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ABSTRACT — The eutrophication of lakes has been the subject of much discussion in scientific journals and the popular press.. Usually the eutrophication process is accelerated by human activities. This study evaluates the extent of lakeshore development and recreational use of Lake Bemidji in north central Minnesota and examines the willingness of lakeshore residents to be assessed for corrective measures to halt deterioration of this valuable recreational lake. The shoreline of Lake Bemidji is highly developed, and the high density human habitation represents a potential source of nutrients from percolation through the sand and gravel soils which surround the lake. Residents around Lake Bemidji believe that growth of algae and aquatic vascular plants is not now severe and that it does not affect their use of the lake for recreational purposes. Although seventy-five percent of the residents favor regulation of lakeshore use and development, only 37 percent indicate willingness to be assessed for construction of a sewer line surrounding the lake.

A lakeshore survey was conducted from May 1 to July 1, 1969, to provide information on the extent of use and development of lakeshore residences around Lake Bemidji, in Beltrami County, Minnesota. These were considered factors which might contribute to the addition of boat motor fuels and plant nutrients, such as nitrogen and phosphorus, to the lake. The opinions of lakeshore residents concerning the water quality of the lake also were surveyed.

No previous surveys of the lakeshore residents or residences around Lake Bemidji have been made other than cottage counts taken by the Minnesota Department of Conservation (Department of Natural Resources) in 1948 and 1966 as part of fisheries-oriented lake surveys.

A questionnaire was designed to gather information on population density, disposal methods for domestic sewage and wastewater, the extent of noticeable algal and aquatic vascular plant growth, and recreational usage. Opinion questions relating to water quality, regulation of lakeshore use and willingness to be assessed for the construction of a sewer line around the lake also were included. Responses were obtained by personal interviews and were recorded on IBM cards.

The shoreline of Lake Bemidji was arbitrarily divided into five areas (Figure 1). A sixth category included all resorts, motels and public facilities. Prior to the interviews, introductory letters outlining the purposes of the project were sent to all lakeshore residents. At the completion of the field survey portion of the project, the data were processed using an item analysis program, Number 40040, on an IBM 1401 computer. This program is on file at Bemidji State College.

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Population density

There are 294 dwellings on the shore of Lake Bemidji, including permanent residences, seasonal cottages, resorts and motels. Survey interviewers contacted occupants of 223 of the 294 residences, or 76 per cent (Table 1.) Those 223 dwellings contain seven hundred and seventy-seven people. All percentages in this paper are based on the number of residences contacted.

TABLE 1. Number of Residents and Residences Per Sampling Area Contacted by the Survey.

Location and fire number		Survey area number	Number of residents	Number of Residences
Southeast Shore	O 100–N 100	1	99	25
City Limits – Northwoods	N 100–N 300	2	157	43
Northwoods Resort State Park	N 300–O 649	3	179	52
State Park – Lavina	O 649–O 300	4	151	41
Lavina – Wayville	O 300–O 100	5	152	50
Resorts & Motels		6	39	12
TOTAL			777	223

The number of people per houshold varied from 1 to 6. The largest percentage of the residences (31 per cent) included 2 persons per household, but households with 3 and 4 persons were common. Twenty-seven per cent of the lakeshore residents had children between the ages of 6 and 12 years and 5 per cent had children under the age of 6 years.

Fifty-five per cent of the residences were occupied for 12 months each year and forty-five per cent of the resi-

