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POTENTIAL SOURCES OF POLLUTION FOR LULU LAKE

by

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ABSTRACT

Potential sources of pollution to Lulu Lake were assessed. Estimates of external and internal loadings were focused on phosphorus (P) using mainly literature data. The major source of total P loading to the lake was nonpoint sources with agriculture being the main contributor. Although the potential for nonpoint P loading was high only small amounts were delivered to the lake because of efficient trapping of sediments and associated pollutants by wetlands and other depositional areas in the watershed. Contribution from swimming was minimal but significant from internal cycling. Current chemical data indicated little change in the good water quality of the lake over the past 20 years. Recommendations were made to preserve the relatively pristine conditions of the lake.

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INTRODUCTION

The Wisconsin Department of Natural Resources (WDNR) has prepared a conceptual master plan to manage a unit of the southern Kettle Moraine State Forest. The plan preserves and enhances high quality natural and scenic resources of the Lulu Lake area while providing compatible recreational, environmental education and research opportunities (WDNR, 1985a). A project was initiated between WDNR and the Water Resources Center, University of Wisconsin-Madison (WRC) to (1) evaluate the potential impact of swimming and boating activities on the water quality of Lulu Lake, (2) determine sources of pollution in the lake's watershed and identify critical land uses that need future improvement and/or long-term protection, (3) develop a phosphorus budget for the lake and (4) investigate the status of beach contamination in Wisconsin.

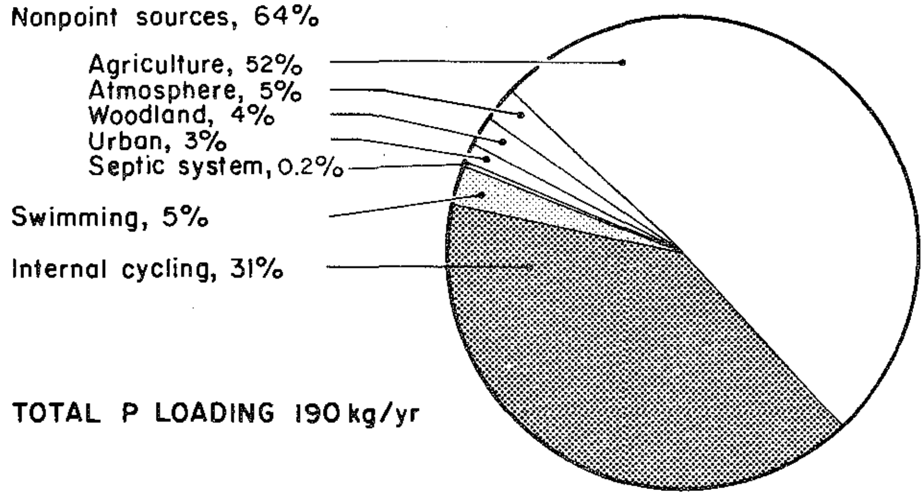
Quantitative and qualitative assessments of the impacts of swimming and boating and land use on the water quality of Lulu Lake were based principally on literature data. Land use information was obtained from Southeastern Wisconsin Regional Planning Commission (SEWRPC) air photos taken in 1975 and 1980. Additional information was obtained by personal contact with personnel of WDNR, SEWRPC and Soil Conservation Service (Walworth County). The lake was sampled in April 1986 to determine its current water quality. Beach contamination in Wisconsin was investigated through questionnaires sent to environmental health officers in selected cities and counties.

SUMMARY AND CONCLUSIONS

The potential impact of water-based recreational activities, particularly swimming, on the water quality of Lulu Lake was evaluated. In addition, sources of pollution in the lake's watershed and critical land uses that need to be improved and/or protected were identified. Assessments were based mainly on literature data supplemented by information and observations provided by local, regional, state and federal agencies and shoreline property owners.

Pollutants can reach Lulu Lake from external and internal sources. External sources include land runoff, wastewater discharges, the atmosphere and groundwater. In-lake processes, such as thermal stratification and sediment resuspension, can regenerate available pollutants from sediments. This provides internal loading to the lake water. Estimating the pollutant load to the lake focused mainly on phosphorus (P). This element is the most limiting to the growth of algae and nuisance aquatic weeds and is easier to control than nitrogen.

The major source of total P to Lulu Lake is external loading from nonpoint sources (64%), i.e. land runoff from the various land uses in the watershed (see pie chart). There are no wastewater discharges (point sources) to the lake but the potential for nonpoint loading is high. However, only about 120 kg/yr or 9% of P from nonpoint sources is estimated to reach the lake. This estimate is based on the assumptions that (a) only land uses within the 400-m corridors along streams, drainage channels and the lake are contributing areas and (b) that delivery ratio of pollutants is low because the morainal type drainage pattern, artificial impoundments and extensive



wetlands upstream from the lake are very efficient at filtering and trapping sediments and P. Agricultural land uses contribute most of the nonpoint loading; row croplands and barnyards are the likely major sources.

Swimming affects water quality by direct inputs of nutrients and fecal bacteria from bodies of swimmers and release of pollutants and increased turbidity from sediment resuspension. Estimated P inputs from 160 swimmers and from sediment resuspension would amount to 10 kg/yr or 5% of the total loading (see pie chart). In the proposed swimming beach, 160 swimmers/day would contribute minimal P loading to the lake. Direct bacteria input from swimmers may elevate concentrations in the water but only for short periods because of die off or dispersal through the lake. The effects of swimmers on recreational water quality are influenced by density of swimmers, frequency of swimming activity, type of lake bottom and ratio of swimming beach to lake area.

Potential exists for sediment resuspension in the shallow areas of Lulu Lake from boating activities. However, nutrient release or increased turbidity is likely negligible because boating is limited.

Although nonpoint sources contribute most of the P loading to Lulu Lake, significant amounts of P (31%) can be regenerated from the bottom sediments during thermal stratification of the lake (see pie chart).

Using a predictive model (p. 28) an "average" value of total P concentration for Lulu Lake was 0.0205 mg/l. This is in excess of the measured values (<0.02 mg/l) probably becuase the model overestimates some components. The measured value should be further refined since methods are available to estimate P down to 0.004 mg/l. However, values of dissolved orthophosphate P of <0.004 mg/l were measured. From data for many lakes the orthophosphate P usually comprises about 40% of the total P. Based on this estimate the total P in the lake water column would be <0.01 mg/l.

Limited chemical data along with visual observations have indicated little or no change in the good water quality of Lulu Lake over the past 20 years. A water quality index was prepared by Lillie and Mason (1983) for Wisconsin lakes based on water clarity, chlorophyll-*a* and total P. The index classification ranged from very poor to excellent in 6 categories. Considering these three parameters, the existing water quality index for Lulu Lake is "good" for clarity and chlorophyll-*a* and "very good" for total P. The low total P content (calculated to be <0.01 mg/l) in the lake indicates that P movement is limited due to the efficient trapping of sediments and associated pollutants by the extensive wetlands, the morainal drainage type pattern and impoundments in the watershed. Present land use patterns and population in the watershed is expected to remain virtually the same for the next 20 years.

This trend will have little or no impact on the current water quality of the lake.

Lulu Lake is relatively pristine because entry of nonpoint source pollutants is naturally buffered by extensive wetlands and other depositional areas. To preserve the good water quality of this lake the following recommendations are made:

1. Loading estimates for Lulu Lake represent a "first cut" attempt and values need to be refined by a monitoring study and investigation of internal nutrient regeneration.
2. The magnitude of the impact of wetlands and impoundments in "cleaning" the runoff generated from the watershed should be investigated to demonstrate natural ways by which lake water quality can be protected or enhanced.
3. Lulu Lake should be included as one of the lakes covered by the Baseline Lake Assessment Program of WDNR so that its water quality could be more thoroughly evaluated.
4. Lakeshore development should be minimized.

STUDY AREA

Lake Description

Lulu Lake--located in the Town of East Troy, Walworth County, Wisconsin--is a small (34 ha) but moderately deep (maximum 12 m) kettle lake (WDNR, 1969). Its kettle shape is slightly modified by encroaching marsh areas to the north and west shores. It is a drainage lake with no impounding structure, although the lake's level may be influenced by Eagle Spring Lake, a man-made lake located approximately 1.6 km to the northeast. A low-gradient channel connects Lulu Lake with Eagle Spring Lake. The channel is navigable by motorboat and is currently the principal means of access to Lulu Lake.

Figure 1 shows the depth contour and characteristics of the lake bottom and immediate surrounding area of the lake. Hydrographic and morphologic data of the lake are presented in Table 1. Marly sand and gravel predominate in about 72% of the nearshore areas. The remainder is fairly well consolidated marl associated with the inlet area. About 35% of the shoreline is bordered

Table 1. Hydrography and morphology of Lulu Lake

Watershed area (including lake), ha	3,740
Lake surface area (ha)	34
Shore length (km)	3.86
Maximum depth (m)	12.1
Mean depth (z), m	7.32
Lake volume (m^3)	2.48×10^6
Lake area < 0.9 m (%)	10
Lake area > 6.1 m (%)	63
Hydraulic residence time (τ), yr	0.55
Ratio of watershed area to lake area	108:1

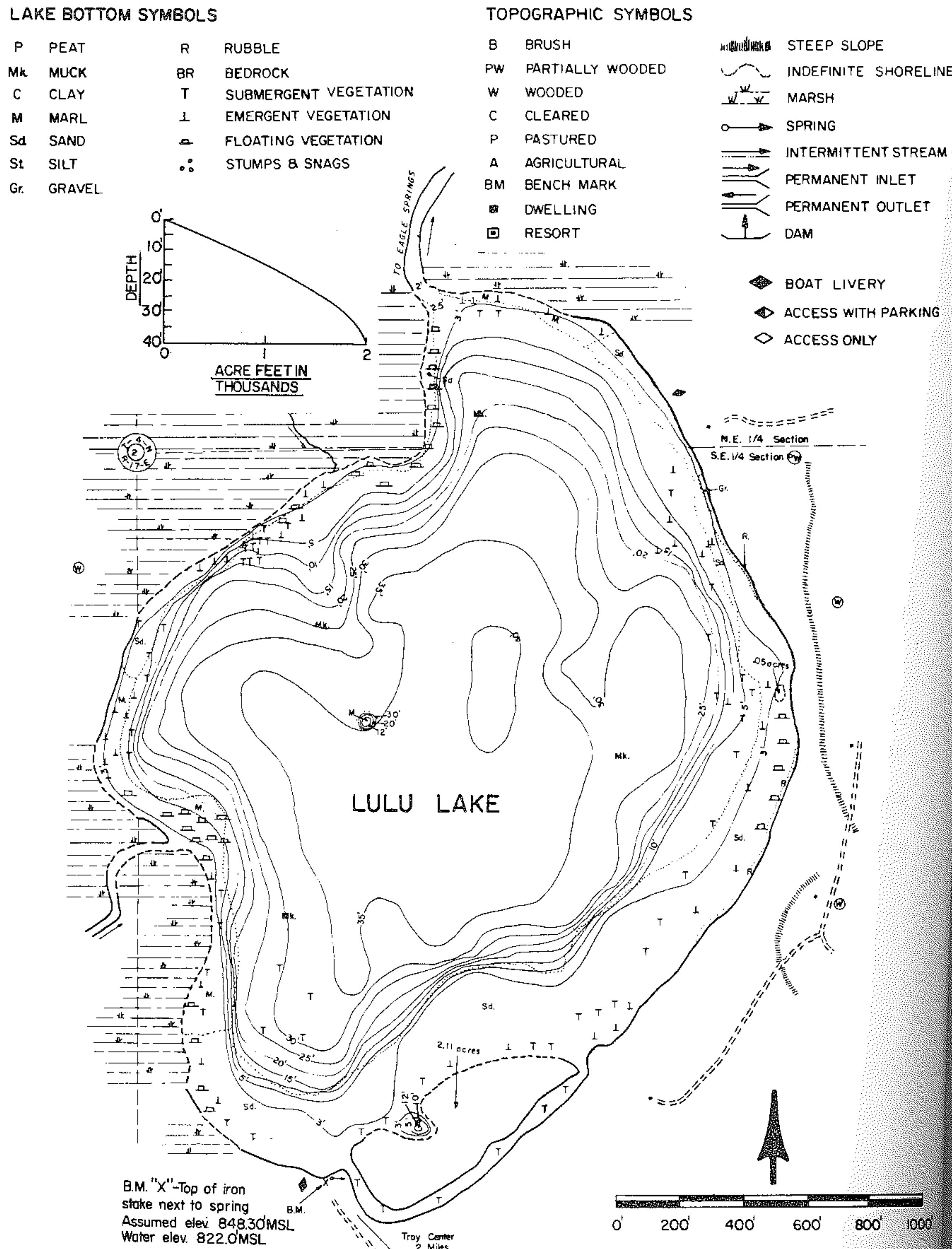


Fig. 1. Hydrography of Lulu Lake.

by wetlands. The mean depth (7.32 m) is more than half of the maximum depth and over 63% of the lake has water deeper than 6 m. The hydraulic residence time (exchange time) is about 0.55 yr, or a flushing rate of 1.8 times/yr.

