytes, zooplankton, and fish is generally high with low absolute numbers of any given species. Eutrophic lakes have high levels of nutrients and algae, and dissolved oxygen is depleted in bottom waters. Transparency is low due to excessive growths of algae. Algae populations are often comprised of high densities of one or two species. Zooplankton populations decrease in anoxic bottom waters and fish populations become dominated by species such as bullhead and carp,

which have the ability to withstand large swings in dissolved oxygen levels. Mesotrophic lakes are lakes that exhibit characteristics intermediate between oligitrophy and eutrophy.

Table 4 presents a comparison of Sylvan Lakes data to trophic state criteria. According to these criteria, both lakes are classified as eutrophic. Upper Sylvan Lake Secchi depth is not an appropriate measure of trophic status because of high densities of macrophytes.

4.3 Macrophytes

4.3.1 Macrophyte Survey

A macrophyte survey was conducted in late May 1983. During this survey, all macrophytes present in the two lakes were identified and areal coverage was determined. A second limited survey was conducted by F. X. Browne Associates, Inc. ~~in August, 1982.~~ During the limited survey, macrophytes in Upper Sylvan Lake were identified, however, areal coverage for each species was not determined. Macrophytes covered the entire surface area of Upper Sylvan Lake in August, 1982. Species diversity was high with the following macrophytes identified:

Open water submergents

Potamogeton crispus
Potamogeton confervoides or P. Pectinatus
Cabomba
Myriophyllum
Anacharis

Shoreline emergents

Nuphar
Sagittaria
Nymphaea

Shoreline submergents

Callitriche
Ludwigia palustris var. americana
Polygonum

The 1983 macrophyte was conducted in late May prior to herbicide application in early June. Potamogeton crispus (Pondweed) dominated the macrophyte population in Upper Sylvan Lake except for the shallow areas where Sagittaria (Arrowhead), Nuphar (Spatterdock), Nymphaea (Water lilies), Polygonum (Smartweed), and Callitriche (Starwart)

Table 4

Eutrophic Criteria

Parameter	Eutrophic Criteria*	Upper Sylvan	Lower Sylvan
Total Phosphorus (mg/l as P) (growing season average)	Greater than 0.020-0.030	0.041	0.060
Chlorophyll a (ug/l) (Summer)	Greater than 5-10	24.3	64.2
Secchi Depth (meters) (Summer)	Less than 1.5-2.0	1.38	0.90
Hypolimnetic Oxygen	Depleted	Depleted	Depleted

Source: Clean Lakes Program Guidance Manual, 1980

dominated. All of the macrophytes found in August 1982 were present in very low numbers in the lake in May 1983. It is expected that species diversity would continue to increase throughout the summer in the absense of herbicide treatment. The areal coverage of Potamogeton crispus in May 1983 was restricted to depths less than six feet, except for the swimming beach where macrophyte density was low. The macrophyte population in Lower Sylvan Lake in May 1983 was a mixed community of Myriophyllum (Milfoil) and Potamogeton crispus (Pondweed). As with Upper Sylvan Lake, areal coverage was limited to depths less than six feet.

4.3.2 Biomass of Macrophytes

In order to estimate the significance of macrophytes on the lake nutrient budget, the literature was surveyed to obtain representative values for:

1) macrophyte biomass,
2) translocation of phosphorus from sediment to water column, and
3) translocation of nitrogen from sediment to water column.

A range of biomass values were obtained. The range is listed below:

Biomass (g/m^2) dry weight	Phosphorus (ug/g) dry weight	Nitrogen (ug/g) dry weight	Reference
88	3073		Carignan and Kalff, 1982
700-1147 (harvested)			Nichols, 1974
49-200	3620	16,983	Landers, 1982

The biomass reported by Nichols (1974) is the annual biomass removed from a lake by a weed harvester. It has been reported that the net release of nitrogen and phosphorus from Myriophyllum tissue to the water column during dieback and decomposition was 47% and 73%, respectively (Landers, 1982). This net release is an autochthonous input (i.e. the nutrient input comes from the sediment, not from watershed inputs).

The source of nutrients for macrophyte growth in a given lake depends upon the relative amounts of nutrients available from the sediments and tributary inputs. Macrophyte growths from a lake with low tributary loadings and rich sediments will obtain a majority of nutrients from the sediments. There is insufficient information available to determine the sources of nutrients used by macrophytes. In addition, macrophyte biomass per unit surface area must be estimated. This will vary from year to year and from lake to lake. Accordingly, a range of autochthonous inputs will be presented for both Upper and Lower Sylvan Lake. It has been assumed that biomass

will range from 49-200 g/m^2 dry weight and that phosphorus and nitrogen plant content will be 3620 and 16,983 ug/g, respectively. The range of autochthonous inputs will be:

Nitrogen - 25-50% of plant nitrogen content
Phosphorus - 50-75% of plant phosphorus content

Based upon these assumptions the load of nutrients translocated from the sediments through the plant tissue to the water column is presented in Table 5.

Table 5

Nutrient Translocated from Sediments Through Plant Tissue to the Water Column

	Upper Sylvan Lake	Lower Sylvan Lake
Phosphorus	1.1 - 8.6 kg/yr	3.7 - 29.8 kg/yr
Nitrogen	3.2 - 25.9 kg/yr	11.0 - 89.9 kg/yr

These autochthonous inputs of nutrients are compared to watershed nutrient inputs in Section 5.0. The input of nutrients to Sylvan Lakes as a result of macrophytes is a significant input to the lakes.

4.4 Sediment Data

4.4.1 Bathymetry

The Sylvan Lakes were surveyed in the spring of 1983. Elevations were determined for the surface of the bottom sediments and for the base of unconsolidated sediments at 64 different locations in the two lakes. These data were used to calculate the volume of each lake and the volume of sediments in each lake. Bathymetric maps are presented in Figure 4. Bathymetric data are listed in Table 6.

Sylvan Lakes were constructed sometime prior to 1882 (Alaimo Engineers, 1980). The estimated sediment accumulation rates for the lakes are approximately:

Upper Sylvan Lake = 2818 ft^3/yr
= 0.19 inches/yr

Lower Sylvan Lake = 11,898 ft^3/yr
= 0.24 inches/yr

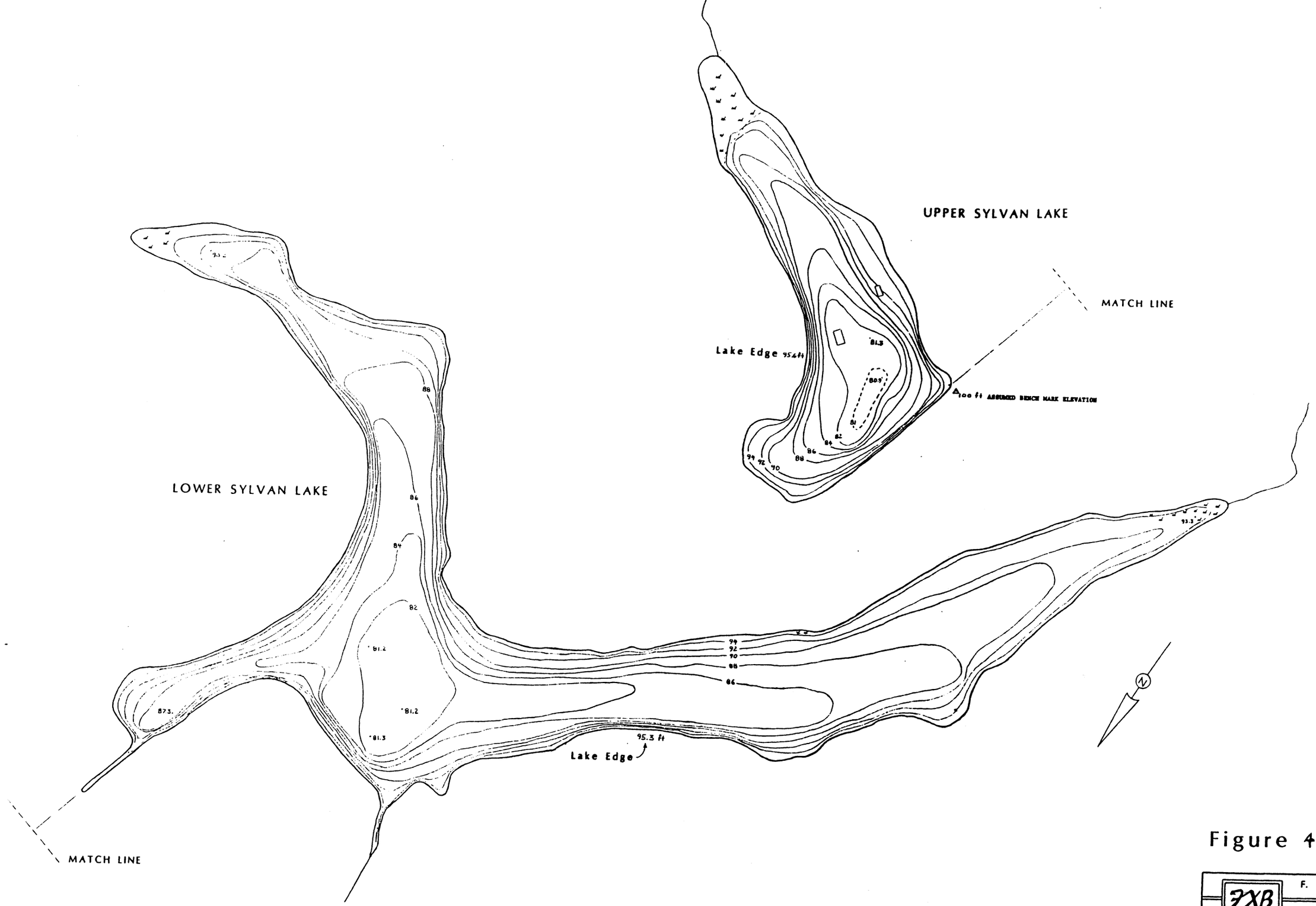

Figure 4

FXB F. X. BROWNE ASSOCIATES, INC. ENVIRONMENTAL CONSULTANTS P.O. BOX 601, LANSDALE, PENNSYLVANIA 19446 TELEPHONE 215-362-3876	
SYLVAN LAKES RESTORATION PROJECT BATHYMETRIC CONTOUR MAP	
Drawn by: K.S.	Scale: 1in.= 45 ft.
Job no: 1032.03	Date: MAY 1983

Table 6

Bathymetric Data for Sylvan Lakes

	Upper Sylvan Lake	Lower Sylvan Lake
Area, acres	4.0	13.9
Volume, cubic feet	1.23×10^6	3.94×10^6
Mean Depth, feet	7.06	6.51
Volume of Unconsolidated Sediment, cubic yards	10,436	44,068
Mean Depth of Unconsolidated Sediment, feet	1.62	1.97

4.4.2 Trace Metals in Sediments

Eight sediment samples were collected from Upper and Lower Sylvan Lakes. These samples were mixed to form two composites and analyzed for trace metals. Measured sediment concentrations were compared to criteria used by NJDEP for utilization and disposal of sludge (NJDEP, 1981). Results of these analyses are presented in Table 7. The sediment concentrations for arsenic are similar to the NJDEP flag limit, however concentrations of all other metals were significantly less than the flag limits.