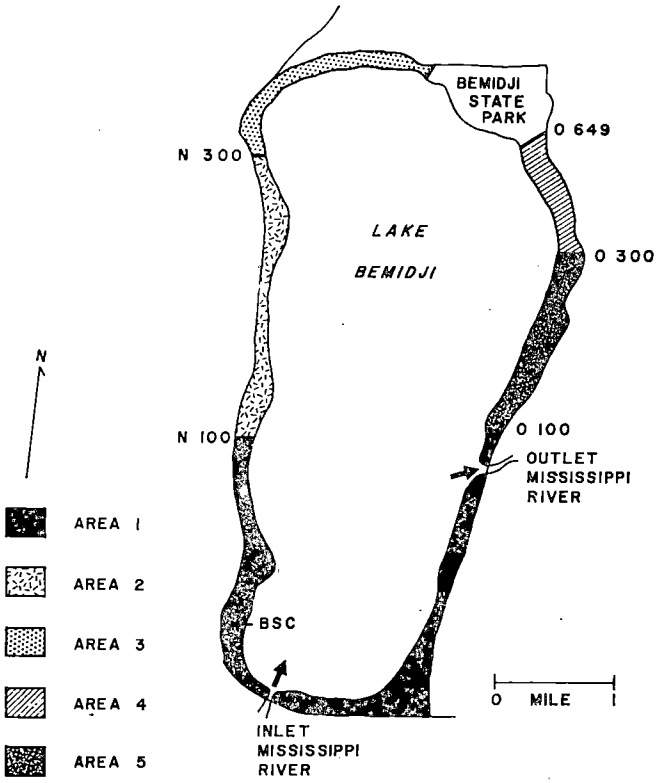

FIG. 1. Map of Lake Bemidji showing survey areas as indicated by rural fire department numbers A sixth category not shown includes all resorts, and other public facilities The location of Bemidji State College is indicated by the letters B. S. C.

dences were used seasonally. Most of the seasonal residents occupied their lake homes for 2 or 3 months during the year. Ninety-three per cent of the lakeshore residents owned their properties, and 7 per cent rented. Seventeen per cent of all residences and public facilities had additional cabins on the propetry.

Sewage, wastewater and effluents

Cesspools were used at 52 per cent of the residences and septic tanks at thirty-eight per cent. Many dwellings had a combination of a septic tank and a cesspool, with the cesspool being used as a dry well. In these situations the disposal facility into which the sewage entered first was recorded for purposes of tabulation. Ten per cent of the residences on the lakeshore, all in Area 1, were connected to the Bemidji city sewer main. One seasonal residence was served by a privy.

Fifty-one per cent of the residences have a sewage disposal system five years old or older. Twenty-seven per cent of these are more than ten years old. Eighteen per cent of the sewage disposal systems are less than two years old. Fourteen per cent of the owners reported having experienced trouble with the disposal system, although owners of property with older systems did not report any greater difficulty than did owners of property with newer systems.

Setback distances between sewage disposal facilities and the lake shoreline were estimated by the residents. Most cesspools and septic tanks are located more than sixty feet from the lake shoreline (Figure 2). Of those residences with cesspools, 70 per cent were located 60 feet or more from the shoreline. Thirty-seven residences with cesspools and 12 residences with septic tanks had these systems located less than 60 feet from the shore.

The slope of the bank at each residence varied considerably around the lake (Figure 3).

Fifty-four per cent of the households surveyed used automatic clothes washers and 39 per cent used automatic dishwashers, and these devices add wastewater to the sewage disposal system. Dishwashers were used for one load per day on the average and clothes washers averaged 4 loads per week.

Other effluents entering Lake Bemidji from various properties included minnow tank overflow (2 per cent), storm sewer flow (4 per cent), streams (5 per cent), and artesian wells (4 per cent).

Forty-one per cent of the lakeshore residents used some type of lawn fertilizer, but the amounts used were not determined.

Aquatic plant and algal growth

Each resident was asked whether he had experienced trouble with excess rooted aquatic plant growth along his lake frontage. Two photographs were included in the survey booklet to help define the term "excess." Forty-four per cent of the residents indicated that a noticeable increase in aquatic plant growth had occurred.

Each resident also was asked about an observable increase in algal blooms. A photograph of an algal bloom from Fogg (1966) was shown to help standardize responses. Twenty-nine per cent of the respondents reported an increase in algal blooms over the past 6 years. Twenty-six per cent reported an increase in algal blooms within the past 2 years.

Each respondent was asked if he believed that a noticeable change had taken place in Lake Bemidji within the past 10 years, "change" being defined as an observable increase in the abundance of aquatic plants or an increasing severity of algal blooms. Fifty-six per cent believed that no noticeable change in the water quality had occurred. But thirty-nine per cent of those responding positively to the question about water quality also said that their use of the lake had been affected by these changes.

Recreational use

Questions pertaining to the recreational use of the lake were asked, and responses were recorded (Figure 4).

The extent of boating activity was determined by the number of boats at each residence, the type of boat motor used, and the amount of boat motor fuel used weekly during the boating season. There were 345 motor-driven boats used by all the lakeshore residents interviewed. The most common type of boat motor was a 2 cycle outboard engine (Table 2). Twenty per cent of the lakeshore residents did not own either a boat or a boat motor.