Lake Use. Lulu Lake offers a variety of fish species and is one of the finest fishing locations in the Fox River watershed. The lake's limited access curtails fishing to some degree. Recent estimates indicate that on average three to four fishing boats per day (15 to 25 hp) are present on the lake, for a total of about 580 boats from May to September (Schumacher, 1986).

Pleasure boating also is limited. An average of two to three pleasure boats are estimated to be on the lake per day, for a total of about 470 boats (including canoes) for the boating season (Schumacher, 1986). About 65% of the boats are motorized (25 to 50 hp), mainly of the pontoon type. Water skiing is very restricted because the speed limit on the lake is limited to 8 km/hr. Because of the size of the lake it cannot support high speed power boats.

Presently, there is no swimming facility at Lulu Lake. A suitable swimming beach area is available along an 85-m stretch of lake frontage on the northeast shoreline of the lake. The remainder of the shoreline is not suited for swimming because of the marsh areas to the west and the high banks to the east. Additionally, except for the northeast nearshore which has a sandy bottom, the rest of the nearshore bottom is somewhat marly and swimming produces turbid water.

Development along the lake shoreline is minimal. Four homesites are located on the east lake frontage and a trailer court is maintained by a resort on the south shore. Their close proximity to the lake makes them potential sources of pollution. Additional homesites are possible above the east slope and a portion of the west shore is occupied by a Travenol

Laboratories building, but the remainder of the shoreline does not have suitable soils for construction.

Aquatic Plants and Algae. Observations in 1967 revealed the extent of rooted aquatic plant growth along the nearshore area of Lulu Lake (WDNR, 1969). The general distribution of submergent, emergent and floating leaved vegetation is presented in Fig. 1. *Chara* was the predominant plant and except for the southern shore covered the bottom in most areas less than 15 m deep. Sedges (*Cyperaceae*) were abundant along the shoreline. The remaining aquatic plants were scattered, with *Myriophyllum* (watermilfoil) dominating the west-central shoreline, while the southern shore had some scattered patches of *Najas flexilis* (bushy pondweed). Small and moderate amounts of plants found to a depth of 5.8 m included *Nitella, Ceratophyllum* (coontail), *Vallisneria* (wild celery), and *Potamogeton pectinatus* (sago pondweed).

Algal blooms were extremely rare in 1967 (WDNR, 1969). Recent observations (Francis, 1986) also indicate no apparent algal blooms.

Drainage System

The lake drains a watershed of 3,740 ha by way of a narrow channel in the marshland to Eagle Spring Lake, Waukesha County. The watershed's relief is moderate, with the headwaters of its inlet stream lying about 18.3 m above the lake surface. Surrounding hills rise to about 15.2 m above the lake surface. Numerous springs are found in the headwaters, many of them have been modified by property owners to provide small recreational impoundments on their property. Other water features found in the headwaters are small kettle lakes and bogs. There are 16 impoundments and kettle and bog areas in the watershed.

A 4-ha impoundment located in the northwest quarter of Section 4 was formed by damming a tributary of the Mukwonago River (Fig. 2). This tributary

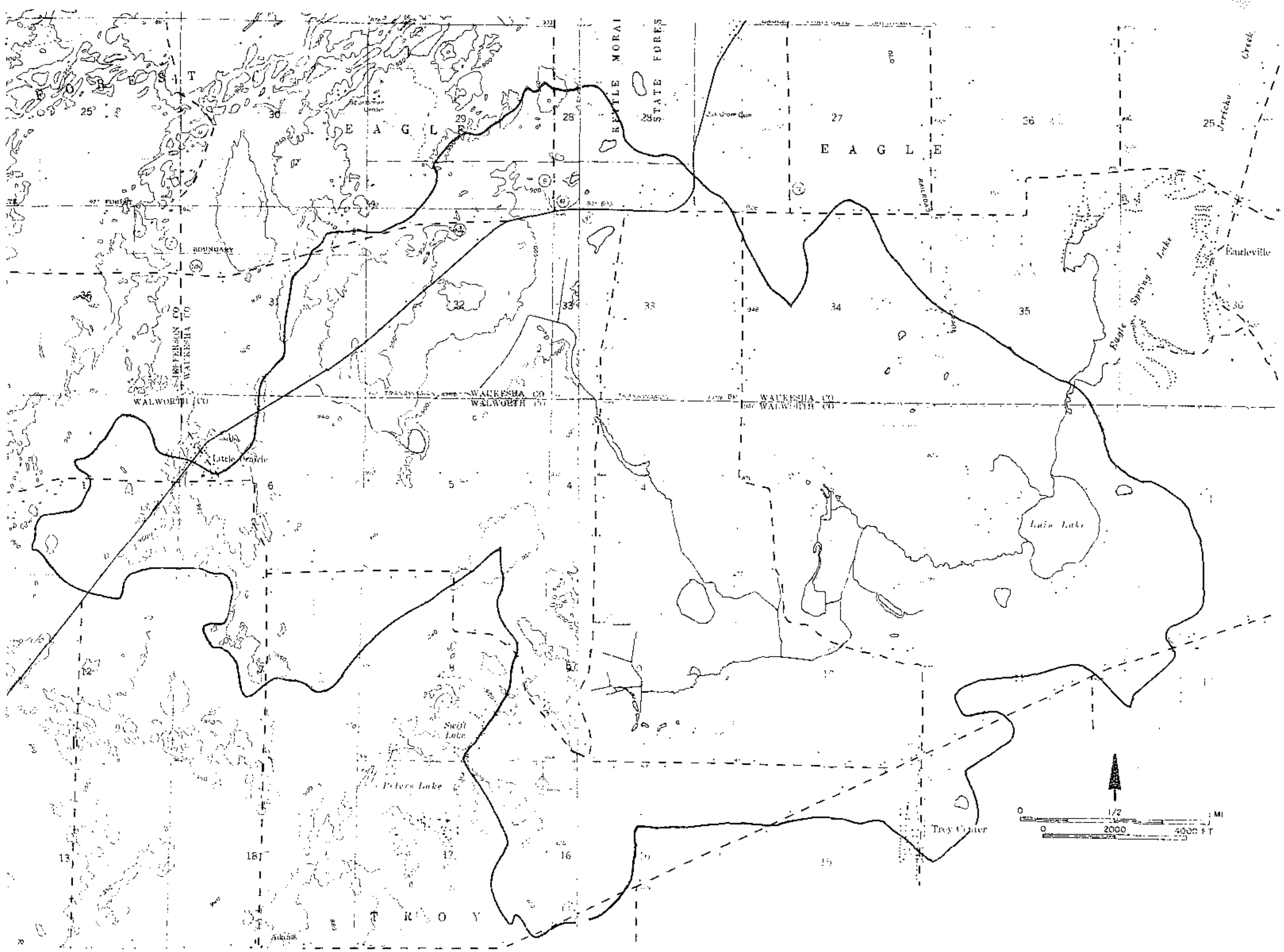


Fig. 2. Drainage system of the Lulu Lake watershed.

drains the upper half of the watershed which is primarily agricultural. Below this impoundment, i.e., the lower half of the watershed, is an 8-ha kettle lake in the northeast part of Section 9 and a 5-ha seepage impoundment in the north-central portion of Section 10. A 1-ha seepage impoundment is located in the center of Section 3, just on the major spring area of the Mukwonago River. Flow from this spring area is estimated to be 5.95 m^3/min and contributes the major baseflow in the Mukwonago River, which ultimately feeds Lulu Lake. East and southwest of Lulu Lake are tamarack bogs with areas of 1 and 2 ha, respectively. The tributary streams and the Mukwonago River meander slowly through a marshy valley bottom. These scattered impoundments and kettle and bog areas, together with extensive marshy streambanks, probably have a strong influence on the quantity and quality of overland and stream flows.

Climate and Hydrology

Data for the Burlington, Whitewater and Waukesha reporting stations in southeastern Wisconsin approximate the precipitation and temperature conditions around the Lulu Lake area. An example of these data is given in Table 2 for 1984. About 46% of the annual precipitation (93 cm) fell from May to September when vegetative growth occurs, 32% in fall (October to December) and 22% as snow in winter or rain in early spring (January to April) and is expressed as spring runoff. Streams in this region have been observed to discharge at above normal rates about 30% of the time, mostly during the spring runoff period (WDNR, 1969).

The average annual precipitation for the last 10 years (1976 to 1985) is 88 cm; or about 3.3×10^7 m^3 of water fell on the watershed each year. Table 3 presents some hydrological data for Lulu Lake based on an earlier estimate (WDNR, 1969). About 22% of the total precipitation reaches the lake as

Table 2. Climatological data for Lulu Lake area--1984*

Month	Precipitation (cm)			Days with rain**			Temperature (°C)		
	Burlington	Whitewater	Waukesha	Burlington	Whitewater	Waukesha	Burlington	Whitewater	Waukesha
Jan.	1.9	1.3	1.4	3	1	1	-9.1	-9.5	-7.9
Feb.	4.1	2.8	2.5	5	3	4	-0.56	-0.39	0.17
Mar.	4.6	3.6	4.1	7	6	4	-2.7	-2.7	-2.1
April	12	8.9	11	12	13	13	6.8	7.9	7.7
May	10	14	12	14	15	13	12	13	13
June	10	8.1	11	11	10	11	20	20	21
July	6.9	6.9	7.6	8	9	6	21	21	22
Aug.	6.4	3.6	7.1	6	4	9	22	22	23
Sept.	7.3	10	6.9	8	7	8	16	16	16
Oct.	13	17	14	13	16	16	11	11	12
Nov.	8.6	11	8.1	9	9	7	2.8	2.9	2.9
Dec.	7.1	5.1	9.9	8	7	12	-2.3	-2.5	-2.1
Total	92	92	96	104	100	104	8.2	8.3	8.2

*Source: Climatological Data, Wisconsin, NOAA National Data Center, Asheville, N.C.
**Precipitation of 0.254 cm (0.10 inch) or more.