4.4.3 Pesticides and Herbicides

Pesticides were measured in Sylvan Lakes sediments. Detectable concentrations were found only for DDT and its degradation products, as shown in Table 7. DDT was detectable in concentrations greater than levels reported where biomagnification has been found to occur in the aquatic food chain (Hickey, Keith, and Coon, 1966). Upper Sylvan Lake levels of DDT and its degradation products are higher than NJDEP sludge flag limits. These parameters will be given special attention when evaluating dredged material disposal options. Other pesticides were analyzed and not detected as listed below:

Aldrin	Heptachlor Epoxide
Chlordane	Lindane
Dieldrin	Methoxychlor
Endrin	Mirex
Heptachlor	Toxaphene

PCB's were also analyzed and not found to be present. Detectable levels of HCB, a fungicide used in farming, were found in Sylvan Lakes.

4.4.4 Physical Characteristics of Sediments

Sediment sample were collected from six locations in the two lakes and tested for percent solids, percent organics and grain size distribution. Results of this testing are shown in Table 8. These tests indicate that the sediments are loamy silts with a very high organic content. The small amount of sand size material is predominantly organic. Due to the small average grain size, these sediments will settle and compact very slowly. A typical grain size distribution is shown in Figure 5.

Table 7

Sylvan Lakes Sediment Characteristics

Parameter	Sediment Concentration (mg/kg dry weight) Upper Sylvan Lake	Lower Sylvan Lake	NJDEP Sludge Flag Limits
% volatile	17.05	17.11	
Arsenic	9.64	11.66	10
Cadmium	2.83	2.42	16
Chromium	42.42	34.50	890
Copper	53.02	46.16	850
Cyanide	1.21	2.05	6
Iron	59,770	32,918	-
Lead	271.1	256	500
Mercury	0.13	0.11	5
Nickel	41.0	44.8	82
Nitrogen, Total Kjeldahl	7,760	6,919	
Phosphorus, Total	5,049	3,259	
Potassium	1,657	1,329	-
Sulfur	47,599	35,436	-
Zinc	747	471	1,740
DDT	0.470	0.0410	0.25
p.p.-DDE	0.422	0.121	0.25
p.p.-TDE	0.265	0.187	0.25
HCB	16.9	0.322	

Aldrin, Chlordane, Dieldrin, Endrin, Heptachlor, Hept. Epox, Lindane, Methoxychlor, Mirex, PCB's and Toxaphene were below detection limits.

Table 8

Sediment Analysis Summary

	% Org.	% Sand	% Silt	% Clay
Upper Sylvan Lake				
Upper End	22	0	87	13
Lower End	17	0	87	13
Average	19.5	0	87	13
Lower Sylvan Lake				
Upper End - East Arm	21	4	90	6
Lower End - East Arm	20	0	78	22
Inlet from Upper Sylvan Lake	15	40	55	5
West Arm	22	0	83	17
Average	19.5	11	76.5	12.5

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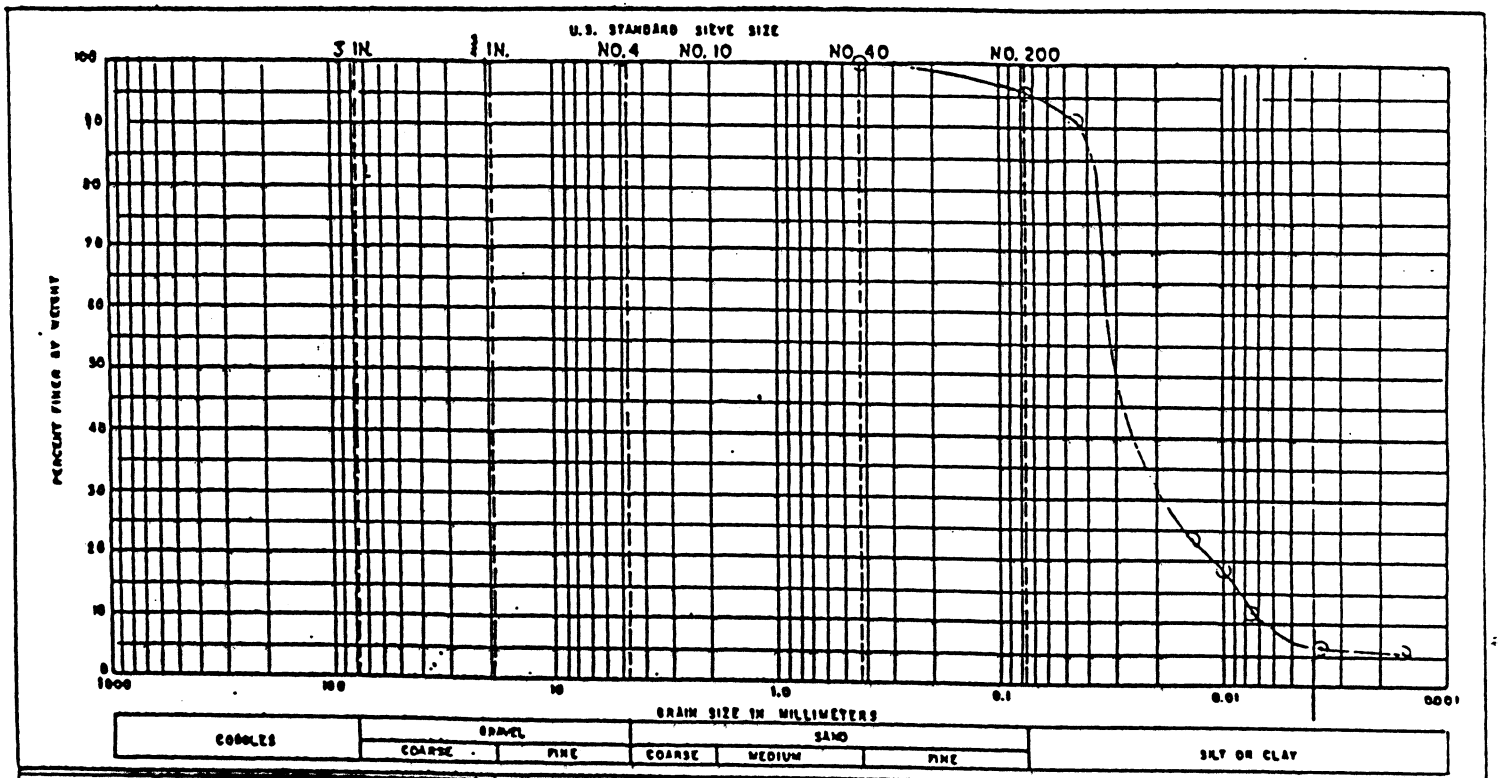


Boring No.	Sample No.	Elev. or Depth	Classification	NMC	L.L.	P.L.	P.I.
	VC		Lake Bottom Silt				
			Medium to High Organic				
			Content				

Project #15899 F.X. Browne Assoc.

Area Sylvan Lakes

Date 4/27/83

GRADATION CURVES

Figure 5. Grain Size Distribution

5.0 Pollutant Budgets

5.1 Watershed Pollutant Loads

Watershed loadings for total phosphorus, total nitrogen, and total suspended solids were estimated using the Unit Areal Loading methodology which uses the land use patterns within each watershed and pollutant export coefficients obtained from literature sources. This approach has been described in the Clean Lakes Program Guidance Manual.

Land use and watershed boundaries for each watershed were determined from recent aerial photographs, U.S.G.S. topographical maps, the Burlington Township Storm Drainage Study, and field verification. Land use data and watershed maps were presented in Section 3.0.

Pollutant export coefficients have been developed for rivers and streams draining from a broad range of land uses, soil types, and topographical relief. Ranges of export coefficients have been compiled in a number of publications, including the EPA Clean Lakes Program Guidance Manual (1980), and Browne and Grizzard (1979). Based upon these literature reviews, two levels of export coefficients were used to develop pollutant budgets for the Sylvan Lakes watersheds. An export coefficient for each land use was selected for input into the lake models. Export coefficients for various land uses in Sylvan Lakes are presented in Table 9.

Pollutant loadings for Sylvan Lakes in kg/yr and kg/ha/yr are presented below:

	Phosphorus		Nitrogen		Suspended Solids	
	kg/yr	kg/ha/yr	kg/yr	kg/ha/yr	kg/yr	kg/ha/yr
Upper Sylvan Lake	16.1	0.72	94.2	4.19	26,763	1191
Lower Sylvan Lake	122.8	0.59	902.0	3.93	174,377	840

Nutrient loadings per unit drainage area in the two watersheds are similar. Suspended solids loadings are larger in the Upper Sylvan Lake watershed.

5.2 Pollutant Budgets for Sylvan Lakes

Pollutant budgets for the Sylvan Lakes have been developed for suspended solids and phosphorus.

Suspended Solids

A suspended solids budget was developed to compare historical sediment accumulations to estimated watershed suspended solids loads. Through this analysis, the accuracy of sediment accumulations and

Table 9

Relationship Between Land Use and Unit Areal Loading from Nonpoint Sources

	Unit Areal Loadings (kg/ha/yr)					
	Forest	Pasture	Cropland	Urban High Density	Medium Density	Low Density
Total Phosphorus						
Low	0.01	0.2	.03	0.25	0.25	0.25
High	1.0	1.1	5.2	5.0	5.0	5.0
Value Used	0.16	0.43	1.14	1.6	1.13	0.41
Total Nitrogen						
Low	1.0	2	1	2	2	2
High	10.0	10	40	20	20	20
Value Used	2.5	5	10	10	5	2
Total Suspended Solids						
Low	40	10	300	200	200	200
High	400	1000	4000	5000	5000	5000
Value Used	56	400	1600	4000	2000	200

Sources: Clean Lakes Program Guidance Manual, 1980.
Browne and Grizzard, 1979.
Northern Virginia Planning District *et al.*, 1978.
Reckhow *et al.*, 1980.
Rast and Lee, 1980.

watershed suspended solids loads may be assessed. The results of this analysis are presented in Table 10. The estimated tributary sediment loads are less than measured sediment accumulations. This is expected due to the fact that watershed sediment delivery is related to land disturbance within the watershed. Higher sediment delivery rates probably occurred during periods of intense agricultural activity prior to World War I and urban development following World War II, (Alaimo Engineers, 1980).