Using an estimate of the total amount of gasoline used by boaters and fishermen in a 12-week season, the amount of fuel entering Lake Bemidji was calculated, based on

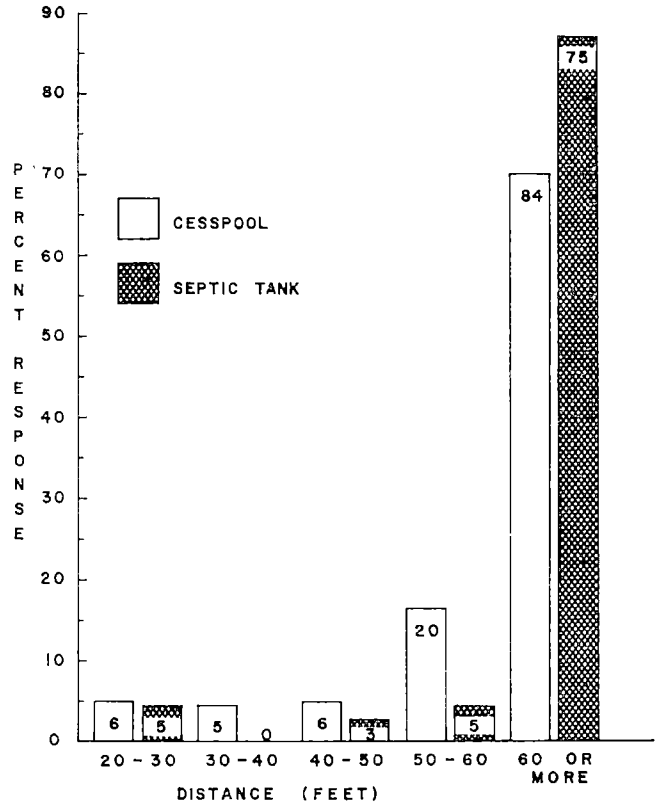

FIG. 2. Set-back distance of cesspools and septic tanks from Lake Bemidji shoreline.

the low value given by Muratori (1968) for wastage of outboard fuel as 10 per cent of the total. Resident boaters at Lake Bemidji used 16,992 gallons of fuel, so the wastage from boat motor exhausts was calculated to be 1,699 gallons per boating season. But, if wastage approaches the more extreme figure cited by Muratori of 40 per cent of the total amount of fuel, the amount entering the lake would be 6,796 gallons per boating season.

General opinion questions

Two questions dealt with opinions on lakeshore regulation and residents' willingness to be taxed for a sewer line around the lake. Regulation was defined as limiting the number of dwellings which can be built on a lot of specified size or restrictions which would control future development on undeveloped lake frontage. Seventy-five per cent of the residents favored some type of lakeshore regulation, 21 per cent were opposed to lakeshore regulation and 4 per cent declined to answer.

TABLE 2. Type of Boat motors used by the Lakeshore Residents Surveyed.

Type of boat motor	Number used	Percent of residences
2 cycle inboard	6	3
2 cycle outboard	151	68
4 cycle outboard	6	3
4 cycle inboard	14	6
TOTAL	177	80

Finally, the lakeshore residents interviewed were divided equally as to construction of a sewer line around Lake Bemidji, with 37 percent in favor and 37 percent opposing an assessment for this. Of the remainder, 13 per cent were undecided, 2 per cent declined to answer, and 10 per cent said the question did not apply to them because their properties already were connected to the Bemidji city sewer main.

Extent of utilization

The most densely populated sections of Lake Bemidji shoreline are survey areas 2 and 3, northerly extensions of the City of Bemidji. Borchert *et al.* (1970) mention that high densities on lakeshore properties in Minnesota reflect specialized extensions of cities and towns, and that homes in these areas may require urban-type services. The number of people occupying shoreline around Lake Bemidji averages 52.9 per mile, and the number of acres of water per dwelling is 22.1. From data for other Minnesota lakes (Orning, 1968), this value for the degree of development of Lake Bemidji shoreline suggests a low level of utilization but most of the available frontage is developed. Borchert *et al.* state that the most crowded lakes average fifteen acres of water per cabin. If all residences around Lake Bemidji had been contacted, our figures would probably indicate even more crowded conditions. Also, due to its elliptical shape, Lake Bemidji is less subject to potential crowding in terms of acres per shore unit than are long-narrow lakes.