Table 3. Annual water budget for Lulu Lake watershed

Source	m^3	%
Precipitation	3.3×10^7	100
Surface runoff at lake outlet	7.2×10^6	22
Evaporation from water surfaces	5.8×10^5	1.8
Evapotranspiration from wetland	4.5×10^6	14
Evapotranspiration from land surface	1.5×10^7	45
Groundwater recharge	5.9×10^6	18

runoff. High water loss (59%) occurs through evapotranspiration from wetlands and land surfaces. Approximately 18% represents groundwater recharge. A part of the groundwater recharge may become baseflow during non-storm events. With a spring flow of 5.95 m^3/min, baseflow would amount to about 3.13×10^6 m^3/yr.

Physiography/Geology

The 3,740 ha of the Lulu Lake watershed lie in the Wisconsin eastern ridges and lowlands geographical province (Martin, 1916). The area is typical of kettle moraine topography, with broad areas of ground moraine and outwash deposited by the retreating Wisconsin age glacier interspersed with steep-sided, kettle-shaped depressions. These depressions remain open as kettle lakes or they have been partially filled with sediment and organic deposits since the retreat of the ice sheet. The land surface is the product of the continental glaciers; glacial deposits have modified and masked the bedrock topography in the watershed. The watershed lies on the Niagara dolomite upland.

Soils

Soils within the watershed exhibit a variety of characteristics which may limit their use and vary the potential impact on water quality. Surface soil texture, slope and landscape position are important indicators of potential erodibility. Figure 3 shows the soil groups within the watershed in relation to these indicators. Soil information was obtained from the *Soil Survey of Milwaukee and Waukesha Counties, Wisconsin* (1971) and *Soil Survey of Walworth County, Wisconsin* (1971).

Bottomland soils in the watershed are in landscape positions which receive runoff and associated sediment. Within the watershed these are mainly organic soils formed from well-decomposed plant material. Examples are the Houghton muck and Palms muck.

Upland soils may generate sediment, depending on land use and management. Gently sloping, upland soils are formed in glacial drift or loess (wind-blown silt) overlying drift. These soils, on slopes of 0 to 6%, generally have a low erosion hazard. Soils formed in drift with loam surface textures include the Casco loam, Fox loam and Warsaw loam. Soils formed in loess generally have silt loam surfaces. Examples are the Fox silt loam and St. Charles silt loam.

Soils formed in drift on the uplands have surface textures that range from sandy loam to sand, which have a lower water erosion hazard than loam or silt loam. Within the watershed these include the Boyer loamy sand, Chelsea fine sand and Fox sandy loam, among others.

Moderately sloping soils of the uplands are also formed in loess or drift found on 6 to 12% slopes. These soils have a moderate erosion hazard, are loam to sandy loam in texture and include the Casco soils and Miami loam. Soils with silt loam surfaces and a slightly greater erosion hazard include the Fox silt loam and McHenry silt loam.

Strongly sloping to steep upland areas contain soils formed in loamy to gravelly drift. These are on slopes greater than 12% and ranging up to about

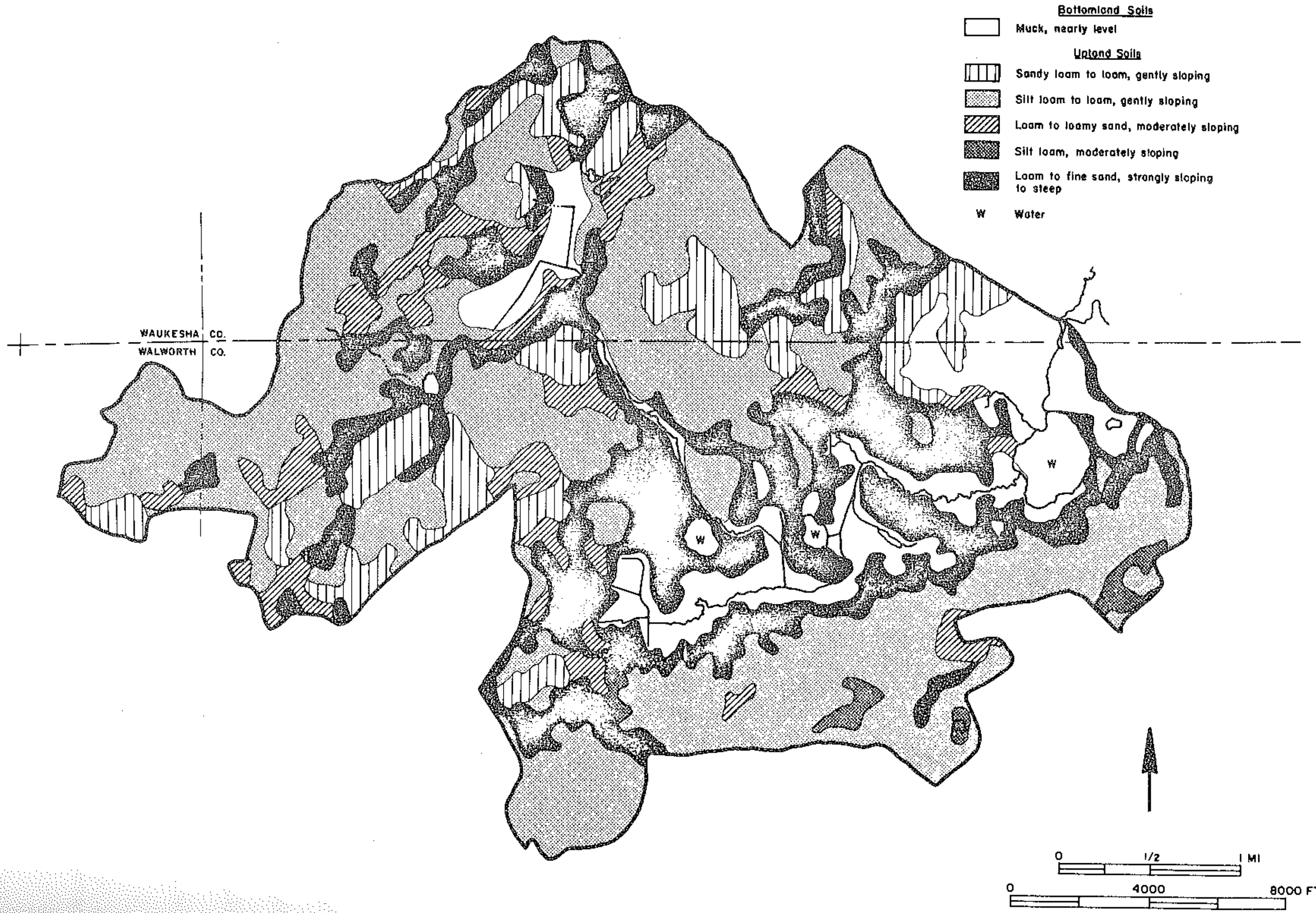


Fig. 3. Soils of the Lulu Lake watershed.

45%. Commonly occurring soils include the Casco loam and sandy loam, and the Rodman gravelly loam. These soils have a high erosion hazard.

Land Use

Land use for the watershed area was measured using SEWRPC delineations and aerial photographs for 1975 and 1980. Land use divisions useful for assessing the impact on water quality are shown in Table 4. Urban land use consists mainly of unsewered single family residences and roads, but there are some commercial, industrial and recreational areas. Rural land use was divided into the following: row crops, non-row (hay, grain and vegetable) crops, pasture, farm buildings, wetland, unused rural, landfill/dump, woodland

Table 4. Land use within the Lulu Lake watershed

Land use	1975		1980		2000*	
	ha	%	ha	%	ha	%
Urban (including recreational)	207	5.5	286	7.6	378	10
Recreational	36	1.0	33	0.9	90	2.4
Rural						
Row crops	1,295	35	1,183**	32	1,156	31
Non-row crops	379	10	343**	9.2	340	9.1
Pasture	508	14	430	12	426	11
Farm buildings (no livestock)	26	0.7	34†	0.9†	34	0.9
Farm buildings (with livestock)	11	0.3	--	--	--	--
Wetland	451	12	455	12	456	12
Unused	127	3.4	280	7.5	262	7.0
Landfill/dump	0.4	0.01	1.1	0.03	1.1	0.03
Woodland	674	18	663	18	610	16
Surface water	62	1.7	65	1.7	64	1.7
Total	3,740	100	3,740	100	3,740	100

*Assumes 94 additional dwellings from 1980 at an average of 0.36 ha per dwelling and that the WDNR master plan has been implemented.
**The division between row and non-row crops was not available for 1980. This number is estimated from the 1975 ratio between row and non-row crops.
†Includes buildings with and without livestock.

and surface water. It should be noted that the division between row and non-row crops was available only for 1975. The 1975 data were used to estimate the percentage of the cropland devoted to row vs. non-row crops in 1980. Twelve livestock operation areas were identified in 1975, one of which was located 152 m from a stream and one 400 m from a stream (SEWRPC, 1979). Update in 1986 shows two livestock operations are within 400 m of a stream (St. Ores, 1986).

In 1975, nearly 60% of the land within the Lulu Lake watershed was in agricultural use. About 35% of the watershed was used for row crops and 10% used for non-row crops. Nearly 14% was in pasture and almost 1% of the area contained farm buildings. Other rural, non-agricultural uses accounted for about 35% of the watershed area. Woodland comprised about 18% of the watershed, wetland about 12%, and surface water nearly 2% of the area. Approximately 3% was unused.

Urban land uses took up about 5% of the watershed in 1975. These uses are mainly single-family residential and roads. The low density residential areas were unsewered. Recreational uses are included in the urban division. Alone, recreational uses comprised nearly 1% of the watershed area.

The 1980 land uses within the watershed did not change greatly from the 1975 uses. Urban uses increased to nearly 8% of the watershed area. Recreational uses did not significantly change. Agricultural uses decreased. Nearly 32% of the watershed was used for row crops and about 9% for non-row crops. Pasture use was down to about 12%. About the same percentage contained farm buildings (1%). Unused land area increased to >7%, while other rural uses did not change signficantly.

Land use in the watershed for the year 2000 was estimated by assuming that current trends would continue (a slight increase in urban uses at the expense of rural) and that the WDNR, Lulu Lake, Mukwonago River Unit Master Plan would be implemented. It was estimated that the number of single-family residences would increase by 94 units between 1980 and 2000 and that these would occupy an average of 0.36 ha each. It is estimated that agricultural uses in the watershed will account for about 52% of the area, little changed from the 1980 figures. Woodland and unused rural land area are expected to decrease slightly. Urban land uses are estimated at about 10% of the watershed area in 2000, about one-quarter of which will be recreational uses (2.4% of the watershed). The actual figure in 2000 will depend upon many factors, including the local economy and the actual amount of State ownership of land within the watershed.

Land use for 1980 is illustrated in Fig. 4. Urban, cropland, pasture, woodland, unused rural wetland and surface water divisions are shown, as well as the locations of farmsteads with livestock.