Table 10

Comparison of Tributary Sediment Loads to Measured Sediment Accumulation Rates

	Upper Sylvan Lake inches/yr	Lower Sylvan Lake inches/yr
Tributary Sediment Load	0.065	0.123
Measured Sediment Accumulation	0.19	0.24

Phosphorus

Phosphorus budgets have been developed for Sylvan Lakes based upon watershed phosphorus export coefficients and measured concentrations of in-lake phosphorus. This analysis concentrates on phosphorus rather than nitrogen because phosphorus was usually the limiting nutrient in Sylvan Lakes and because controls for watershed delivery of phosphorus are more feasible than for nitrogen. Futhermore, blue-green algae are capable of fixing atmospheric nitrogen. Therefore, control of phosphorus is most effective for lake restoration. A variety of empirical phosphorus models were tested for Sylvan Lakes including Walker (1977), Reckhow's general model (1979), and Reckhow's oxic model (1979), Dillon (1975), and Vollenweider (1975). Walker's model was selected because Sylvan Lakes morphological characteristics fit within all the limitations of the Walker model, and the predicted phosphorus concentration is similar to measured values.

The steady state in-lake phosphorus concentration is predicted by the following formula:

$$P = \frac{LT}{Z}\left[\frac{1}{1 + .824^{.454}}\right]$$

where...

P = steady state phosphorus concentration, mg/l
T = detention time, yr^{-1}
Z = mean depth, m
L = annual areal phosphorus loading, g/m^2-yr

The steady state phosphorus concentration was assumed to be the concentration measured at fall turnover. The outflow phosphorus load from Upper Sylvan Lake was considered as an input to Lower Sylvan Lake. Utilizing this model, predicted in-lake phosphorus concentrations are listed below:

	Upper Sylvan Lake	Lower Sylvan Lake
Phosphorus Load (kg/yr)	16.1	122.8
Areal Phosphorus Load (g/m^2-yr)	0.99	2.18
Predicted Phosphorus Concentration (mg/l)	0.067	0.064
Measured Concentration	0.058	0.060

Lakes with extensive weed growths are not modelled well since weeds restrict mixing and interact directly with lake sediments. To address the problem of sediment interaction with weeds, autochthonous inputs have been compared to watershed phosphorus loads. Table 11 presents this comparison.

Table 11

Comparison of Sediment Phosphorus Loads Translocated Through Macrophytes to Tributary Phosphorus Loads

	Upper Sylvan Lake (kg/yr)	Lower Sylvan Lake (kg/yr)
Sediment Load	2.1 - 8.6	7.3 - 29.8
Tributary Load	16.1	122.8
Sediment Load as a Percent of Tributary Load	13 - 53%	6 - 24%

Table 11 clearly demonstrates that macrophytes can significantly increase the phosphorus content of Sylvan Lakes during certain times of the year, such as during the fall when macrophyte annual dieback occurs.

5.3 Acceptable Phosphorus Loading

Acceptable loading rates can be determined by Vollenweider's critical loading model, which is listed below:

$$Lc = Pc^{z} \left(\frac{1 + T}{T}\right)$$

where...

Lc = critical phosphorus Load (g/m^2-yr)
Pc = critical phosphorus concentration (ug/l) = 20 ug/l
Z = mean depth (meters)
T = hydraulic detention time (yr)

Critical phosphorus loads for Upper and Lower Sylvan Lakes are 0.154 and 0.345 g/m^2-yr, respectively. To achieve these loading rates, watershed phosphorus loads will have to be reduced by 65% in each watershed.

6.0 Watershed Management and Lake Restoration Alternatives

The uses of Sylvan Lakes have been severely impaired due to excessive siltation and an over-abundance of aquatic vegetation. The objective of the Sylvan Lakes Restoration Project is to restore the following recreational uses of the lakes: boating, fishing, swimming, and general aesthetics.

Measures for watershed management are needed for Sylvan Lakes because current nutrient loading rates are elevated resulting in eutrophic conditions in the lakes. Existing problems with dense macrophyte growths and sediment accumulations cannot be resolved with watershed management practices and will require lake restoration procedures. Watershed management and lake restoration measures that will effectively reduce water quality problems in Sylvan Lakes are discussed in this section. Preliminary cost estimates have been prepared for feasible alternatives. Measures that are most cost effective and environmentally effective are considered in a comparative cost analysis in Section 9.0. The costs for selected alternatives will be subjected to detailed cost evaluations during the Step 4 Engineering Design.

6.1 Watershed Management Alternatives

6.1.1 Agricultural Best Management Practices

As shown in Table 1, Section 3.0, agricultural land uses comprise a small percentage (12%) of the total watershed area for the two lakes. Furthermore, the township Master Plan indicates that agricultural land uses are expected to change to medium density residential. Therefore, agricultural best management practices will not be a major part of the Sylvan Lakes Restoration Project. However, current agricultural activities should utilize good soil erosion control and fertilizer management practices. As the soils in the areas of agricultural activity are sandy soils, soil erosion control techniques are relatively effective. Accumulations of sandy sediments were noted along the north shore of the west arm of Lower Sylvan Lake. Agricultural activities in this area should employ more effective soil erosion control practices. One possible method for controlling soil erosion is to install gabion baskets in the area of active runoff. The gabion baskets would act as a temporary dike and sediment filter. Shallow groundwater flows from agricultural lands are substantial in sandy soils and the low cation exchange capacity for sandy soils can result in increased nutrient concentrations in groundwater following fertilizer applications. Therefore, fertilizer applications should be keyed to crop needs, and applications should be scheduled for periods of low rainfall.

6.1.2 Urban Best Management Practices

Urban best management practices (BMPs) are used to offset the detrimental water quality impacts that occur during and after urban development. Street sweeping has been used in existing urban areas to remove pollutants associated with sediment particles that acumulate in impervious areas. Infiltration basins have been used in areas with high soil infiltration of rainwater. Infiltration basins promote groundwater recharge and thus prevent pollutants associated with urban runoff from entering receiving waters. Infiltration basins are often referred to as retention basins and volume controls, however, the function of all these BMPs is the same. Detention basins, traditionally used for flood control (water quantity), can also be used for water quality control. Minor modifications can be made during the design phase that can optimize pollutant trap efficiency. The basic concept is to pond urban runoff for a specified period of time to permit settling of pollutants associated with particulate matter. If detention time is long enough, pollutant removal can be accomplished by biological processes. Wetlands have been used for this purpose. The Burlington Township Land Development Ordinance, 19:12-8, currently requires detention basins for all major developments. Storage in the basins should be for a twenty-five year storm, with the outflow from the basin limited to a ten year undeveloped storm. The discussion that follows is intended as additional guidance for urban development in the Sylvan Lakes watershed so that planned future development does not result in significant increases in urban non-point source pollution.

Street sweeping is not a viable alternative for reducing urban runoff pollution due to the high cost and limited effectiveness. Data collected from recent U.S. EPA Nationwide Urban Runoff Program studies indicate that vacuum street sweeping phosphorus removal efficiencies of 0-20% (Pitt and Shawley, 1981).

Infiltration basins are a viable BMP for both existing and future urban development. These basins are most appropriate for areas with infiltration rates greater than 2 inches/hour. A five foot deep infiltration area of 0.1 to 0.2% as a percentage of the contributing catchment area can provide from 50 to 90% reductions in total phosphorus loads from urban areas (personal communication, E.D. Driscoll & Associates, 1983). The suitability of an infiltration basin was evaluated for the Rosewood East subdivision in the Lower Sylvan Lake watershed (Longwood Drive, Cypress Road). Conditions needed for an effective infiltration basin are:

1) Five feet of aerated permeable soil above the normal groundwater elevation, and

2) A contiguous area of land that is 0.1-0.2% of the contributing catchment area.

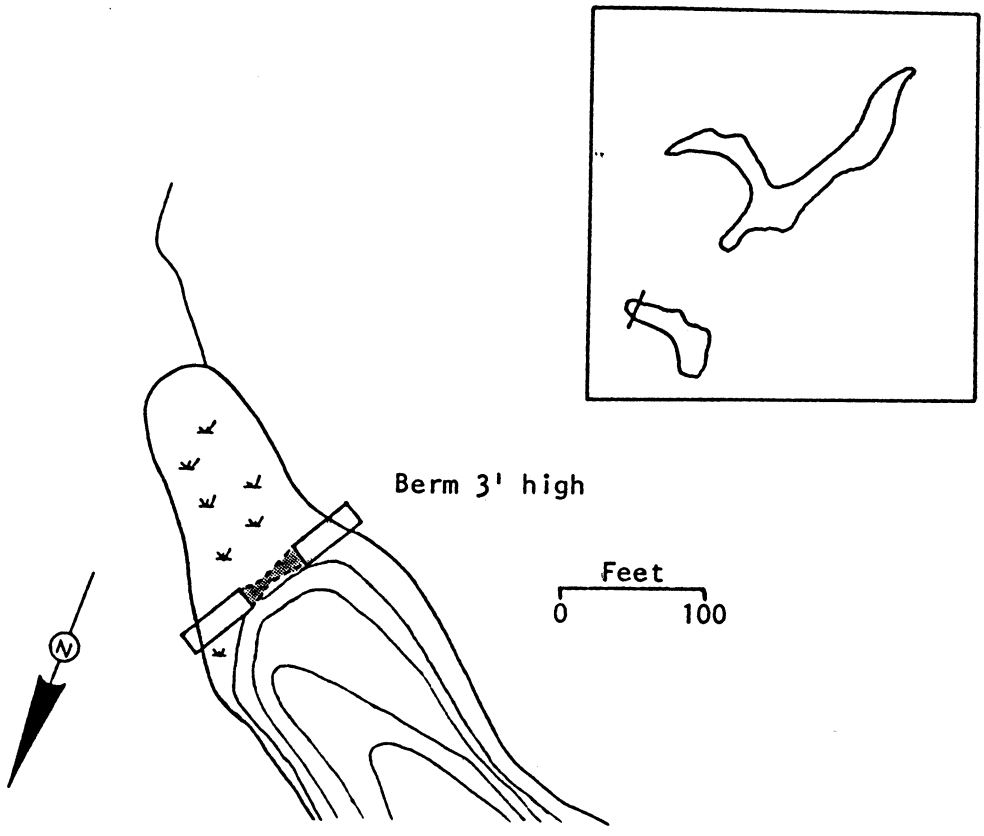
In the Town Estates subdivision, the water table is only one to two feet below the gound surface, and a contiguous area of land, approximately 0.25 acres, is not available. Residents in the area also reported that stormwater runoff discharges under pressure out of manholes during periods of intense rainfall. For these reasons, an infiltration basin is not feasible for the Rosewood East subdivision. Infiltration basins are, however, suitable for areas of future development with high soil infiltration rates.

Detention basins with a permanent pool can provide from 40 to 60% reductions in total phosphorus loads from urban areas. These efficiencies can be attained when basin area is from 0.3 to 0.5% of the contributing catchment area. Detention time for frequent storms should be in the range of 24 to 48 hours.