Lake Bemidji is in the final stage of Threinen's historical pattern of development. According to Threinen (1961) development proceeds from large undeveloped tracts of wild shores to the ringing of the shoreline with human habitations. In the last stage, the physical character of the lakeshore is "improved" by removing beds of aquatic vascular plants to facilitate swimming and boating activities.

The majority of the cesspools or septic tanks of lakeshore homes on Lake Bemidji are more than 5 years old and are located at least 60 feet from the lakeshore. But few are or can be located 30 feet above the high water wark of the lake, as recommended by Bishop (1969).

The soil surrounding Lake Bemidji is glacial outwash sand and gravel, which permits material from cesspools to enter the lake by percolation to the water table. Borchert *et al.* state that heavy development on some of the coarse, sandy shoreline classified as suitable for on-site sewage systems can result in pollution because percolation can be so rapid that the chemical reactions required to neutralize sewage contaminants is incomplete.

Many former summer lake homes around Lake Bemidji have been converted to permanent dwellings. Borchert *et al.* state that, after such conversion, the amount of sewage, particularly of suspended solids, increases by more than six times. Thus, it may be expected that nutrient addition to Lake Bemidji will increase as the lakeshore is occupied by an increasing number of permanent residences.

Addition of nutrients to natural bodies of water usually is manifested by an increase in the growth of algae and aquatic vascular plants, which may constitute a serious

problem in recreational waters. Such increased growths exist in Lake Bemidji. Ten per cent of the homes surveyed were connected to the municipal sewer system, which does not discharge into the lake. From an average value of 7.7 pounds of nitrogen per person per year cited by Sawyer (1947), Van Vuran (1948), Bush and Mulford (1954), and MacKenthun and McNabb (1961), the total amount of nitrogen entering all cesspools ringing Lake Bemidji is estimated to be approximately 3,000 pounds per year. Similarly, from data of Polta (1969), the amount of nitrogen entering the lake may be reduced by as much as one-third by chemical reactions in the soil.

Phosphorus is added to Lake Bemidji in much smaller quantities. From the average value of 1.9 pounts of phosphorus per person per year from Sawyer, Van Vuran, Owen, (1953), Bush and Mulford, Metzler (1958), Engelbrechte and Morgan (1959), Mackenthun and McNabb, and Sawyer (1965), the total amount of phosphorus from human excretion entering private disposal facilities per year is estimated to be about 800 pounds. But, the contribution of phosphorus from detergents used in automatic clothes washers and automatic dishwashers is much greater. In this study it was estimated that approximately 2,788 pounds of phosphorus is added annually to the private sewage disposal systems in wastewater containing detergents. Thus, the total amount of phosphorus added each year to all sewage systems is 3,588 pounds. Again, the amount of phosphorus added to the lake is reduced by absorption in the soil, but exact ratios are unknown.

A majority of the respondents believed that there was neither an increase in the severity of algal blooms nor in aquatic plant growth. If these are the criteria used to indicate a change in water quality, then Lake Bemidji is still considered by those living on its shores to be useable for recreational purposes. Areas 2 and 3, where respondents reported that the growth of algae or aquatic vascular plants had increased, are the most densely populated, most recently settled, and have the highest percentage of permanent homes.

Although an almost equal percentage of respondents felt that the growth of aquatic vegetation had increased in Lake Bemidji, these changes do not appear to reduce their use of the lake for recreational purposes. Except for water skiing, the extent of each recreational use is similar. At the present level of use, Lake Bemidji averages 18.9 acres of water per resident water ski boat. Threinen (1964) states that twenty acres of water are required for each ski boat. Thus, Lake Bemidji is barely capable of supporting this sport, and the lake's capacity to support this activity is further exceeded by non-property owners and tourists who bring in water ski boats.

The discharge from outboard motors at present utilization would not be expected to taint the flesh of fish in Lake Bemidji, under accepted standards. The volume of Lake Bemidji is 62,266,676,500 gallons, and the estimated loss of fuel at the high 40 per cent rate is 6,796 gallons or a ratio of 0.11 gallon of fuel to every million gallons of lake water. Surber *et al* (1963) reported from field tests that fish flesh tainting becomes probable at a fuel ratio of 0.17 gallons/million gallons of water per season. Muratori reported that a fuel level greater than one gallon per million gallons of lake water per season is sufficient to raise the threshold odor level.