Population

Estimates of the population within the Lulu Lake watershed for the years 1970, 1975, 1980, 1985 and 2000 are shown in Table 5. Trends in residential

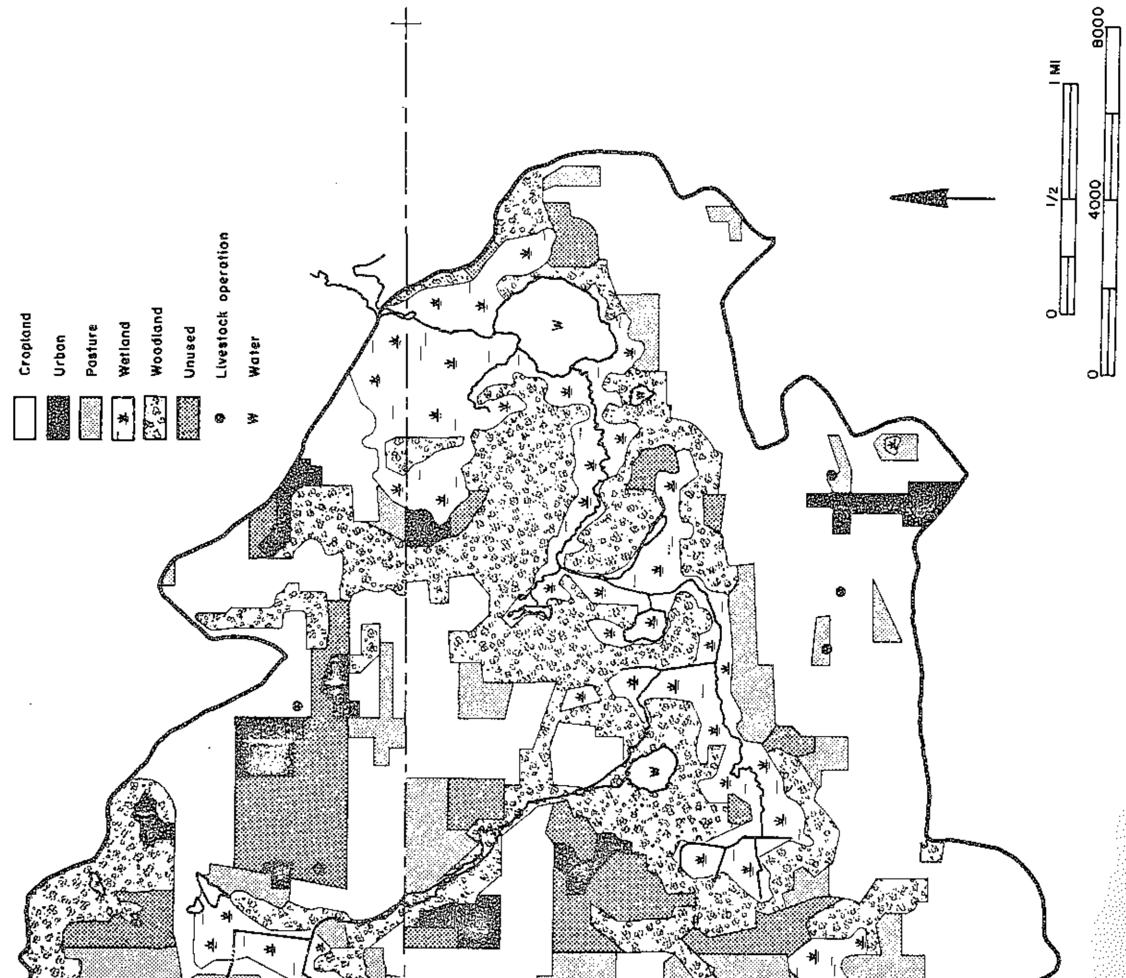
Table 5. Estimated population within the Lulu Lake watershed

	Number of dwellings*	Estimated population**
1970	138	472
1975	171	585
1980	229	783
1985	243	831
2000†	323	1,105

*Number of dwellings as counted on SEWRPC aerial photographs, scale 1" = 400'.

**Population estimated as 3.42 persons per dwelling unit (SEWRPC, 1979)

†For the year 2000, the number of dwellings was estimated by assuming an increase of 10% over 5 years.


Cropland
Urban
Pasture
Wetland
Woodland
Unused
Livestock operation
Water
WAUKESHA CO.
WALWORTH CO.
0
1/2
1 MI
0
4000
8000 FT

growth were estimated by counting the dwellings in the 84 quarter sections within the watershed and calculating the percentage increase per 5-year interval until 1985. The approximate number of dwellings within the watershed boundaries was found using the percentage changes and the tally for 1975 (171 dwellings). The counting was done on SEWRPC aerial photographs at a scale of 1" = 400'.

Watershed population estimates were based on the number of dwellings. It is assumed that there are approximately 3.42 persons per dwelling (SEWRPC, 1979).

For the year 2000, it was estimated that the number of dwellings would increase by 10% over 5 years. This is an arbitrary estimation and the actual number of residences will depend on many economic factors and land ownership patterns.

SOURCES OF POLLUTION

Wastewater disposal, land drainage, land use activities in the watershed, intensity of use of water-based recreational facilities and in-lake processes have an impact on the water quality of a recreational lake. Pollutants can enter Lulu Lake from external and internal sources. External sources include land runoff, wastewater discharges, the atmosphere (precipitation and dry fallout) and groundwater. In-lake processes, such as thermal stratification and resuspension, can regenerate pollutants that have settled in the sediments, thus providing internal loading to the lake water. Estimation of pollutant loadings is focused mainly on phosphorus (P) since this element is most limiting to algal and aquatic weed growth. Phosphorus, along with nitrogen (N) are singled out as the major promoters of lake eutrophication. However, P is considered more manageable because it is added primarily from allochthonous (outside) sources. Literature values were heavily relied on to arrive at estimated loadings.

External Loading

Nonpoint sources of pollution are major contributors of contaminants to waterbodies (Novotny and Chesters, 1981). Water quality management planning must include delineating those lands and land use activities in the watershed that pose the most severe threat to receiving waters. Information on the extent of the areal pollution source and the attenuation of pollutants during delivery between the source and the receiving water is needed to define these "hazardous" lands in the watershed.

Nutrient loadings from nonpoint sources are associated primarily with land runoff following precipitation in the watershed. Under a given climatological regime, specific land use types yield or export characteristic quantities of nutrients to a downstream waterbody. Annual total P and N loadings to a stream or lake from nonpoint sources can be estimated if the area of each land use in a watershed and the quantities of nutrients exported per unit area of these land uses are known. Several investigators (Reckhow *et al.*, 1980; Rast and Lee, 1983) have compiled and assessed nutrient export coefficients-land use relationships from the literature. They have used the export coefficients to estimate nutrient loadings for lakes. The Reckhow *et al.* (1980) approach of selecting P export coefficients for given land uses is largely subjective. The user must rely mainly on matching specific land-use characteristics in the watershed of interest with those for which export measurements are available (Table 6).

Table 6. Phosphorus export coefficients (kg/ha-yr) adapted from Uttormark *et al.* (1974) and Reckhow *et al.* (1980)

Level	Agriculture	Forest	Precipitation	Urban	Septic tank*
High	3.0	0.45	0.60	5.0	1.8
Mid	0.40-1.70	0.15-0.30	0.20-0.50	0.80-3.0	0.40-0.90
Low	0.10	0.02	0.15	0.50	0.3

*kg/capita-yr.

Rast and Lee (1983) developed generalized nutrient export coefficients based on broad land-use categories applicable to large parts of the United States (Table 7). Sonzogni *et al.* (1980) summarized unit area loadings of various rural and urban land uses derived from eight pilot watersheds located in the Canadian and United States portions of the Great Lakes basin. A 5-yr monitoring study in the Menomonee River watershed showed that in a 2,144-ha predominantly agricultural subwatershed the total P and soluble P loadings ranged from 0.30 to 0.75 and 0.15 to 0.26 kg/ha-yr, respectively (Bannerman

Table 7. Phosphorus export coefficients (Rast and Lee, 1983)

Land Use	Total P (kg/ha-yr)
Urban	1.0
Rural/Agriculture	0.5
Forest	0.05-0.1
Atmosphere*	0.25

*Atmospheric load consists of precipitation and dry fallout directly onto the surface of a waterbody.

et al., 1984). This subwatershed consisted of 44% row crops, 30% pasture and small grains, 10% woodland, 0.6% feedlots, 2.3% wetlands and 11% urban land.

Estimation of external loadings of P arising from various land uses in the Lulu Lake watershed is based on the 1980 land use inventory of SEWRPC. As presented in an earlier section (Land Use), the watershed (3,740 ha) consists mainly of agricultural lands (53%), followed by woodlands (18%), wetland (12%), urban lands, primarily unsewered single family residential (7.6%) and unused lands (7.5%). The agricultural portion is predominantly row croplands comprising 32% of the watershed, while non-row crops, pasture and livestock operation areas occupy 9, 11 and 0.27% of the watershed, respectively.

A range of P export coefficients presented above (Tables 6 and 7) is expected because of the variability of sources due to watershed topography and geology, erosional patterns, and intensity or type of land use. The coefficients selected for Lulu Lake are given in Table 8. They represent "most likely" unit loading for each land use based on evaluation of literature information and knowledge of the existing land use and land use activities in the watershed. The "low" value for the urban area is attributed to the primarily low density residential nature of the land use with large lots and

Table 8. Total P export coefficients (unit loadings) selected for Lulu Lake

Land use/source	Total P (kg/ha-yr)	Reference
Urban	0.20	Bannerman *et al.* (1984)
Agriculture*	0.50	Reckhow *et al.* (1980), Rast and Lee (1983), Bannerman *et al.* (1984)
Woodland	0.05	Reckhow *et al.* (1980), Rast and Lee (1983)
Septic system*	0.40**	Reckhow *et al.* (1980)
Atmosphere	0.25	Reckhow *et al.* (1980), Rast and Lee (1983)

*According to SEWRPC (1979) inventory in 1975 about 968 animal units were found in 11 ha or 88 units/ha. The human population in 1975 was 585 living in 171 dwellings or 3.42 persons/dwelling. Thirty-six dwellings had septic systems located in soils with severe limitations.
**kg/capita-yr.

extensive grassed areas. Note that the agricultural land uses are lumped with an export coefficient of 0.50 kg/ha. This value is considered conservative since the extensive row croplands and presence of livestock operation areas may increase the unit loadings. Two livestock operations in the Lulu Lake watershed are located within the 400-m corridor of the drainage network. Also, some pasture lands (grazing) are present in sloping areas adjacent to the tributary streams. It was found during pilot watershed studies in the Great Lakes basin that livestock operations including feedlots contribute about 20% of the agricultural load of soluble P (Sonzogni *et al.*, 1980). Pastures, non-row cropland and vegetated unused lands would contribute much lower loadings. Wetlands were assumed to contribute little or no P to the lake but act as sediment and nutrient traps. The importance of groundwater to the nutrient budgets of lakes is poorly understood and attempts to quantify groundwater seepage contribution are difficult. Based on some estimates of Lake Mendota in southeastern Wisconsin, groundwater represents about 33% of the water that enters the lake but it is low in nutrients, and is not a significant source of P (Brock, 1985). From a nutrient loading standpoint Lulu Lake can be considered a drainage lake. Baseflow, which is similar to groundwater seepage during non-storm events, may also be a source of P but input is not quantified in the study.

The estimated potential annual loading of total P from nonpoint sources to Lulu Lake is about 1,280 kg (Table 9). About 90% of the external loading

Table 9. Total P loadings from nonpoint sources

	Area		Total P	
Land use/source	ha	%	kg/yr	%
Urban	286	7.6	57	4.4
Agriculture*	2,270	61	1,135	88
Woodland	663	18	33	2.6
Septic system	123**		49	3.8
Atmosphere	34†	0.9	9	0.7
Total	3,740	88	1,283	100

*Includes unused land (280 ha) and area devoted to livestock operations (10 ha).
**Number of persons.
†Area of lake.

is contributed by agricultural land uses; row croplands and livestock operations are probably the major sources. The "average" total P concentration of the lake can be predicted using the empirical input-output model developed by Reckhow (1979a):

$$P = \frac{L}{v_s + q_s}$$

where, on an annual basis,

P = lake phosphorus concentration (mg/l)

L = annual areal phosphorus loading (g/m^2-yr of lake surface)

v_s = apparent settling velocity (m/yr) = 11.6 + 0.2 q_s (Reckhow, 1979b)

q_s = annual areal water loading (m/yr) = $\frac{Q}{A} = \frac{z}{\tau}$

Q = annual volume rate of water inflow (or outflow) to lake (m^3/yr)

A = lake surface area (m^2)

z = lake mean depth (m)

τ = hydraulic detention time (m/yr).