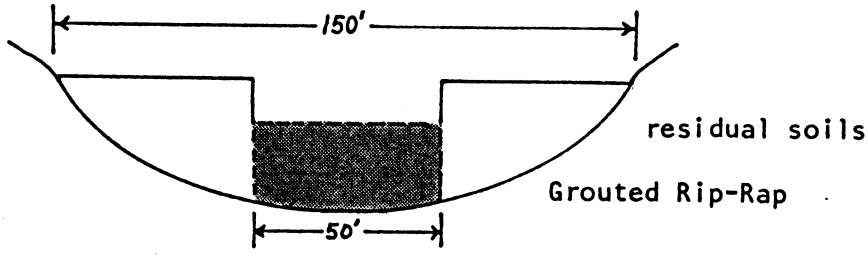
A field survey was conducted to identify potential areas for detention basins to reduce the existing high nutrient loads to Sylvan Lakes. The primary criteria in determining potential areas were high existing densities of urban development, documented high nutrient inputs, and adequate surface area for the contributing catchment area.

Three sites were identified in the Sylvan Lakes watershed. The site identified in Upper Sylvan Lake was the wetland area around the main tributary input (see Figure 6). Wet weather total ortho-phosphorus concentrations for this input were higher than concentrations measured in any other tributary or drain during a storm water quality survey conducted by the Burlington County Health Department in 1978-1979 (unpublished data, Burlington County Health Department). Approximately one acre of low lying marshland is about 10 feet below the elevation of nearby houses on Wall Avenue and 17th Street, thus impoundment of water in this area would not create flooding problems for existing residences. A three foot berm with a one foot freeboard would provide approximately 14 hours detention for a 1.0 inch runoff event. A phosphorus load removal rate of 50% is expected. The projected cost for a 100 foot long earthen berm with 3:1 side slopes and a 50 foot grouted riprap outlet is $13,000.

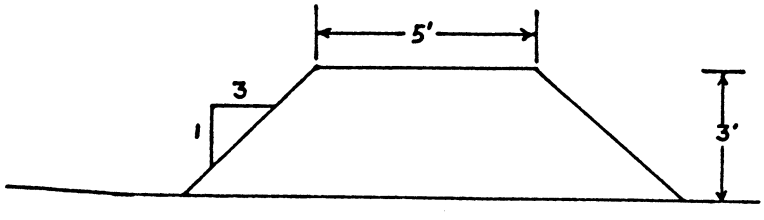
The second and third potential detention ponds for reducing existing high nutrient inputs are in the east and west arms of Lower Sylvan Lake (see Figure 7). The west arm is a good location for a detention basin because of the high density of development in the Rosewood East subdivision. As well, data from the storm water quality survey conducted by the Burlington County Health Department indicated that the runoff from the Rosewood East storm drain contains high phosphorus concentrations. In fact, the only input to Sylvan Lakes that exceeded the average phosphorus concentration for the Rosewood East drain was the main tributary input to Upper Sylvan Lake. Siting this detention pond was complicated by the relative lack of topographical relief in the land surrounding the upper west arm. As illustrated in



Upper End, Upper Sylvan Lake

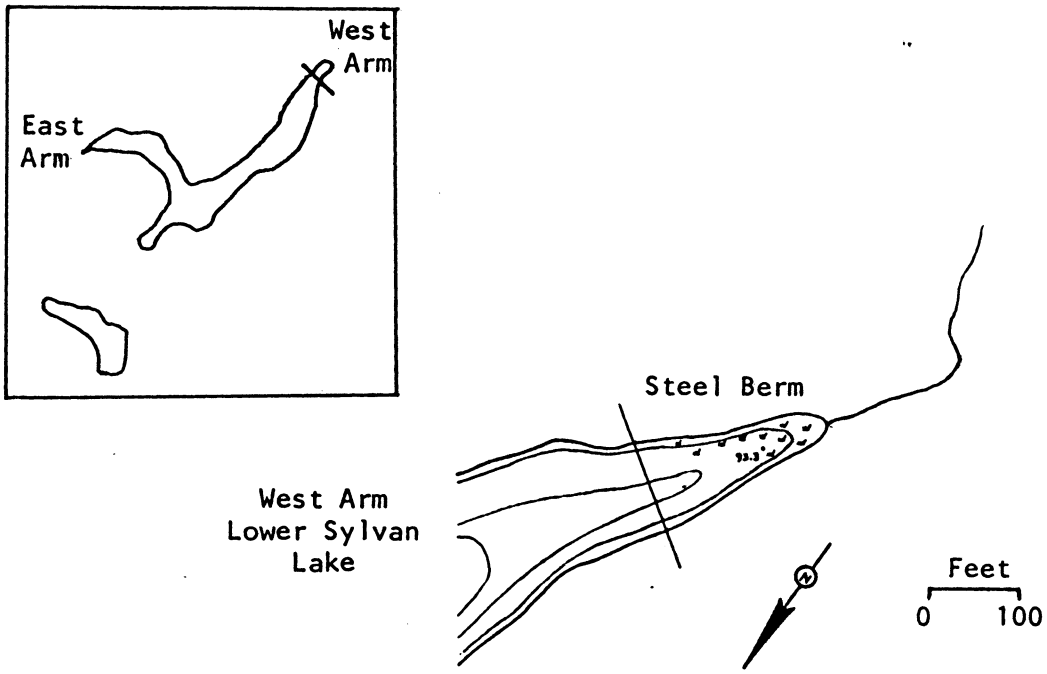


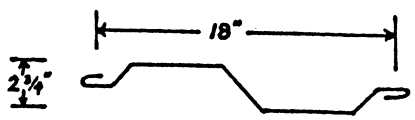
Berm Cross-Section



Typical Berm Profile

Figure 6. Proposed Detention Basin, Upper Sylvan Lake





Unit of Corrugated Steel Piling

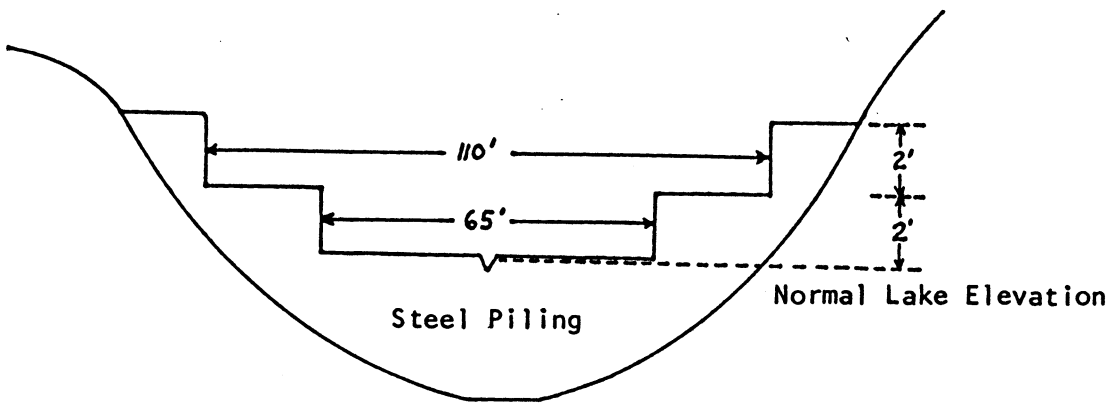


Figure 7. Proposed Detention Basin, West Arm, Lower Sylvan Lake

Figure 7, the detention basin would occupy a portion of Lower Sylvan Lake. In addition, excavation of about 2000 cubic yards of low lying land (0.22 acres) would occupy the area of the west arm of Lower Sylvan Lake that is currently covered with emergent macrophytes (Spatterdock). The construction of this detention basin would not prevent access to any riparian residents who currently have lake access. The construction schedule for this detention basin is listed below:

1) Remove all existing silts and organic material to an average water depth of 4 feet during the Sylvan Lakes dredging operation (to be discussed in Section 7.0).

2) If hydraulic dredging is required for the lakes, consider removing the soil contained in the low lying area with a swamp dozer.

3) Install sheet piling as shown in Figure 7. The specifications of the basin (to be finalized during design) are listed below:

   Volume = 120,000 cubic feet at normal pool
   240,000 cubic feet at maximum pool
   Surface Area = 0.75 acres
   Overflow Rate = 0.5 ft/hour for 0.5" runoff
   Projected Phosphorus Removal Efficiency = 40%

The sheet piling would be designed so that the peak flow from a 100 year rainfall could pass through the basin with a two foot rise in the detention basin elevation. This change in elevation in the detention basin would not increase upstream flooding. The projected cost for this detention basin is $28,500.

The detention basin for the east arm of Lower Sylvan Lake would be quite similar to the detention basin proposed for the west arm. The outlet structure would be constructed with sheet piling, the basin would have a surface area of 0.30 acres and a volume of 65,000 cubic feet at normal pool, and the projected phosphorus removal efficiency is 50%. The projected cost for this basin is $15,000.

Future developments in the Sylvan Lakes watershed should incorporate the most up-to-date design techniques for detention basins. The pond should be designed to prevent short circuiting, prevent scour, and obtain a surface overflow rate of 90 gpd/ft^2 for 0.5 inches of runoff. The outlet should be designed so that frequent storms, generally with runoff of less 0.5 inches, have a detention time from 24 to 48 hours. Specific guidelines that the Burlington Township Engineer can use for development review will be developed in the Step 4 Design Study.

6.2 Lake Restoration Alternatives

The major objectives of any lake restoration technique will be to reduce the densities of macrophytes, reduce sediment releases of nutrients to the overlying water column, improve fishing, and to increase the aesthetic appearance of the lakes.

A list of potential lake restoration methods is presented in Table 12.

A number of lake restoration methods are not presented in Table 12, as the methods are not applicable for Sylvan Lakes. For example, selective discharge is not a feasible alternative because no method exists for selectively discharging nutrient rich water from the bottom of the lakes. Each of the potential lake restoration methods is discussed in detail in the following sections.

Table 12

Lake Restoration Methods Suitable for Sylvan Lakes

Sediment sealing
Herbicide Application
Aquatic Weed Harvesting
Aeration/Circulation
Dilution/Flushing
Dredging

6.2.1 Sediment Sealing

Physically covering lake sediments has been used to control the release of nutrients from sediments and the growth of macrophytes. A variety of materials have been used as sediment sealants, ranging from sand, clay and fly ash to synthetic sealants and burlap. The success and cost of sediment sealing varies with the type of material used as a sealant. Synthetic sealants are generally the most expensive while sand, clay and burlap are less expensive. Clay, sand and fly ash have the disadvantage of decreasing the depth of a lake. These layers are often disrupted by a build-up of gases and both macrophytes and nutrients are able to break through the seal.

These problems are reduced by a sediment sealant such as Aquascreen. Aquascreen, a polyvinyl coated fiberglass, eliminates weeds by physically compressing existing plants and by filtering out the sunlight necessary for their growth. Because of its design, gases produced naturally in the bottom muds should be able to escape. Although expensive, Aquascreen has the advantage of lasting for up to five years if sediment loads to a lake are low.