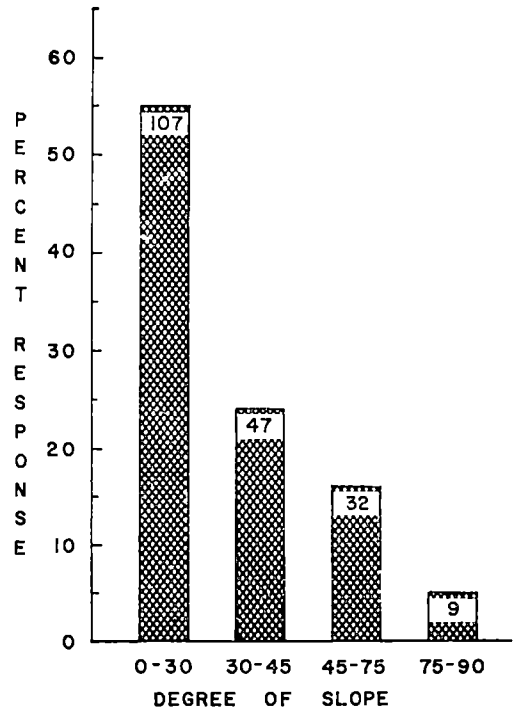

FIG. 3. Estimates of degree of slope of Lake Bemidji frontage.

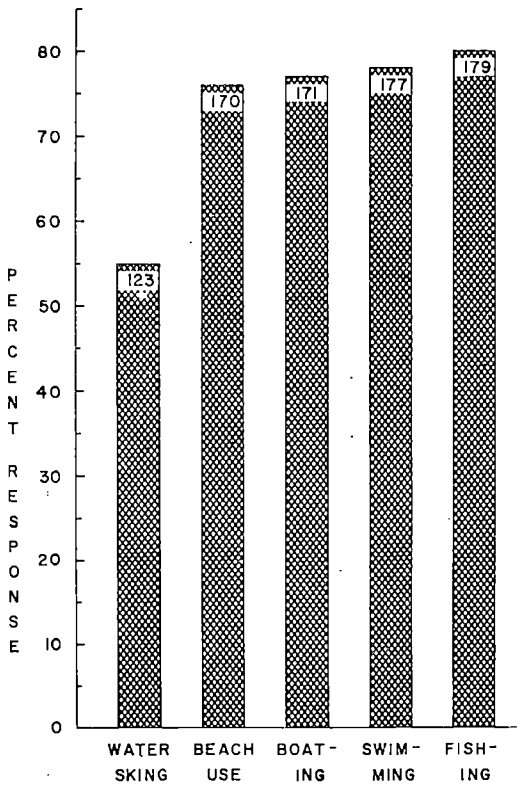

FIG. 4. Recreational uses of Lake Bemidji by owners of lakeshore dwellings.

The flushing action of the Mississippi River through the south Basin of Lake Bemidji will probably reduce the level of wasted fuel remaining in the lake. It is possible, however, that products may be concentrated in limited areas of the lake, and a study of this problem has been undertaken.

Borchert *et al.* listed Lake Bemidji as one of the 10 most developed lakes in Minnesota. This survey estimated 20 buildings per mile of total shoreline around Lake Bemidji, far exceeding the average for other lakes in Beltrami County of 3.2 seasonal and permanent homes per mile of total shoreline and the average of 4.0 seasonal and permanent homes per mile of privately owned shoreline, as mentioned by Borchert *et al.* In view of those figures, the fact that 75 per cent of the persons interviewed around Lake Bemidji favored some form of regulation of lakeshore use is not surprising. Borchert *etal.* also found that most lake home owners are notably protective about the introduction of new uses to their lakes and are highly sensitive to lake water quality management.

Threinen (1961) suggested that if 75 per cent of the lakeshore on any lake has moderate use, the remaining 25 per cent should be preserved in a wild state by public ownership to serve as fish and game habitat. Estimates in this study indicate that approximately 86 per cent of the Lake Bemidji shoreline is developed for moderate use (i.e. cottages). This extensive development reduces the potential effectiveness of the proposed regulatory measures. It is, however, fortunate that the extent of public land holdings bordering Lake Bemidji, especially on the southeast shore, is large, and that extensive segments are preserved as fish and waterfowl habitat.

Although there is no strong preference among residents for implementation of corrective measures now, as the effects of eutrophication process continue in Lake Bemidji, many who are presently undecided can be expected to favor corrective efforts in the future. It is also likely that many seasonal residents will continue to oppose additional assessments because they believe they already carry a heavy tax burden for lake properties.

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