The equation can be written as:

$$P = \frac{L}{11.6 + 1.2\ q_s} .$$

The "average" total P concentration for Lulu Lake based on external loadings, drainage and lake characteristics is estimated at 0.135 mg/l.

The predicted total P concentration is more than seven times higher than the measured concentration (<0.02 mg/l) in the lake (see section on Water Quality). Because the size of the watershed is large relative to the lake area (108:1) perhaps portions of the potential P loadings do not reach the lake. The amount of P from land uses directly draining to the lake and from land uses close to the tributary streams is probably higher than inputs from land uses further away. The impact of land drainage on the lake depends on the distance of the source to the receiving water and on the processes occurring during overland and stream flows. In addition to distance, such factors as slope, vegetation, soil type, depressions or bottomlands, including wetlands, perviousness and land use activities determine the amounts of nutrients transported to the receiving streams or lake. Thus, several factors determine the delivery of pollutants from the source to the receiving water-body.

Phosphorus is associated with sediment and its transport during surface runoff is intimately related to sediment delivery (Novotny and Chesters, 1981). As much as 40 to 60% of total P in runoff is associated with particulates (Sonzogni *et al.*, 1980; Bannerman *et al.*, 1984; Brock, 1985). Sediment delivery is the proportion of eroded material transported to a receiving waterbody expressed as a ratio ranging from 0 to 1.0. In a study of the Koshkonong Creek (Water Resources Management Workshop, 1982), sediment delivery was determined by applying delivery ratios to the soil loss occurring within 400 m of any ditch or channel in the drainage network. It was assumed that erosion occurring beyond 400 m would not be delivered to a receiving waterbody. The WDNR is using a 400-m corridor in its rural nonpoint source inventory program to locate critical source areas (WDNR, 1985b). This type of inventory was conducted in the Turtle Creek watershed in Walworth and Rock Counties (WDNR, 1984). Roehl (1962) studied the relationship of sediment delivery ratio and watershed size. Sediment delivery tends to decrease as watershed area increases because sediment is transported over a greater distance and there is more opportunity for sediment to be deposited enroute. The estimated delivery ratio of total P in a predominantly agricultural subwatershed of the Menomonee River watershed was 0.15 (Novotny *et al.*, 1979).

The local topography and morainal drainage network of the Lulu Lake watershed could tremendously reduce sediment delivery (hence total P), particularly in the upper portion of the watershed. Surface runoff traverses a series of wetlands, depressions (kettles and impoundments) and other depositional areas before entering the lake. The upper 50% of the watershed, which is mainly agricultural, is above a dam. An extensive wetland area is found in the lower portion of the watershed. It is apparent that these wetlands, kettles and impoundments provide excellent filtration or trapping of sediments during runoff, thus minimizing the amounts of P transported. Total external loadings based on aggregation of inputs from each land use in a large watershed may be overestimated. In a large watershed with land that is mostly pervious like agricultural areas, a significant portion of those nutrients attached to sediments or particulate matter may be filtered from the runoff by vegetation, or redeposited during overland and stream flows or in intermittent stream channels (Novotny *et al.*, 1986). Thus the actual amounts of nutrients reaching a waterbody can be much less than those generated in the upland sources (i.e., delivery ratio is <1).

Wetlands are able to improve water quality by removing pollutants through plant uptake and sediment deposition. Sediment deposition may be responsible for much of the pollutant trapping in wetlands (Johnston *et al.*, 1984). This removal mechanism is more permanent than plant uptake because most of the pollutants taken up by herbaceous vegetation are released when the vegetation dies and decomposes. Sediments are capable of transporting adsorbed nutrients, pesticides, heavy metals and other toxins. In wetlands where there is little reworking of sediments, particulate deposition can result in virtually permanent removal of most pollutants (Boto and Patrick, 1979). Significant amounts of nutrients could also be removed when dissolved components are scavenged by the depositing sediments, due to the affinity of nutrients and various toxic materials for sediments (Oschiwald, 1972).

The magnitude of nutrient removal by wetland deposition has been estimated in a few quantitative studies. Based on sediment accretion rates in a Louisiana tidal marsh, DeLaune *et al.* (1978) calculated annual streamside removal rates of 2.10 g/m^2 for N and 1.65 g/m^2 for P. Using net sedimentation rates, Johnston *et al.* (1984) estimated annual accumulation of 2.0 kg sediment/m^2, 2.6 g P/m^2 and 12.8 g N/m^2 in a seasonally flooded lakeside wetland in northeastern Wisconsin. Mitsch *et al.* (1979) reported higher annual deposition rates for both sediment (5.6 kg/m^2) and P (3.6 g/m^2) in a floodplain swamp along a major river containing high sediment loads in southern Illinois. Treatment of urban runoff by wetland filtration indicates that about 60 to 80% of the total P is retained in the wetland (Wenck, 1981; Barten, 1983; Weidenbacher and Willenbring, 1983).

Total P input from land runoff can be modified by assuming (1) that 400-m corridors along streams, channels and lakes are contributing areas; about 38% (1,250 ha)* of the watershed (except wetlands) is within these corridors and (2) that there is 70% trapping of total P by wetlands, kettles and impoundments. Table 10 presents a more "realistic" estimation of external P loadings to Lulu Lake (cf. Tables 9 and 10). The "predicted" total P concentration for Lulu Lake considering the modified nonpoint loading is 0.013 mg/l, which is within the range of the measured total P levels of <0.02 mg/l (see Water Quality section).

Table 10. Modified total P loadings from nonpoint sources

		Total P		
Land use/source	Area (ha)	kg/ha-yr	kg/yr	%
Urban	93**	0.06	5.6	4.6
Agriculture*	668**	0.15	100	82
Woodland	494**	0.015	7.4	6.0
Septic system	3.3[†]	0.12	0.4	0.3
Atmosphere	34[††]	0.25	9	7.3
Total	1,254**		122.4	100

*Includes unused land and area devoted to livestock operations.
**Estimated area within 400-m corridors along streams, channels and lakes (except wetlands) is 38%; two livestock operation areas were identified in 1986 within this corridor.
†Number of persons; only one dwelling with failing septic system is estimated to be within the 400-m corridor.
††Area of lake.

*Consists of 39, 25, 15, 13 and 7% of woodlands, row croplands, pasture and other agricultural lands, rural open lands and urban lands, respectively. Also, two livestock operation areas presently exist within the 400-m corridor.

Direct Effect of Swimming on Water Quality

Land- and water-based recreational activities may impact water quality in different ways. It is helpful to distinguish between the impacts of various user groups' when managing recreational areas. Swimming/bathing and boating, for example, can affect bacteriological and chemical characteristics of a recreational lake directly or indirectly.

The effects of swimmers/bathers on recreational water quality is not well documented. The impacts may include direct release of nutrients and bacteria from bodies of swimmers and sediment resuspension due to agitation of bottom sediments. Sediment resuspension increases turbidity and also releases nutrients and bacteria to the water column. The literature contains few investigations concerning the amounts of nutrient and number of bacteria inputs contributed by swimmers.

The nutrient input from bathers was quantified by Schulz (1981) of West Germany under laboratory conditions. The daily nutrient input from a bather was found to be 94 mg total P and 3,100 mg total N (Table 11). About 98% of the total P and 45% of the total N originated from direct urinary excretions of bathers. Considerable N is coming from the oil used by bathers as sunscreen.

Table 11. Daily input (mg) of total P and total N by a bather (Schulz, 1981)

Element	Sunscreen oil	Skin	Urine	Total
P	0.02	1.1	93	94
N	1,600	115	1,400	3,100

A 60 x 60-m swimming beach was proposed for Lulu Lake's northeast shore. The projected number of swimmers is 160 daily during a 90-day swimming season. Using the Schulz (1981) experimental values it is estimated that 160 swimmers will add 1.4 kg total P and 45 kg total N to the lake during the swimming season. About 1.3 kg total P and 20 kg total N will come from urinary excretions. Estimation of inputs from urinary excretions can also be made from the data compiled by Altman and Dittmer (1972) of 1.4 liter average daily urine excretion/person* containing 850 mg total P (99% inorganic P) and 15,000 mg total N (76% urea). Assuming a person spends 2 to 3 hrs swimming per day, nutrient input from 160 swimmers to Lulu Lake will be 1.0 to 1.5 kg total P and 18 to 27 kg total N. These estimates assume no bathroom facilities are available near the swimming area.

Swimmers have been implicated as a potential source of bacteria at swimming beaches (Horak, 1974; Winslow, 1976). Laboratory pool studies have shown that humans shed large numbers of fecal bacteria while swimming (Robinton and Mood, 1965; Hanes and Fossa, 1970). As a person swims, bacteria are washed off the skin and out of some body cavities. The number of bacteria contributed to bathing water is large and variable. This variability is to be expected because of the personal bacterial variability cited by Rosebury (1962). Hanes and Fossa (1970) determined that the average density of coliforms of fecal origin contributed by a bather was 23×10^7 (Table 12). Other bacteria identified were enterococci and pseudomonads.

Assuming that all the coliform from swimmers are of fecal origin, the fecal coliform loading in the proposed Lulu Lake swimming beach for 1 swimming day is estimated to be 6.6×10^3/liter or 660/100 ml. This represents the worst case that may occur during peak swimming activity (usually weekends) of short duration. In actuality much less fecal coliform could be present due to deposition of bacteria that have adhered to resuspended sediments,

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*A body weight of 70 kg was assumed.

Table 12. Number of total bacteria and fecal coliform shed from one swimmer

Swimming time (min)	Mean	Median	95% Confidence limit of mean
	Total bacteria (10^{-9})		
0-15	320	15	460
15-30	170	37	200
0-30	550	61	700
	Coliform (10^{-7})		
0-15	16	4.8	12
15-30	7.8	0.04	22
0-30	23	5.2	23

redistribution in the lake water and die-off during swimming intervals. If fecal coliform input is dispersed throughout the lake, bacterial density would be 15/liter or 1.5/100 ml.

Effect of Sediment Resuspension on Water Quality

When bottom sediment is resuspended associated pollutants may be returned to the overlying water through resuspension of sediment particles, dispersal of interstitial water and desorption from the resuspended solids. Resuspended sediment, however, may adsorb dissolved contaminants from the overlying water, thereby decreasing the amounts of pollutants in the water. Furthermore, soluble species (e.g. orthophosphate) associated with anaerobic sediments may be precipitated into insoluble species when they come in contact with oxygenated overlying water. Readsorption and precipitation of the released contaminants followed by settling of the resuspended sediment may carry the pollutants back to the bottom. The contact time between the resuspended sediment and the overlying water--i.e., the duration of resuspension--could partly modify the exchange process.

Investigations of nutrient exchange agree that agitation with resultant resuspension of sediments releases nutrients to the overlying water (Lee, 1970). This implies that any physical process that disturbs or resuspends sediments (e.g., wind-induced wave action, fall and spring overturn, water-based recreational activities of swimming, bathing and scuba diving) tends to promote release of nutrients. Although there is no direct evidence showing the release of P during agitation of bottom sediment by swimmers, amounts released can be estimated from results of investigations on other physical perturbations such as boating.