Burlap has also been used successfully as a sediment sealant and reduces macrophytic growth (Jones, G.B. and Cooke, G.D., 1983). The cost of materials is a fraction of that of Aquascreen but burlap decays rapidly, even when treated with a rot retardant, and must be replaced yearly.

Of the Sylvan Lakes, the greatest benefit can be expected from covering the sediments of Upper Sylvan Lake where macrophyte growth is the most dense and the lake area is small. Even in Upper Sylvan Lake, however, the cost of materials for covering the bottom of Upper Sylvan Lake with Aquascreen is expensive at approximately $42,000, and is not recommended. The cost of sealing the sediments with burlap is only $6000 but labor costs and the inconvenience are greater because the burlap would have to be replaced yearly.

Since the use of sediment sealants is only a temporary measure to improve the use of the Sylvan Lakes it is not recommended at this time. Sealing does not remove the organic silt layer from the lake bottom and does not reduce nutrient and sediment loads to the lakes. If the lakes are dredged and nutrient loads reduced, the use of a material such as Aquascreen may be valuable in limited trouble spots in Upper Sylvan Lake and should be reevaluated at that time.

Chemical sealing has been accomplished by applying large doses of alum to the lake bottom. The alum chemically binds sediment phosphorus even during anaerobic conditions, thus chemical sealing can dramatically reduce phosphorus releases from lake sediments. Alum treatments of this nature would cost approximately $102,000. The main problem with alum treatments is that while the alum treatment reduces sediment releases of phosphorus, macrophyte growths increase due to increased water transparency resulting from reduced algae growths (Cooke and Kennedy, 1981). Therefore, alum treatments to bind sediment phosphorus is not recommended for Sylvan Lakes.

6.2.2 Herbicide Application

Macrophytes can generally be controlled with herbicides if the proper chemical is selected and correctly applied. This lake restoration technique has been used in Sylvan Lakes. Depending on the type of chemical, herbicides are effective either immediately or through systemic action. Herbicide treatment is often used around the shores of lakes; however, in some cases entire lakes have been treated.

According to Conyers and Cooke (1982), herbicides have many drawbacks, including:

1. Dead vegetation is not removed from lake.

2. Plants release nutrients upon death and decomposition.

3. Dissolved oxygen concentrations are depleted due to microbial decomposition (this may induce the release of nutrients from the sediments).

4. Algal blooms often occur due to increased nutrient levels.

5. Herbicides can be toxic to non-target species.

6. Some plant species may be tolerant to the herbicide.

7. Some herbicides are suspected to be mutagenic and carcinogenic.

8. The waiting period (10 days or more in some cases) following application of many herbicides interferes with recreational lake uses.

9. Unsightly conditions are often created.

Herbicide treatment provides only temporary relief from chronic aquatic weed problems. In many instances, application is required at least twice per year (US EPA, 1973).

Although chemical control of aquatic weeds has been extensively used, there is relatively little documentation regarding environmental impacts. Although refuted by chemical manufacturers, there are still questions regarding the toxicity of certain herbicides on fish and other food chain organisms. For example, copper sulfate has been shown to be toxic to fish under certain circumstances (Bartley, 1976). Unlike compounds containing heavy metals, most of the organic chemicals do not appear to accumulate in lake systems.

The specific dosage rate for a particular lake must be chosen carefully. Professional expertise with experimental in-situ testing in a limited area is needed to arrive at the dosage rate which will control the target species without producing undesirable side effects. Some herbicides are more effective at controlling certain plant species. Herbicide treatment is a cosmetic treatment method to reduce the negative effects of lake eutrophication. Herbicides cannot reduce the long-term effects of eutrophication, and therefore are not considered an effective long-term lake restoration strategy for Sylvan Lakes.

6.2.3 Aquatic Weed Harvesting

Aquatic weed harvesting is used to physically remove nuisance vegetation and incorporated nutrients and organic matter from the lake ecosystem. A variety of machinery is available for aquatic weed harvesting. Those types which cut the macrophytes and immediately remove them by means of a conveyor are generally considered the most efficient.

The harvesting of macrophytes strictly for the removal of nutrients is not a common lake restoration approach. When possible, plants absorb nutrients in excess of their needs (i.e., "luxury" uptake). Burton et al., (1979) reported that as much as 0.05 to 0.4 g/m /yr of phosphorus could be removed from a lake by mechanical harvesting. However, in order to have a net effect, the removal rate must exceed the annual phosphorus accumulation rate. Even if this were possible, it would most likely take years to deplete the supply of phosphorus which is stored in the upper layers of the sediment.

More often weed harvesting is used primarily to restore the recreational uses of a lake. However, the technique presents a maintenance problem since the equipment seldom removes the entire plant. Most lakes usually require two to three cuttings per year in order to maintain the weeds at a non-nuisance level (Nichols, 1974). The frequency of cutting, however, may be reduced after several years of harvesting.

The potential environmental impacts of weed harvesting include:

1) Ecological impacts on benthic and aquatic organisms,

2) Change in the dominant plant species,

3) Dissolved oxygen depletion due to plant decomposition,

4) Nutrient release to the water column from decaying plant matter, and from ruptured plant stems.

Due to a combination of factors, a significant increase in the levels of algae may occur after harvesting (Nichols, 1974).

In summary, harvesting can significantly reduce the densities of certain aquatic plants, however, other plants may fill the gap in the ecological niche. As well, harvesting will not eliminate nutrients releases from lake sediments and will not address the aesthetic problems associated with siltation. Therefore, weed harvesting has not been considered as a long-term restoration strategy for Sylvan Lakes.

6.2.4 Aeration/Circulation

Aeration/circulation is a technique to mix the bottom and surface waters of a lake and increase the dissolved oxygen concentration at the bottom of the lake. Aeration units are generally designed to circulate the entire lake volume once every two to four weeks, depending on the hypolimnetic oxygen depletion rate. Aeration/circulation is most commonly accomplished by pumping air through diffusers on the lake bottom. The rising air bubbles draw water up with them, mix the water column and increase the dissolved oxygen concentration.

If properly designed, aeration/circulation can increase dissolved oxygen concentrations at the lake bottom and destroy any thermal stratification. In certain lakes aeration has been beneficial and has resulted in reduced phosphorus and algae levels and increased transparency. These improvements have been attributed to reduced phosphorus release from the sediments.

In other lakes the opposite reaction has been observed. The main problem reported in unsuccessful aeration experiments has been reduced algal settling due to increased circulation (Gulliver and Stefan, 1982). Mixing may also bring phosphorus-rich water from the lower portion of a lake into the photic zone where it is available for algal growth. Artificial circulation also causes the summer temperatures at the sediment water interface to be higher than during normal summer conditions. The increase in temperature often increases sediment phosphorus releases, particulary where the sediments contain large amounts of organic material.

Under current conditions in the Sylvan Lakes, the primary benefit of aeration will be an increase in the aerobic zone in the lake and expansion of zooplankton and fish habitats. Even under aerobic conditions at the sediment-water interface, anaerobic conditions will still exist in the deeper lake bottom sediments and the sediments are likely to release phosphorus to the overlying water. Although the Sylvan Lake sediments contain sufficient levels of iron to bind phosphorus and prevent the release of soluble phosphorus, sulfur levels are also high. As a result, reduced iron diffusing upward through the sediments is likely to bind with sulfur rather than phosphorus (Stauffer, 1981). Under these conditions i.e., aeration and increased circulation with continued nutrient release from the sediments, water quality conditions will not improve.

Dredging the organic sediments from both lakes will be necessary to reduce nutrient release and translocation of nutrients from the sediments to the water column. Given two scenarios, 1) aeration or 2) dredging and aeration, the benefits from aeration are expected to be the same: increased zooplankton and fish habitat. Nutrient releases will be better controlled by dredging rather than aeration because of the chemistry of the lake bottom sediments, therefore aeration is not recommended unless the lakes are dredged.

Aeration can be used in conjunction with dilution (see next section) to offset the impacts of continual high watershed nutrient loadings. A cost was developed for aeration of both Upper and Lower Sylvan Lakes. The capital cost is $7000 and the electricity cost for a six month period is $600.

6.2.5 Dilution/Flushing

Dilution/flushing is a lake restoration technique that is based upon flushing the nutrient enriched water of a lake with nutrient poor water. The result of flushing is overall lower nutrient concentrations in the lake. This technique has been most effective in lakes that have a narrow configuration (Lomax and Orsborn, 1971), such as the east and west arm of Lower Sylvan Lake. This technique is most effective when the dilution water has a low concentration of phosphorus and a high concentration of iron. The iron from the dilution water can combine with dissolved phosphorus in the lake water and a ferric hydroxide phosphate precipitate develops. The dilution water in effect "strips" the lake water of phosphorus, which results in decreased algae levels. For iron to remove phosphorus from lake water, however, the water must be aerobic, as iron does not precipitate phosphorus under anaerobic conditions. In most cases, groundwater has been the source of dilution water. Many groundwater aquifers have a high iron content, thus if a steady supply of groundwater with a high iron content can be located, dilution can improve receiving lake water quality.

In summary, dilution/flushing works by diluting the ambient lake nutrients and phosphorus precipitation by chemically binding with iron. A significant number of springs with high iron content were observed during field surveys. The springs are probably the source for the name of the community of Springside which surrounds Upper Sylvan Lake. Accordingly, the feasibility of dilution was investigated for Sylvan Lakes. The first ofjective in the evaluation of dilution was to find a source of high quality groundwater. Samples were collected from two shalow wells and a subsurface drainage pipe. These samples were analyzed and the results, presented in Table 13, indicate that shallow groundwater contains relatively low concentrations of phosphorus and higher concentrations of iron. A separate set of samples collected from each station were aerated for five minutes to determine if aeration enhances phosphorus precipitation by iron. After aeration, the samples were allowed to sit for one hour, and then the water was analyzed for total phosphorus. This simple test indicates that shallow groundwater supplies, if aerated, will provide a suitable source of dilution water for Sylvan Lakes. Deep groundwater water quality data from the United States Geological Survey (personal communication, Tom Fusillo, USGS, 1983) were evaluated to determine water quality and data from wells in the vicinity of Burlington Township. These data indicate that deep groundwater supplies have uniformly low phosphorus concentrations (less than 0.01 mg/l) and high iron concentrations (greater than 4.0 mg/l).

The second objective in the evaluation of dilution was to develop a cost effective supply of groundwater. Costs were developed for two sources of groundwater: shallow groundwater (about 25 feet deep),

Table 13

Shallow Groundwater Data, Sylvan Lakes

Sample	2	3	4
Location	Crestwood Ave.	Wall Ave.	Cypress Rd.
Well Depth	15 feet	15 feet	underdrain
Total Phosphorus, mg/l	<0.01	0.04	0.04
Iron, mg/l	0.08	0.12	2.1
Alkalinity, mg/l	26.0	106.0	40.0
pH	5.03	7.53	7.06
Total Phosphorus, gm/l, after 5 minutes aeration, 1 hour quiescence	<0.01	<0.01	<0.01

and deep groundwater (100 to 200 feet deep). Deep groundwater supplies are more dependable, however, pumping costs are higher. The problem with shallow groundwater wells is that special permission would be required from Burlington County, and the pumping rates may cause drawdown of shallow groundwater supplies.

The preliminary engineering design for the dilution system was based on the following assumptions:

1) Deep groundwater supplies will be an easier water source to develop than shallow groundwater,

2) The iron concentration in the groundwater source will be at least 2.0 mg/l, and

3) The dilution system will be used in conjunction with an aeration system (see Section 6.2.4) to ensure that the phosphorus conplexing capability of iron is maintained.

The dilution system, if implemented, will consist of one deep 4 inch well with steel casing for Upper Sylvan Lake and six deep wells for Lower Sylvan Lake. The estimated cost of an installed well with associated equipment is $3000. The cost for installation is $22,000 for both Upper and Lower Sylvan Lakes. The annual energy cost per well is $600.

In summary, dilution/flushing in conjunction with aeration has the potential for dramatically reducing the in-lake phosphorus concentrations in Sylvan Lakes. If this program is installed after the lakes are dredged, both algae and macrophytes growths should be reduced substantially. Because relatively little design information exists for a lake restoration system such as the proposed system, a dilution and aeration system is recommended for Upper Sylvan Lake following dredging. If the system performs as expected, then the system should be constructed for Lower Sylvan Lake. The cost for installation of the dilution and aeration system is $6800 with an annual operation and maintenance cost of $1600. ?

dilution $3000
600
aer. 3500
300

6.2.1 Dredging

The physical removal of lake sediments can be used to achieve one or more objectives, including macrophyte removal, lake deepening, and nutrient removal (Peterson, 1981). The most obvious advantage of dredging is the immediate removal of virtually all plants from the lake bottom. Therefore, all of the nutrient compounds and organic matter which comprise the existing vegetative biomass are permanently removed from the lake system. Proper elimination of the macrophytes would include the removal of all plant parts such as seeds and roots which could case a recurrence of nuisance growths.

The actual deepening of a lake can have several benefits. First, dredging to depths below the photic zone limits the amount of light available for macrophyte growth.

Simply increasing the water depth can cause changes in the types of macrophytes that grow which result in reduced problems for lake users. Moreover, the removal of soft organic sediment to a hard sand or clay bottom often results in reduced plant growth rates and densities (Nichols, 1974). Dredging has been successfully performed to reduce macrophyte problems in a number of small lakes, including Steinmetz Pond (Snow et al., 1980) and Sunshine and Krause Spring Ponds (Carline and Brynildson, 1977).

The objective of dredging for macrophyte control should not be considered synonymous with macrophyte eradication. Any macrophyte dredging plan must account for the preservation of fish spawning and nursery areas, water fowl feeding areas, and other wildlife habitats.

The second significant benefit of dredging is the enhancement of recreational activities. Also, a larger lake volume generally allows greater levels of fish production (Carline and Brynildson, 1977). These benefits are not obtained from a program solely aimed at controlling macrophytes.

The third major objective of most dredging programs is to remove nutrients from the lake system. For most lakes, large quantities of nutrients have accumulated in the sediments. These nutrients serve as fertilizer to rooted aquatic plants. The nutrients can also be returned to the water column where they are available to support the growth of floating plants and phytoplankton. The release of these nutrients to the water column occurs via two separate mechanisms. First, direct release from the sediments to the water column can occur under certain chemical conditions (Snow and DiGiano, 1976). Although phosphorus release rates are generally higher under anoxic (zero oxygen) conditions, Lee et al. (1976) demonstrated that substantial quantities of phosphorus can also be released under oxic (oxygenated) conditions. Since they are not tightly bound into sediment deposits, most nitrogen compounds are more subject to direct recycle into the water column.

The second mechanism which causes the transfer of nutrients from sediments is via rooted vascular plants. Some researchers (Schults and Maiueg, 1971; Twilley et al., 1977; Carignan and Kalff, 1980) have documented that various species of freshwater aquatic plants extract nutrients from the sediment during their life cycles and translocate them to the surrounding water (i.e., act like nutrient "pumps"). Others (Lie, 1979; Welch et al., 1979; Barko and Smart, 1980) have contended that the major quantities of nutrients released from macrophytes occur during the periods of plant senescence and decay. In either case, the presence of macrophytes increases the transport of settled nutrients back into the water column.

Therefore, for many lakes it is desirable to remove both macrophytes and nutrient-laden sediments by dredging to a nutrient-poor sediment layer.

There are two categories of dredging methods: (1) in-lake sediment removal and (2) drawdown and excavation. The first category includes methods which do not necessitate a complete drawdown of the lake, such as dragline and hydraulic dredging. The second category involves the actual drainage of a lake and sediment removal by the use of specialized earthmoving equipment. Most types of dredging are relatively expensive when compared to other methods of lake restoration. However, the costs of dredging are often offset by the long-term benefits.

The dredging of a lake can have significant environmental impacts. Both types of dredging cause destruction of the benthic community (including fish food organisms). If the entire lake basin is dredged, two to three years may be required to re-establish the benthic fauna. However, if portions of the bottom are left undredged, the restoration may be almost immediate or within one to two years (Peterson, 1981). In any case, according to Peterson, the effect on the benthic community appears to be of relatively short duration compared to the longer term benefits derived from sediment removal.

Problems with in-lake dredging often occur due to the resuspension of sediments and nutrients during the dredging operation. These phenomena can result in detrimental impacts such as algae blooms, increased turbidity levels, dissolved oxygen depletion, and the resuspension of toxic materials. However, the continued improvement of hydraulic dredging equipment and methods have helped to minimize these adverse impacts.

Of course, the complete drainage of a lake would have a severe impact on the aquatic ecosystem. During the period of lake lowering, certain organisms such as amphibians and reptiles could seek refuge in other portions of the tributary system. However, in most instances it is desirable to manually transport as many organisms as possible, particularly fish, to a suitable location. The lake would, therefore, have to be stocked after refilling.

As explained by Stefan and Hanson (1980), it is not desirable to dredge a shallow lake to the point where it becomes thermally stratified during the summer. Such stratification could cause depleted oxygen conditions and the subsequent increased recycling of nutrients to the hypolimnion where they could be released to the entire lake during periods of turnover.

One problem which sometimes occurs after a dredging project is a change in the phytoplankton characteristics (i.e. algal composition and density) for a given lake (Lee, 1973). This change should not be harmful in most instances since the overall nutrient concentrations in the lake should theoretically be lower after dredging.

Another major concern which must be addressed for all dredging projects is the size and location of the spoils disposal area. With regard to size, a hydraulic dredging project usually requires a larger disposal site due to the quantities of water which are pumped along with the sediments. Hence, large settling basins or large areas of vacant or agricultural land with high infiltration rates are normally required. Also, chemical treatment of the effluent from these basins is sometimes necessary to ensure that a sufficient portion of the nutrients and suspended solids precipitate out of the water. Sediments which have already been dewatered in the lake bottom prior to removal do not necessitate as much disposal area.

Besides the quantity of sediments, quality is also an important factor. Sediments which contain high concentrations of heavy metals or toxic organic compounds could contaminate surface water and groundwater resources at the disposal site. Mitigative measures, such as a clay liner, would be required in such an instance. Based on the sediment tests presented in Section 4, this is not a concern for Sylvan Lakes.

In summary, dredging is effective in reducing macrophyte growths, sediment releases of phosphorus to the overlying water, and hypolimnetic oxygen depletion. Dredging will increase the overall depth of the water, improve the aesthetic appeal of the lakes, and increase water transparency. The next section will present an analysis of sediment disposal methods and sites.

7.0 Sediment Disposal Methods and Sites

7.1 Disposal Sites

Existing topographical land use maps, and aerial photographs were reviewed to identify suitable sites for disposal and/or dewatering of dredged sediments from Sylvan Lakes. The primarly objective was to find a large, preferable contiguous, site within one mile of the lakes. Field surveys and consultation with Burlington Township personnel provided additional site-specific information regarding potential sites. Based upon this work, six areas were identified as potential disposal sites. These sites are shown in Figure 8 and are described in detail in Table 14.

Site 1, the Cox Farm, is currently not used for crop production and has excellent drainage. The Galestown sandy soils have an infiltration rate of 2-6 inches per hour with a clay substratum that has slower infiltration rates, generally less than 1.0 inch per hour. Sediments will dewater quickly, and the clay substratum will reduce the possibility of groundwater contamination. This site can be used for hydraulically dredged spoils. Surface water contamination problems and soil erosion can be prevented by placement of low profile berms.

Site 2, the Heal Farm, is currently used for crop production, and the owner has expressed interest in using the lake sediments as a soil conditioner. The planned capacity available at this site is less than Site 1 so that the operation would not interfere with crop production activities. This site is similar to Site 1 in that soils are Galestown sands with a clay substratum. Berms would also be used with this site to prevent surface water runoff and soil erosion problems.

Site 3, as shown in Figure 9, can be used to contain hydraulically dredged lake sediments. A ten foot high berm would be used to contain the sediments. A drop outlet structure would deliver runoff to a secondary treatment area that would provide additional settling enhanced by polymer addition. The main problem with this site is that the floodway channel for Sylvan Lakes would have to be rerouted around the containment site. Trees currently found in the area would also have to be removed, and fencing might be required to prevent harm to young children playing in the area.

Site 4, a bermed containment area below Upper Sylvan Lake, could also be used for disposal of lake sediments. This site, however, requires a great amount of berm construction for a small disposal volume. This site, accordingly, has not been seriously considered as a disposal area for lake sediments.