Changes in water quality due to mixing by motorboats were studied in some shallow lakes of Central Florida (Yousef *et al.*, 1980). The lakes differed in average water depth, sediment characteristics and trophic state (Table 13). It is evident that mixing due to boating activities in the open lake significantly increases turbidity, ortho-P, total-P and chlorophyll-*a* in Lakes Claire and Jessup. The results obtained from Lake Mizell were not as conclusive. Lake Mizell is substantially deeper and the bottom sediment is sandy in the shallower depths. The increase in the ortho-P content of Lakes Claire, Mizell and Jessup averages 43, 16 and 77% which corresponds to an average of 46, 24 and 105 mg P/m^2 of bottom sediment, respectively (Table 14). Similarly, the increase in the total P content for Lakes Claire, Mizell and Jessup averaged 39, 28, and 55%, which corresponds to an average of 84, 58 and 249 mg P/m^2,

Table 13. Characteristics of Florida lakes

Lake	Mean depth (m)	Area (ha)	Sediment type (shallow areas)	Trophic state
Claire	2.3	8.1	Sand mixed with fine black organic matter	Oligotrophic
Mizell	4.0	25.1	Sand with low organic matter	Eutrophic
Jessup	1.8	4422	Silty with high organic matter	Hypereutrophic

Table 14. Release of P after mixing*

Lake	Mixing zone (m)	Ortho P (mg/l)		Total P (mg/l)		P released (kg/ha)	
		Before	After	Before	After	Ortho P	Total P
Claire	2.6	0.042	0.060	0.085	0.20	0.46	0.84
Mizell	3.4	0.044	0.051	0.061	0.078	0.24	0.58
Jessup	1.5	0.091	0.16	0.30	0.47	1.1	2.5

*Average boating time in Lake Claire was 4.7 hr (Yousef *et al.*, 1978) during the experiment.

respectively. The average release rate in Lake Claire was 0.092 mg/liter-day ortho-P and 0.169 mg/liter-day total-P.

The rate of increase in P content with mixing was much higher than the rate of decline after mixing ceased. Pre-mixing concentrations were not reached 20 hr after cessation of mixing.

The most visible physical effect of sediment resuspension is increased tubidity. Excessive turbidity, besides reducing aesthetic acceptability, can damage aquatic ecosystems by reducing light penetration, clogging gills of fish and disturbing benthic community habitats. Turbid swimming areas pose dangers to swimmers because swimmers cannot be seen by lifeguards.

Yousef *et al.* (1980) observed significant turbidity in shallow lakes after mixing by motorboats (Table 15). Positive correlations existed between turbidity and P content in the water column.

Table 15. Turbudity after mixing

Lake	Turbidity (JTU)	
	Before	After
Claire	4.0	4.7
Mizell	3.9	4.5
Jessup	13	18

Bottom sediments of lakes are able to store large numbers of viable fecal bacteria in proportion to the degree of contamination of the overlying water. This stored fecal contamination could be resuspended into bathing areas creating conditions potentially hazardous to swimmers. Limited investigations have been conducted in the relationship of sediment-stored bacteria to water quality on natural bathing areas.

A study conducted at Acacia Beach, Grand Lake, Arizona showed concentrations of fecal coliform in sediment were significantly higher during the swimming season than during the nonswimming season (Winslow, 1976). This indicates that nearshore sediment of the beach serves as a reservoir for large numbers of fecal bacteria throughout the summer months. Fecal bacteria in the sediment originates from swimmers and pets, which shed bacteria directly into the water, and from surface runoff carrying dog and wild animal fecal matter from the surrounding watershed and beach area. Concentrations as high as 48×10^3/100 ml of sediment can occur even where swimmers and pets are the only apparent sources of contamination. Sediments with predominantly silt or clay-sized particles or with high organic matter contain much higher numbers of fecal bacteria than those without these characteristics. Overall increases in numbers of sediment-stored bacteria between Friday and Sunday can be accounted for by the deposition of fresh fecal bacteria by large weekend crowds.

Accumulation of fecal bacteria in sediment is strongly influenced by currents, wave action and agitation by swimmers. Resuspension of bacteria-laden sediment by wave action or swimmers may contaminate the overlying water. Resuspended fecal bacteria and freshly deposited bacteria from the bodies of swimmers appear to be the major immediate sources of contamination in the water at Acacia Beach (Winslow, 1976). Fecal bacteria in water may be redistributed from the swimming area depending on the prevailing currents near the beach.

There is some potential for sediment resuspension in the shallow areas (<3.0 m) of Lulu Lake by boating activities. However, release of nutrients or an increase in turbidity due to sediment resuspension may be negligible because of the limited boating activity in the lake. During the boating season--May to September--three or four fishing boats (15 hp) and two to three pleasure boats--mostly pontoons--(25 to 50 hp) were observed per day (Schumacher, 1986). Water skiing is very minimal. Sediment resuspension due to mixing by motorboats is influenced by water depth, power and size of boat and type of lake bottom (Yousef *et al.*, 1980). The number of boats, kind and intensity of boating activity and boat speed also affect the resuspension process.

Phosphorus release from sediments resuspended by bathers in Lulu Lake can be estimated by assuming a mean beach depth of 1.5 m, an area of 3,720 m^2, a sandy bottom, release rate of P similar to that in Lake Claire (Yousef *et al.*, 1980) and a swimming time of 2 to 3 hr daily. For a 90-day swimming season, loading will range from 4 to 6 kg ortho-P and 7 to 11 kg total P. Agitation of bottom sediments by bathers may temporarily increase bacteria and turbidity in the overlying water. The effect of swimming on sediment resuspension is governed by the number of swimmers, frequency of swimming and type of lake bottom.

Overall Effect of Swimming on Water Quality

Swimming affects recreational water quality by (1) direct inputs of nutrients and bacteria from bodies of swimmers and (2) release of pollutants and increased tubidity from sediment resuspension. In Lulu Lake the estimated P inputs from 160 swimmers and from sediment resuspension are 1.0 and 7.0 kg for the swimming season, respectively. Fecal bacteria originating from 160 swimmers was estimated to significantly increase bacterial density in the water column of the swimming area. Agitation of bacteria-laden bottom sediments may also increase bacterial density, however, quantification is difficult.

Apparently, 160 swimmers in the proposed swimming beach of Lulu Lake will contribute minimal P loading to the lake. Direct bacterial input from swimmers may elevate concentrations in the water column for short periods, particularly during peak swimming activity (usually weekends). Bacterial density declines as bacteria that have adhered to resuspended sediments are deposited on the lake bottom, as bacteria are redistributed in the lake water and as they die-off during swimming intervals.

The effects of swimmers on recreational water quality is influenced by such factors as density of swimmers, frequency of swimming activity and size of lake (i.e., ratio of swimming beach area to lake area). Shulz (1981) investigated the effect of nutrient inputs from bathers on the water quality of a large and a small lake in West Germany. Total P and ammonia-N concentrations in both lakes increased when there was a high density of bathers. This increase is due to direct inputs from bathers and from sediments stirred up during bathing. A positive correlation existed between the daily increases in nutrient concentrations and number of bathers. The daily increase in nutrient concentrations was notably greater in the small lake even though significantly more bathers were in the larger lake. The amount of nutrients added by bathers only affected the water quality of the two lakes for a short period; both lakes recovered during the night. During the bathing season no enrichment of nutrients could be detected within the bathing areas. The nutrient input by bathers is of little consequence in large lakes but could be an important source of eutrophication in smaller lakes with a high density of bathers.

Internal Regeneration of Nutrients from Sediment

During the summer, lakes are thermally stratified and oxygen is depleted below the thermocline. Under anoxic conditions nutrients are released from bottom sediments and are concentrated in the hypolimnion. Some of the nutrients may diffuse across the thermocline during stratification; however, the bulk of the hypolimnetic nutrients remains unavailable to algal growth until it is mixed into the photic zone during overturn. Several investigations have been undertaken to determine the contribution of hypolimnetic P release to overall P budgets and to evaluate the physical and chemical controls on both sediment release and availability of P to the photic zone (Vollenweider, 1968; Filos and Swanson, 1975; EPA, 1980; Jacoby *et al.*, 1982; Holdren *et al.*, 1983; Lazoff, 1983; Raman and Evans, 1985; Stauffer, 1985). It has been recognized recently that internal loading is a significant source of nutrients and should be included in nutrient budgets and management studies of lakes.

Vollenweider (1968) estimated sediment nutrient release rates of 12 and 0.10 kg/ha-day for ammonia-N and P, respectively, under anaerobic conditions. Filos and Swanson (1975) reported P release rates of 0.012 and 0.26 kg/ha-day under aerobic and anaerobic conditions, respectively. The Clean Lakes Program of the EPA (1980) suggests P values of 0.014 to 0.14 kg/ha-day under aerobic conditions and 0.27 to 0.55 kg/ha-day under anaerobic conditions.

Lulu Lake stratifies during summer and anoxic conditions occur starting at 6 m depth (WDNR, 1969). This means that about 60% or 20 ha of lake bottom can become anoxic in summer. It is likely that half or 10 ha of the lake bottom is completely anoxic in midsummer (July-August). A small amount of wind fetch creates a fairly shallow mixed layer in the lake during summer. Based on the release rates determined by Vollenweider (1968), the amount of P released from the bottom sediments during the midsummer period (62 days) is approximately 60 kg/yr.

Comparison of Phosphorus Sources for Lulu Lake

The soluble- and total-P sources for Lulu Lake are presented in Table 16. Although nonpoint sources contribute most of the P loadings to the lake, significant amounts of P can be regenerated from the bottom sediments. Holdren (1983) estimated that internal P release can be a significant source of loading for some lakes. Contributions from 160 swimmers either directly or as a result of sediment resuspension is small.

Table 16. Phosphorus sources for Lulu Lake

Source	Soluble P kg/yr	Soluble P %	Total P kg/yr	Total P %
Nonpoint	49*	43	122	64
Swimming (160 swimmers)	6	5.2	10	5.2
Internal regeneration	60	52	60	31
Total	115	100	192	100

*Assuming 40% of total P is soluble (Sonzogni *et al.*, 1980; Bannerman *et al.*, 1984; Brock, 1985).

Based on all sources "average" annual total P concentration of the lake predicted by Reckhow's model (Reckhow, 1979a) is 0.0205 mg/l. This value is higher than the measured concentration of <0.02 mg/l (see section on Water Quality). It is likely that some model parameters are overestimated. Errors can arise from selection of export coefficients and use of a laboratory-derived release rate of P from anaerobic bottom sediments. Loading estimates from various sources are uncertain because of the many assumptions made. The loading estimates for Lulu Lake at this time represent a "first cut" attempt and values need to be refined by a monitoring study and an investigation of internal regeneration of nutrients. In spite of the shortcomings of the "guestimate" exercise comparison can still be made to determine the significant sources of P for Lulu Lake.

WATER QUALITY

Water samples were collected on April 30, 1986 to determine the water quality status of Lulu Lake. Tables 17 and 18 compare parameters that may reflect changes in water quality of the lake. The alkaline pH of the lake has remained essentially unchanged over a 20-yr period; slight variations exist between some parameters, probably due to differences in sampling techniques and analytical procedures. Phosphorus--total P and dissolved P--levels in the lake did not increase from 1966 to 1986.

Table 17. Water quality of Lulu Lake, April 6 and September 13, 1966 (WDNR, 1969)

Parameter*	April at depth of 0.9 m	September at depths of 3.0 m	September at depths of 7.3 m
pH	8.3	8.3	7.9
Total alkalinity	220	200	220
Electrical conductivity	440	370	410
Ca	48	17	23
Mg	27	27	26
Na	1.0	2.0	1.6
K	1.1	0.90	1.0
Fe	0.02	0.01	0.02
Cl	2.0	2.5	2.9
SO_4	20	27	26
Total P		0.01	0.01
Dissolved P	0.03	0.01	

*Values in mg/l except pH (units) and electrical conductivity (μmhos/cm).

Table 18. Water quality of Lulu Lake and related waterbodies, April 30, 1986

Parameter*	Lake average**	Lake at depths of 0.9 m	Lake at depths of 7.3 m	Wetland	Stream[†]
pH	8.2	8.3	8.3	7.7	8.6
Total alkalinity	250	240	240	260	280
Total hardness	290	280	270	280	330
Electrical conductivity	430	410	420	420	490
Ca	63	60	61	65	69
Mg	31	30	30	30	36
Na	3.0	2.9	2.9	2.4	7.7
K	0.68	0.70	0.69	0.74	0.87
Fe	0.047	0.013	<0.011	0.024	<0.011
Mn	0.006	0.008	0.005	<0.003	0.003
Cl	5.8	5.8	5.8	1.6	15
SO_4	20	21	21	17	28
Total P	<0.02	<0.02	<0.02	0.02	0.06
Dissolved ortho-P	<0.004	<0.004	<0.004	0.007	<0.004
Total N	0.40	0.40	0.40	0.60	1.0
NH_3-N	0.03	0.03	0.04	<0.02	0.02
NO_3+NO_2-N	0.33	0.32	0.32	0.02	0.25
Turbidity	1.7	1.1	1.5	7.7	2.6
Chlorophyll-*a*	0.006				

*Values in mg/l except pH (units), electrical conductivity (μmhos/cm) and turbidity (FTU); total alkalinity and total hardness expressed as $CaCO_3$. Aluminum, copper, boron and zinc were determined but values were below detection limits of 0.352, 0.025, 0.029 and 0.010 mg/l, respectively. Secchi disk reading was 3.0 m.

**Average of 5 samples collected at the inlet, middle and outlet of the lake.

[†]Below a 4-ha impoundment.

Phosphorus concentrations in the lake remain low over the years (Table 18). The present P concentration of <0.02* mg/l, although it may vary during the year, indicates that the lake is noneutrophic (lakes with >0.02 mg/l total P are considered eutrophic or fertile). Recent observations showing the absence of algal blooms (Francis, 1986; Schumacher, 1986; Miller, 1986) also confirm the high quality of the lake. A Secchi disk reading on April 30, 1986 of 3 m suggests a high degree of clarity in spring. Water clarity may decrease in summer due to phytoplankton growth, but no algal bloom is evident. Schumacher (1986) has observed water clarity of no more than 1.2 m during summer. Chlorophyll-*a* concentration in spring is low (0.006 mg/l) but may increase in summer as phytoplankton proliferates--the extent of which is not known at this time.

A water quality index was prepared by Lillie and Mason (1983) for Wisconsin lakes based on water clarity and concentrations of chlorophyll-*a* and total P. The index classification ranged from very poor to excellent in 6 categories (Table 19). Considering these parameters, the existing water quality index for Lulu Lake is "good" for clarity and chlorophyll-*a* and "good" to "very good" for total P.

Thermal stratification appears to begin in mid-spring, however, the water column is still well-oxygenated at this time (Fig. 5). Earlier data showed that complete anoxic conditions of the hypolimnion occur in July (WDNR, 1979).

Total P concentrations in water tend to decrease from the stream to the lake, i.e., stream >> wetland > lake (Table 18). Although sediments and

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*Concentrations below 0.02 mg/l can now be detected but it was not done in this study. This type of analysis would provide valuable information. Assuming 40% of total P is dissolved orthophosphate-P (<0.004 mg/l), the calculated total P level would be <0.01 mg/l.

Table 19. Water quality index for Lulu Lake*

Index	Water clarity (m)	Chlorophyll-a (mg/l)	Total P (mg/l)
Excellent	>6.0	<0.001	<0.001
Very good	3.0-6.0	0.001-0.005	0.001-0.01
Good	2.0-3.0	0.005-0.01	0.01-0.03
Fair	1.5-2.0	0.01-0.015	0.03-0.05
Poor	1.0-1.5	0.015-0.03	0.05-0.15
Very poor	<1.0	>0.03	>0.15
Lulu Lake	3.0	0.006	<0.02**

*Based on a report prepared by Lillie and Mason (1983) for Wisconsin lakes.
**Calculated value is <0.01 mg/l (see footnote on p. 45).

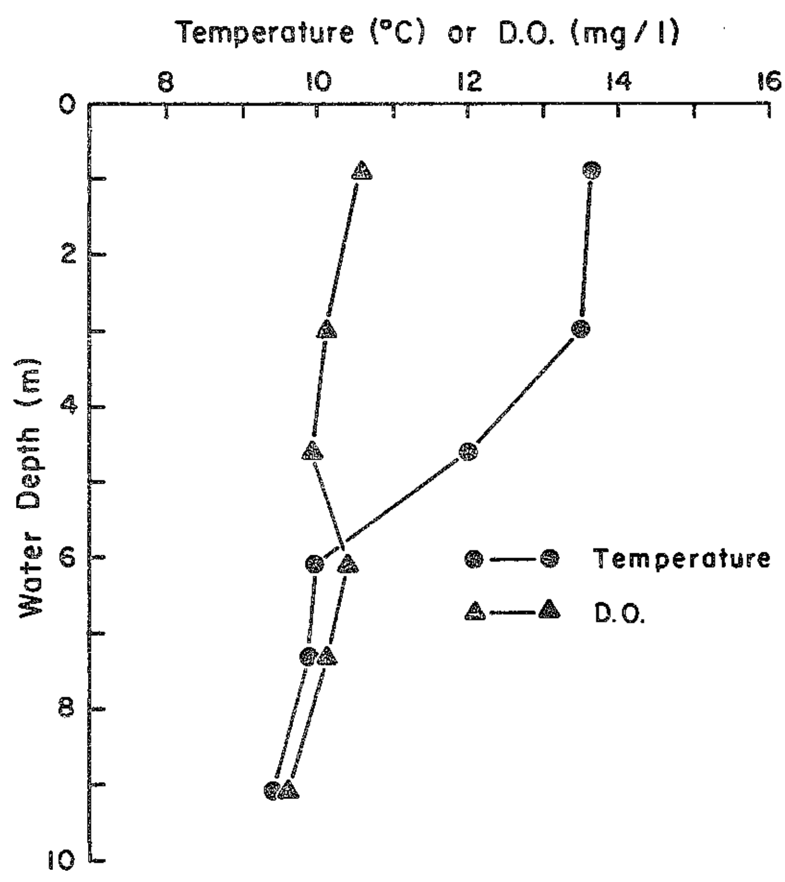

Fig. 5. Temperature and dissolved oxygen profiles of Lulu Lake, April 30, 1986.

associated nutrients may be trapped in a 4-ha impoundment at the middle of the watershed, the effluent still contains a relatively high level of P. However, high levels of P are not detected downstream, which may indicate further trapping of P in the wetland.

Limited chemical data along with occassional visual observations have indicated negligible deterioration in water quality of Lulu Lake for the past 20 years. Changes in land use patterns and population in the watershed are predicted to be minimal over the next 20 years. This trend will have little impact on the current water quality of the lake.

It is possible that state ownership of lands in the area with minimal lakeshore development, or implementation of the master plan (WDNR, 1985a), will mitigate pollution from nonpoint sources because critical source areas and other resources will be more carefully managed and protected.

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APPENDIX

STATUS OF BEACH CONTAMINATION IN WISCONSIN

STATUS OF BEACH CONTAMINATION IN WISCONSIN

L. Gould, G. V. Simsiman and G. Chesters

INTRODUCTION

A three-tiered survey was conducted between March and June 1986. Environmental and public health officers representing 16 counties and 11 cities were surveyed regarding beach contamination and related information (Table A1). Although this is a nonrandom survey, we feel that it is a good representation of individuals capable of answering our questions.

PRELIMINARY SURVEY

A preliminary survey was distributed to 27 individuals in March 1986. The information obtained from this questionnaire was used to estimate the extent of beach contamination in Wisconsin. Questions were directed towards whether sampling was conducted, which bacterial indicators were tested, and if beaches had been contaminated in the past 5 years.

Results

We received a very high response (96%) to the first survey (Table A2). Six individuals answered *no* throughout the questionnaire, indicating that they neither sample nor have seen any signs of beach contamination in their region. Of the health officials surveyed, 58% reported at least one contaminated beach in their area of jurisdiction in the past 5 years.

Of the 15 health departments that collect water samples, 100% test for fecal coliforms, 47% test for two or three bacterial indicators listed in the survey, and 13% test for all three. None of those surveyed collects bottom sediment samples for bacterial analysis.

SECOND SURVEY

A follow-up questionnaire was distributed in April 1986 to 20 individuals who answered yes to any question on the previous survey. The intent of this survey was to futher explore the methods and frequency of sampling, to compile information on the types and sources of beach contamination, as well as determine how many beaches were closed because of contamination (Table A2).

Results

Response (95%) to the second survey was also very high (Table A3). The one questionnaire not returned should not affect the conclusions drawn from the survey. In the preliminary survey this individual reported that the WDNR conducted sampling for the district.

Sampling Program. Sixteen of the health departments surveyed reported that they conduct their own water sampling while WDNR collects for three departments. Fifteen of them (79%) take samples throughout the swimming season, one throughout the year and another only during emergency periods. An emergency period was defined by 12 health administrators as an occurrence when a chemical, physical, or biological problem exists on land or in water that poses an immediate risk to public health. Warnings are posted at the beach and the beach is officially closed to the public (Question 10, Table A4).

The majority of the health departments (69%) collect water samples one to five times a week during the swimming season. A few departments (10%) do sampling one to seven times per week during swimming and emergency periods and one department only samples when an emergency occurs. All departments who sample regularly during the swimming season collect water on Mondays and usually on one other weekday. Three agencies sample every weekday. There are no reports, however, of sampling on weekends during peak swimming hours.

Mondays, however, probably give a good indication of the extent of contamination by swimmers occurring over the weekend. Sampling time (from early morning to late afternoon) appears to depend on the route taken by the inspectors. In general, it appears that sampling is conducted in the first half of the day.

Grab sampling (79%) is the main method of collecting water samples. Sampling depths vary from surface to >24 inches but most departments collect samples at depths of 0-6 (32%), 6-12 (16%) and 12-24 (21%) inches. The number of samples collected per beach appears to be fairly uniform, i.e. 1 to 2 at small and medium beaches and one to four at large beaches.

Contamination. Fifty-eight beaches in the counties and cities surveyed have been reported as contaminated in the past 5 years. Approximately 71% were contaminated by bacteria alone, 19% by chemicals alone and 10% by both.

Approximately 53 (91%) of those beaches reported contaminated were closed. Thirty-six (68%) were closed for bacterial contamination, 10 (19%) for chemicals and 3 (6%) for poor visibility and/or excessive algal and weed growth.

Sources of beach contamination are varied and often multiple. As a result, health officials checked more than one answer to Question B3 (Table A3). To apply these responses to the 58 contaminated beaches, the number of times each source was checked on the survey was tabulated and those percentages were calculated. Major sources of contamination were runoff from cropland (listed 6 times), runoff from residential areas (6), septic systems (3), and runoff from feedlots and manure storage (8). Pollution due to road salts, sanitary treatment plants, and runoff from parks and campgrounds, were each listed twice; swimmers/bathers once; and cottage development areas none. "Other" sources of contamination specified were houseboats, duck manure, and overflowing sewers during periods of high rainfall.

TELEPHONE SURVEY

To complete the information compiled on contaminated beaches the 12 health departments who reported beach contamination and conducted their own sampling were contacted by telephone in June 1986. The intent of this third survey was to obtain more quantitative information, to formulate an idea of how individuals intepreted certain questions on the second survey and to understand how each person defined terms such as emergency period, size of beaches, etc.

Discussion

Contamination has closed approximately 55% of the 53 contaminated beaches at least once in the past 5 years. Additional quantitative data received over the phone was not compiled because many health officials did not keep adequate records and therefore spoke from memory. Table A4 consists of general comments and interpretations to each question.