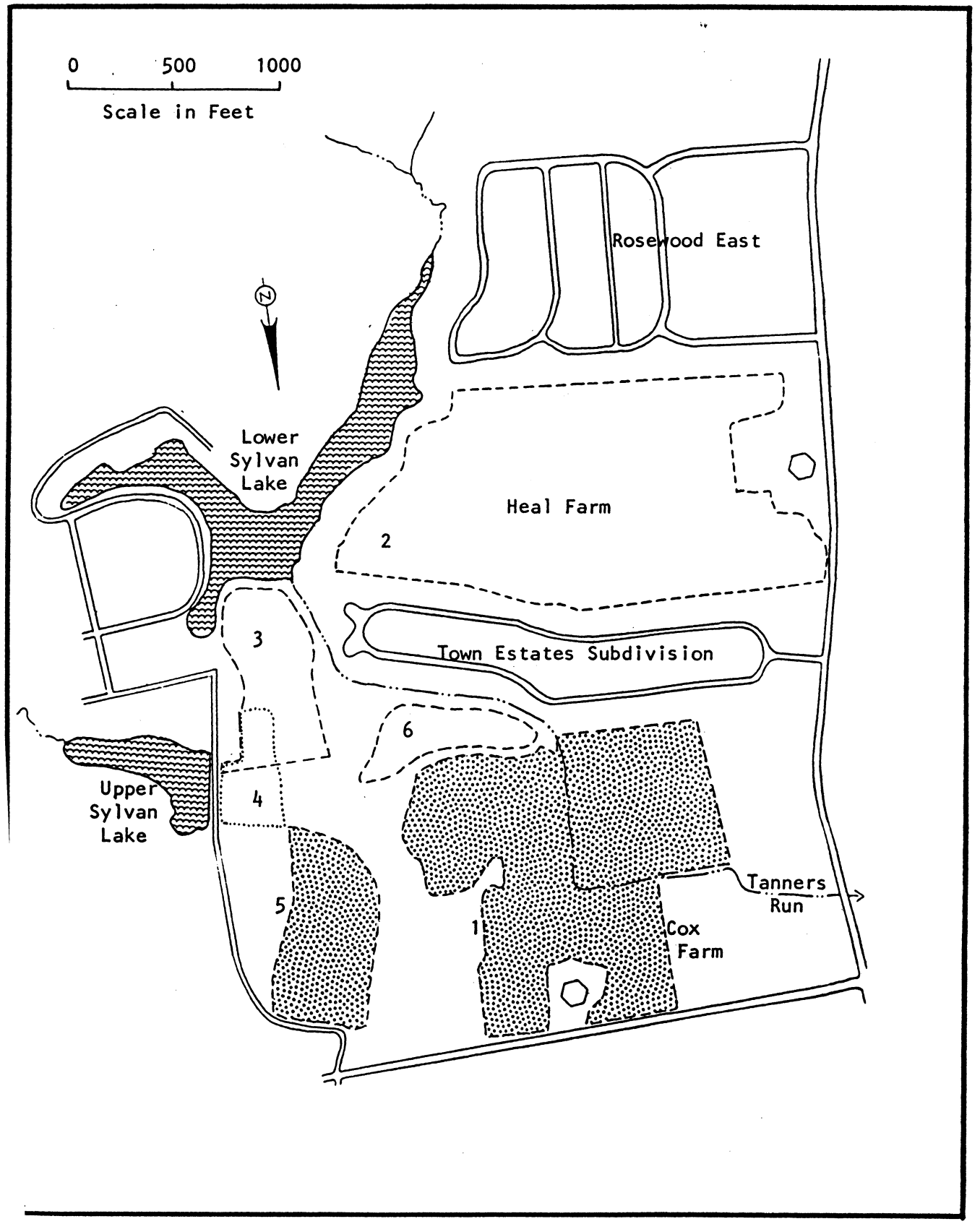


Figure 8. Potential Disposal Sites for Lake Sediments

Table 14

Potential Disposal Sites for Sylvan Lakes Sediment

Site	Area (acres)	Average Spoils Depth (feet)	Volume (cubic yards)
1. Cox Farm	35	1.0	54,500
2. Heal Farm	34	0.5	27,225
3. Lower Sylvan Lake Dam	7.5	7.2	86,860
4. Upper Sylvan Lake Dam	2.9	4.1	18,944
5. Township Compost Area	8.25	1.0	13,333
6. Rosewood Ditch	6.5	0.5	5,240

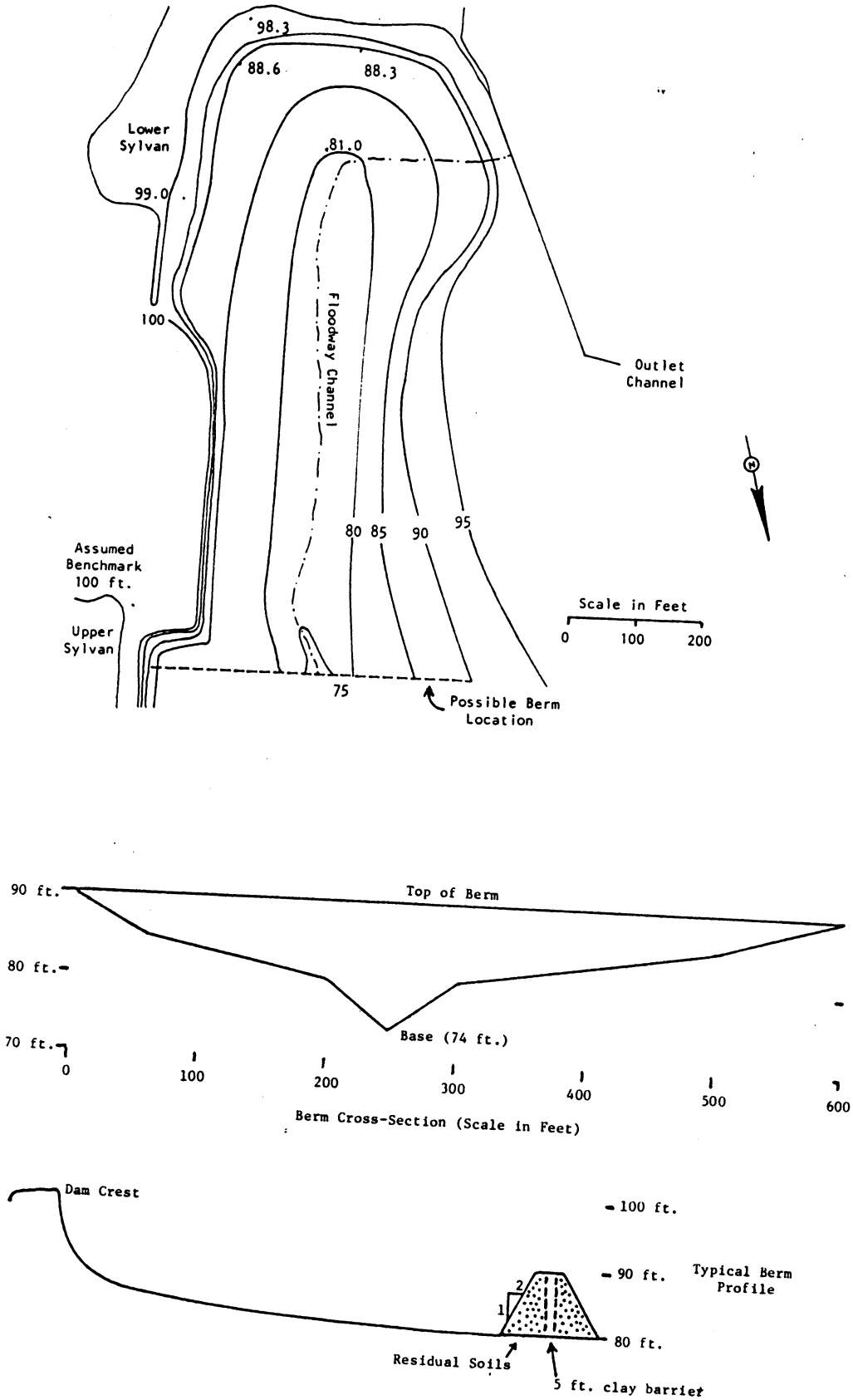


Figure 9. Disposal Area 3 - Bermed Containment Site for Hydraulically Dredged Lake Sediments

Site 5, the Burlington Township compost area, could be used to dewater lake sediment. Additional berm construction would be required, however, the site could be easily set up for sediment dewatering as fencing has already been constructed and the lake is currently owned by the Township. The Township has a definite need for this site for its current uses, therefore Site 5 should not be seriously considered as a dewatering site unless as a last resort.

Site 6 is a natural ditch behind the Rosewood East subdivision. A short berm with underdrainage for the natural ditch would be the only work necessary to contain solids. The area, however, has extensive forest cover which would have to be removed. Due to the problems associated with forest cover, and the small disposal volume available, Site 6 should not be seriously considered as a sediment disposal site.

Mechanically dredged sediments can be placed at all of the sites listed above. Site 3, the bermed containment area below Lower Sylvan Lake, could be reduced in size to handle the more compact spoil material that results from mechanical dredging. In addition, treated mechanically dredged sediments can be used as soil cover by nearby landfill operations. The increased cost in trucking can often be offset by a payment by the landfill operator for the material. The demand for soil cover, however, is variable, and thus, the cost effectiveness of utilizing dewatered sediments as landfill soil cover cannot be confidently determined until the time of dredging.

7.2 Mechanical Dredging

The basic operation for mechanically dredging 54,500 cubic yards of sediments from Sylvan Lakes consists of the following tasks:

- Dewater lakes with siphons.
  - Dewater Upper Sylvan Lake in 2 days
  - Dewater Lower Sylvan Lake in 4 days

- If a containment area is used, construct berm below Lower Sylvan Lake. General specifications:

  Volume: 62,000 cubic yards
  Berm length = 380 feet
  Maximum height = 17 feet
  Width - top of berm = 10 feet
  Berm side slopes = 2:1
  Thickness of clay core = 5 feet
  Surface area of disposal site: 3.9 acres

- Excavate trenches through lakes to provide a low flow channel and dewatering.

- Let Upper Sylvan Lake dewater for one month to consolidate sediments.

- Construct temporary stream crossings to cross trench.

- Remove sediments with special wide-track swamp dozers. Projected time for both lakes: 62 days.

- Load sediments with a loader onto trucks. There will be at least five truckloads per hour.

- If a containment area is used, place fine grained sediments in a pile. Lay down coarse sediments first. Compact sediments with a vibratory roller (minimum two passes).

- Close disposal site and apply grass seed.

If the sediments are used for soil cover at a landfill, the containment area construction will not be needed. Costs were developed for mechanical dredging and disposal at a containment area and at a landfill.

Cost for mechanical dredging and containment area: $294,000 ($5.40 per cubic yard).

Cost for mechanical dredging and truck to Burlington City Landfill (higher cost assumes no payment for sediments, lower cost assumes $2/C.Y. for sediments): $215,000-$280,000 ($3.94 to $5.14 per cubic yard).

There are a number of advantages to dredging the lake sediments using mechanical means. Most importantly, the sediments can be easily dewatered and can be put to beneficial uses. If no beneficial use is found, less disposal area is needed. The other main advantage of mechanical dredging over hydraulic dredging is that a bulldozer is not bothered by rocks, logs, or stumps, whereas a hydraulic dredge must shutdown when a rock clogs the intake line. The main disadvantage is that truck traffic around the lakes will be substantial, at least five truckloads per hour will be delivered 8 hours per day, 5 days per week. This may damage roads, and any possible spilling from the trucks will increase dust levels in the area and may potentially cause odor problems. In addition, the lakes will be dry for one summer and will prevent recreational uses of the lakes and generally cause a short-term aesthetic problem.

7.3 Hydraulic Dredging

The basic operation of a hydraulic dredging program is relatively simple and is described below:

- Construct berm for the containment area below Lower Sylvan Lake or at the farm(s). If farmland is used, two foot berms would be constructed to prevent soil erosion. If the containment area is used, the berm would meet the specifications presented in Figure 9 in Section 7.1.

- Unload dredge from delivery truck with a crane.

- Layout disposal area pipeline (pipeline generally comes in 20 foot lengths) and install booster pump.