It was discovered that several health officials had misinterpreted questions B1 and B2 in the second survey. Instead of stating how many different beaches had been contaminated and closed, some wrote the total number of contamination episodes that have occurred in the past 5 years. Most of these errors have now been corrected.

Many health officials (66%) report that high rainfall is the most frequent cause of contamination in their region. High rainfall promotes beach contamination by (a) generating runoff from various land uses, including feedlots and manure storage areas and (b) causes overloading of waste disposal (STPs and septic) and sewer systems resulting in overflows and failures.

Runoff from land surface and overflows/failures of waste treatment systems are the major sources of beach contamination, as indicated in Question B3 of the second survey. Some departments have developed formulas based on amount of rainfall over time for closing down their beaches. For example, one health department closes four beaches which are located on rivers when rainfall exceeds 0.5 inches in 4 hours.

Bacteriological standards mandated by the state for closing beaches are not always adhered to. According to the Wisconsin Administrative Code (HSS 171.21), if the fecal coliform count exceeds 200/100 ml the water should be resampled and consideration be given to closing the beach. Many departments often close their beaches when the 200/100 ml value is reached. However, a few departments do not close unless sample counts reach 1000/100 ml, while others "never" close their beaches. Reasons given for a no-closing policy are:

1. Although the beach is sampled, it is not city owned and therefore never closed even if contamination does occur,
2. Although bacteriological counts frequently exceed the Wisconsin State standard, the safety hazard posed by having no lifeguards is far worse than the current contamination problems,
3. Because most bacterial contamination is due to high rainfall and only lasts 48 hours, by the time the result of the sample analysis comes back from the laboratory a week later, the contamination is "history."

Questions B1 and B2 from the second survey are now viewed in a different light: the number of reports of contamination and closings are directly related to that particular health department's definition of contamination and its closing policy.

CONCLUSIONS

The exceedingly high response rate on all three surveys allows some safe assumptions to be made concerning the status of beach contamination in Wisconsin. The most frequent type of contamination on beaches in Wisconsin is bacterial (68%). It appears that bacterial contamination is related closely to high rainfall events. High rainfall generates runoff from such land uses as feedlots, croplands and residential areas and also causes overflows/failures of sanitary waste disposal and sewer systems. This contamination problem tends to recur at least once a swimming season. Chemical contamination rarely occurs and is an accidental phenomenon. In contrast to varying policies towards beach closing in regard to bacterial contamination, health departments are quite conservative when confronted with chemical hazards.

The extent of beach contamination in Wisconsin is difficult to assess because individual health departments have separate closing policies and definitions of how much contamination presents a risk to public health. It is therefore recommended that standard methods be established for the State. Sampling should be conducted on the same days of the week and at the same time of day, the same number of samples should be collected at each site, and the same type of analyses should be conducted. If all beaches are tested in the same way, uniform closing policies could be established. It is also recommended that a record of past contamination episodes be kept.

Table A1. The Water Resources Center, University of Wisconsin-Madison wishes to thank the environmental health and public health administrators listed below for their help and kind cooperation in the survey.

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Table Al. Continued

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Table A2. This preliminary questionnaire was distributed to 27 health administrators and officers throughout Wisconsin in March 1986. Twenty-six surveys were returned (96%). The questionnaire displayed below has been slightly altered from the original form. The right hand columns indicate the frequency of answers to each question.

The Water Resources Center of the University of Wisconsin-Madison and the Wisconsin Department of Natural Resources have a cooperative project to investigate the status of beach contamination in Wisconsin. It would be greatly appreciated if you could provide yes or no answers to the following:

Question	Respondent (%)		
	Yes	No	NA*
1. Do you conduct water sampling of swimming beaches in your area of jurisdiction?	62	38	
1a. Do you have specified methods of collecting water samples?	54	46	
1b. Do you sample with specified frequencies during the swimming season and at other times?	58	42	
1c. Do you analyze water samples?	58	35	7
for total coliforms?	40		
for fecal coliforms?	100		
for fecal streptococci?	20		
2. Do you collect bottom sediments at swimming beaches for bacterial analysis?		100	
3. Have any beaches been contaminated during the last 5 years in your area of jurisdiction?	58	42	
3a. Have the sources of contamination been identified?	31	42	19

*NA - no answer.

Table A3. This follow-up questionnaire was distributed in April 1986 to 20 individuals who answered yes to any question on the previous survey. There was a 95% return rate. The questionnaire illustrated below has been slightly altered from the original form to accomodate the fact that individuals could check more than one answer to each question. A total of 58 beaches have been contaminated in the past 5 years. However, only 53 of those beaches were closed.

Thank you for your help and cooperation in completing the questionnaires we sent you in March 1986 concerning the status of swimming beach contamination in Wisconsin. We received an exceedingly high response (26/27) to the preliminary survey. We are conducting a follow-up survey and we would appreciate very much if you could provide answers to questions appearing below. Please check one or more appropriate answers to A1, A3, A4, A6 and B3.

Question	Respondent (%)
A1. Do you conduct water sampling of swimming beaches	
(a) during the swimming and non-swimming seasons?	5
(b) only during the swimming season?	79
(c) only during emergency periods?	5
(d) no answer	11
A2. How frequently do you collect water samples during the	
(a) swimming season? 1 to 5 times/week	68
(b) non-swimming season only?	0
(c) emergency periods?	5
(d) swimming + emergency periods? 1 to 7 times/week	11
(e) no answer	16
A3. Do you collect water samples by	
(a) grab sampling?	79
(b) depth samplers?	11
(c) other methods (please specify)	0
(d) no answer	10
A4. Do you sample at water depth(s) of	
(a) 0-6"?	37
(b) 6-12"?	16
(c) 12-24"?	21
(d) >24"?	5
(e) b, c and d	5
(f) a and b	5
(g) no answer	11

A5. How many samples per week do you collect	once	twice	three x	four x
(a) small beach?	69	31	0	0
(b) medium beach?	73	27	0	0
(c) large beach	50	25	17	8

Table A3. Continued

A6.	Do you collect water samples	18
	(a) early morning?	18
	(b) late morning?	6
	(c) early afternoon?	0
	(d) late afternoon?	12
	(e) morning (a or b)	5
	(f) afternoon (c or d)	12
	(g) late AM or early PM	29
	(h) throughout day?	
A7.	Which days of the week do you sample	16
	(a) Mondays only?	37
	(b) Mondays plus one other weekday?	16
	(c) all weekdays?	31
	(d) no answer	
B1.	How many local swimming beaches have been contaminated in the*	
	last five years with	71
	(a) bacteria alone?	
	(b) chemicals alone (includes nutrients, salts, oils and	19
	grease, pesticides and other toxics)?	10
	(c) bacteria and chemicals	
B2.	How many local swimming beaches have been closed in the last*	
	five years due to	68
	(a) bacterial contamination?	19
	(b) chemical contamination?	2
	(c) bacterial and chemical contamination?	
	(d) excessive poor visibility caused by color, deposits,	2
	oils, grease, etc.?	5
	(e) excessive algal and weed growth?	4
	(f) other	
B3.	Have you identified the major source(s) of beach contamination as**	17
	(a) runoff from cropland?	23
	(b) runoff from feedlots and manure storage?	17
	(c) runoff from residential areas?	6
	(d) runoff from parks and campgrounds?	6
	(e) road salts?	8
	(f) small scale waste disposal system (septic tank)?	6
	(g) sanitary treatment plants (STPs)?	3
	(h) swimmers/bathers?	0
	(i) cottage development areas?	6
	(j) sewers/high rainfall?	6
	(k) others (please specify)?	

*A total of 58 beaches were contaminated in the past 5 years but only 53 were closed.

**Because many health officials identified more than one contamination source, and there may have been more than one source for each contamination episode, the above percentages represent the total number of times each source was checked, i.e., runoff from cropland was checked 6/35 times = 17%.

Table A4. After compiling the data from the second survey, it was felt that additional information could be used. Twelve health departments who reported beach contamination and conducted their own sampling were contacted by telephone and asked the questions listed below. Some individuals lacked adequate records and spoke mostly from memory while others were able to retrieve the information from files. The results given below are therefore mostly qualitative but contribute significantly to the conclusions made for the entire survey on the status of beach contamination in Wisconsin.

1. How many beaches are in your area of jurisdiction?

   Total number of beaches = 85
   Total number closed at least once in past 5 yr = 47

2. What size are the beaches that you have reported contaminated? What is your definition of a large, medium, small beach?

   Shoreline footage estimates of beaches ranged anywhere from 30 to 4,000 ft. The definition of a large, medium or small beach depended on the size of beaches that each had in his/her area of jurisdiction. For example, while one individual considered a 4,000-ft beach to be medium sized, others considered 1,000 to 2,000-ft to be large.

3. How big is the lake/river where contamination has occurred? Do you have any idea how much of the lake is being contaminated?

   Because health officials are not responsible for testing outside of the beach limits, they rarely have any idea of how extensive contamination is throughout a lake or river body. However, some health inspectors who sample at the smaller inland lakes find that the entire lakes are being contaminated. Their reports come from residents who experience problems on their private beaches.

   When contamination is occurring on large lakes like Michigan or Superior, health officials felt that the source of contamination was extremely isolated. They knew this because other beaches that they sampled at just a short distance down the shore would have no contamination.

4. Where is the contaminated beach in relation to town or city?

   There are an equal number of beaches within city limits as there are outside.

5. Is the contaminated beach adjacent to campgrounds and/or picnic areas?

   All health officials interviewed do not believe that campgrounds and/or picnic areas have any relationship to beach contamination.

6. How many swimmers does each beach (reported contaminated) get during the week? During peak periods?

   Most health officials hold no information on these two questions. It therefore remains unresolved whether state standards are followed regarding the density of swimmers on the beaches. There is no indication, however, that the number of swimmers contributes to the decreasing water quality of these beaches.

7. How many times a year is a contaminated beach closed?

The most common reason for closing a beach is high rainfall; the rapid influx of water creates bacteriological problems by generating runoff from feedlots and other land use areas and causing sanitary waste disposal and sewer systems to overflow as well as septic systems to fail. As a result, some departments use a safety formula that involves closing a beach as soon as a certain amount of rainfall occurs in a prescribed amount of time. The number of times that a beach will be closed is in direct relation to the wetness or dryness of that summer season. One individual indicated that closing may occur 4-5 times during a dry summer and possibly 10-12 times during a wet one.

8. Does the same beach become contaminated year after year?

When high rainfall is the cause of contamination, the same beach will be polluted year after year. Chemical contamination appears to be a much more accidental type phenomenon.

9. Do you feel that the number of samples that you collect in order to determine contamination is sufficient?
Do you feel that you are liberal or conservative when closing a beach?

All except one health official answered yes to the first part of this question. This individual had the most "conservative" attitude towards appropriate human safety.

All health officials felt that they were either conservative or fair when making a decision to close a beach. However, each individual's concept of what was conservative differed. Some follow the Wisconsin State code exactly. A few report that although they sample, they never close their beaches because it is more hazardous to human health to not have a lifeguard than to be exposed to high fecal counts. The attitude also depends on the type of contamination. Health officials are more concerned about chemical than bacterial contamination and will close a chemically polluted beach much more readily.

10. What is your definition of an emergency episode in relation to closing a "contaminated" beach?

Despite the fact that health officials close their beaches at varying levels of fecal counts (anywhere from 200-1,000 counts/100 ml sample), they all gave surprisingly similar definitions of an emergency episode: an occurrence when a chemical, physical, or biological problem exists on land or in water that poses an immediate risk to public health.

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