- Set up cable network for maintaining proper directional alignment during dredging.

- Commence dredging Upper Sylvan Lake. Then proceed to the west arm of Lower Sylvan Lake, and finally finish the remainder of Lower Sylvan Lake.

The hydraulic dredge production rate can range from 50 to 120 cubic yards per hour. In open water areas, a production rate of 120 per cubic yard/hour is possible. In areas with heavy emergent macrophyte growths, logs, or large rocks, the dredge intake line can become clogged. At this point, the cutterhead must be raised to remove the obstruction. During the process of removing the obstruction, the pump continues to pump water through the pipeline to the disposal area. Excessive clogging can thereby reduce the production rate of a hydraulic dredge. The uncertainty regarding the number of obstructions that will be encountered during a hydraulic dredging operation makes it difficult to predict the duration of a dredging program for Sylvan Lakes, however, it is estimated that the dredging process would take 85 days, based upon an assumed production rate of 72 per cubic yard/hour. The volume of a given mass of lake sediments increases after hydraulic dredging due to the mixing of water and sediments. This is referred to as a "bulking factor". The bulking factor used to design a containment area varies, generally in the range of 1.0 to 2.25. If a dredging program takes place over a long period of time, the sediments that have been placed in a containment area have ample time to compact. In this case, the bulking factor selected would be on the low end of the range listed above. Also, if the disposal area used for the sediments has an optimal dewatering system, such as underdrainage, or soils with high permeability, the selected bulking factor would also be on the low end of the range listed above. Organic content in sediments and small grain size generally causes more bulking. As two different types of sediment disposal techniques are being considered as disposal alternatives (land application to farmland and a bermed containment area), two different bulking factors have been assumed. The bulking factors used for the disposal techniques are given below:

Disposal Technique	Bulking Factor
1) Land application to farmland	1.3
2) Bermed containment area	1.6

Costs were developed for hydraulic dredging utilizing these two disposal techniques and are given in Table 15.

Table 15

Costs for Hydraulic Dredging

Dredging Technique	Cost
1) Hydraulic dredging, bermed containment area (volume = 86,900 cubic yards)	$235,000
2) Hydraulic dredging, Cox Farm	$182,000
3) Hydraulic dredging, Cox Farm and Heal Farm	$200,000

One advantage to hydraulic dredging is that the operation is relatively simple. No trucks are needed, therefore, soil erosion and dust problems around the lakes due to truck traffic is nonexistent. Also, the lakes can be used for recreational purposes during the dreding operation.

The uncertainty regarding the number of obstructions that will result in temporary shutdowns is a major disadvantage to hydraulic dredging. The other disadvantage to hydraulic dredging is that the sediment volume increases in size due to an increase in the void ratio.

8.0 Alternatives Comparison

8.1 Environmental Impact Assessment

The major objective of the Sylvan Lakes Restoration Project is the improvement of water quality in Upper and Lower Sylvan Lakes. Therefore, the long-term environmental impact to the lakes will be positive. However, with any project that involves earth movement and construction, some negative environmental impacts will occur. In this section, the positive environmental impacts resulting from the feasible restoration measures listed above will be presented, then the negative environmental impacts will follow.

8.1.1 Positive Environmental Impacts

Dredging. Dredging the nutrient-rich sediments from Sylvan Lakes will reduce the rate of diffusion of phosphorus from sediments to the water column, plus dredging will reduce available nutrients for macrophyte growth. Dredging will also remove the root systems and seeds of macrophytes. Controlling nutrient releases and macrophyte growths will have a number of closely associated benefits, namely reduced algae growths and decreased oxygen consumption rates from decay of macrophytes and settling algae. Also, dredging will improve habitat for fish spawning and macroinvertebrate and aquatic insect colonization. Increased diversity of the aquatic insect community is expected, which in turn will improve fishing. As long as the sediments remain in Sylvan Lakes, restoration efforts will not completely address existing water quality problems.

Detention Basins. The phosphorus loads to Sylvan Lakes will be reduced as shown in Table 16 and the concentration of phosphorus in Upper Sylvan Lake will be reduced from 0.041 mg/l to 0.03 mg/l under current development conditions. The phosphorus concentration will be reduced from 0.06 to 0.039 mg/l under current conditions. The detention basins will change the trophic state of Upper Sylvan Lake from a current eutrophic condition to a mesotrophic condition. The detention basins in Lower Sylvan Lake will significantly reduce phosphorus loads to Lower Sylvan Lake but will not significantly change the trophic state of the lower lake. Chlorophyll a levels will decrease, and oxygen consumption rates in the hypolimnion will be reduced, improving conditions for fish. In addition, the detention basins will reduce the suspended solids loads to the lakes and will extend the life of the lakes after dredging.

A lower sediment accumulation rate will reduce macrophyte growths by keeping the nutrient rich sediments out of the lake. Reducing sediment accumulations will extend the life of the lake.

Dilution and Aeration. The main benefit to diluting Sylvan Lakes with groundwater will be reduced concentrations of phosphorus in lake water. Aeration will assure that iron from groundwater inputs will

Table 16

Effect of Detention Basins on Phosphorus Loads and Phosphorus Concentrations in Sylvan Lakes

	Percent Reduction in Phosphorus Load	Predicted in-lake Phosphorus, mg/l
Upper Sylvan Lake		
- Present Land Use	44	0.03
- Projected Future Land Use	44	0.036
Lower Sylvan Lake		
- Present Land Use	37	0.039
- Projected Future Land Use	34	0.046

continue to bind phosphorus. Reducing the concentration of phosphorus in the lakes will reduce algae concentrations, increase water transparency, decrease the amount of settling particulate organic matter, reduce sediment oxygen demands, and improve habitat for fish and aquatic insects. The dilution has been designed to provide a 4:1 mass-to-mass ratio of incoming iron from groundwater to incoming phosphorus from the watershed. Jar tests described in Section 6.2.5 indicate that a 4:1 iron to phosphorus ratio should be sufficient to reduce the phosphorus concentration in lake water down to less than 0.01 mg/l, which is indicative of oligotrophic water quality conditions. However, due to incomplete mixing, small areas of anaerobic hypolimnetic waters, and rapid changes in tributary flow inputs, complete removal of phosphorus may not occur. It is expected that the in-lake phosphorus concentration should remain around 0.02 mg/l, which is still two to three times lower than current concentrations. Dilution and aeration, in combination with dredging, has the greatest potential for improving water quality in Sylvan Lakes.

8.1.2 Negative Environmental Impacts

Dredging. Dredging will cause a short-term decrease in macroinvertebrate populations in Sylvan Lakes, however, recolonization should occur rapidly and population diversity and density should be greater after dredging than before dredging. Increased turbidity levels are often observed in outflow waters downstream from dredging projects. With proper design, this problem can be effectively controlled.

Mechanical dredging causes greater disruptions to the lakes and surrounding area than hydraulic dredging. With mechanical dredging, at least five truck trips per hour are anticipated. Over a period of three months, lake residents and people using the lake for recreational purposes will be affected by elevated noise levels and dust conditions. Mechanical dredging will also necessitate dewatering of the lakes, which will prevent use of the lakes for recreational purposes and will require fish removal. The primary negative environmental impact for hydraulic dredging will be the possible groundwater contamination from the sediment/water slurry. Chemical analysis of the sediments has indicated, however, that groundwater contamination from Sylvan Lakes sediments will not be a substantial problem.

Detention Basins. The primary negative environmental impacts will result from construction activities necessary for detention basin construction. Soil erosion control procedures will be employed to minimize negative impacts. Detention basins should be constructed to assure that no increases in flooding result from the impoundment of water.

Dilution and aeration. Groundwater pumping for dilution water may deplete groundwater supplies. This potential negative environmental impact will be further evaluated during the design phase of this project. The aeration rate should be planned to assure that the mixing rate does not exceed the settling rate for tributary inputs of sediments.

8.2 Analysis of Costs

The cost for each feasible lake restoration and watershed management alternative was presented along with the description of the alternatives in Sections 6.0 and 7.0. In this section, a cost comparison is presented. Construction and operation and maintenance costs for the most feasible alternatives are presented in Table 17. Mechanical dredging with wide-track swamp dozers is more expensive than hydraulic dredging. High watershed nutrient inputs necessitate other lake restoration or watershed management techniques and costs for these alternatives are also presented in Table 17. Aeration and dilution have a lower construction cost than detention basins, however, higher operation and maintenance costs are associated with aeration and dilution. To resolve these differences, a present worth analysis was conducted to determine the most cost effective technique to reduce the effect of high nutrient watershed inputs. The present worth of a project represents the amount of capital that would have to be invested now to cover all the costs of a project over a specified planning period. In this analysis, a 9% interest rate and a 20 year planning period was assumed. The present worth comparison is presented in Table 18. This analysis indicates that dilution and aeration is slightly less expensive over a 20 year planning period, primarily due to lower construction costs. The costs of the two alternatives are within 20% of each other, and therefore, the cost difference is not considered to be substantial. The selection between these two alternatives for reducing the impacts of excessive nutrient inputs should be made based upon other considerations, such as environmental benefit and ease of implementation.

8.3 The Selected Alternatives

Dredging of 54,500 cubic yards of sediments from Sylvan Lakes is recommended to restore acceptable water quality conditions. Hydraulic dredging is the recommended method for removal of sediments from Sylvan Lakes, and lake sediments should be applied to farmland. The Cox Farm, and possibly the Heal Farm (identified in Figure 8 in Section 7.0) are suitable areas for the lake sediments.

Additional measures are needed to negate the effects of existing elevated watershed inputs of nutrients. The most environmentally effective procedure is dilution and aeration. Dilution and aeration is less costly than construction of two regional detention basins,

Table 17

Analysis of Costs for Lake Restoration Alternatives for Sylvan Lakes

Lake Restoration and/or Watershed Management Alternative	Construction Cost	Annual Operation and Maintenance Cost
Mechanical Dredging using wide-track swamp dozers, use as landfill soil cover.	$280,000	
Hydraulic Dredging, Application to Cox and Heal Farms	$200,000	
Hydraulic Dredging and Detention Basins	$256,500	$4000/year
Hydraulic Dredging, Aeration and Dilution for Both Lakes	$222,000	$5800/year
Hydraulic Dredging, Aeration and Dilution for Upper Sylvan Lake	$206,800	$1600/year

Table 18

Present Worth Analysis - Aeration and Dilution Versus Detention Basins for Sylvan Lakes

Assumptions: planning period = 20 years
interest rate = 9%

Lake Restoration Alternative	Present Worth
Aeration and Dilution for Both Lakes	$75,000
Detention Basins	$93,000

however, the proposed dilution and aeration system, as described in Section 6.0, is an innovative lake restoration system. Accordingly, it is recommended that the system be installed for Upper Sylvan Lake, at a construction cost of $6800, and tested for one year to verify the projected benefits. Should the system operate as expected, the system should be installed for Lower Sylvan Lake.

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