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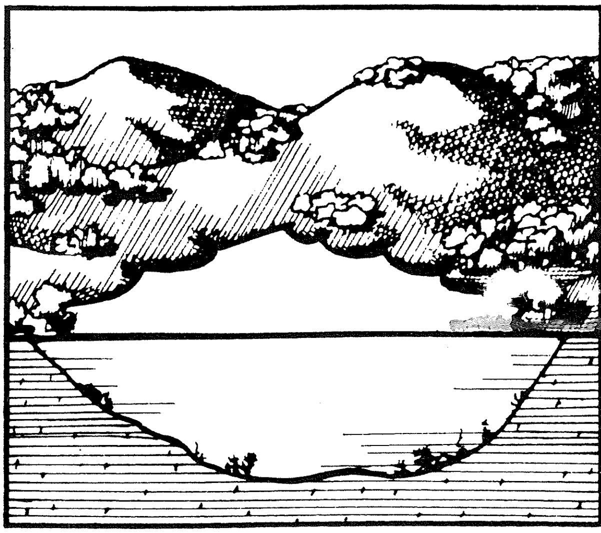

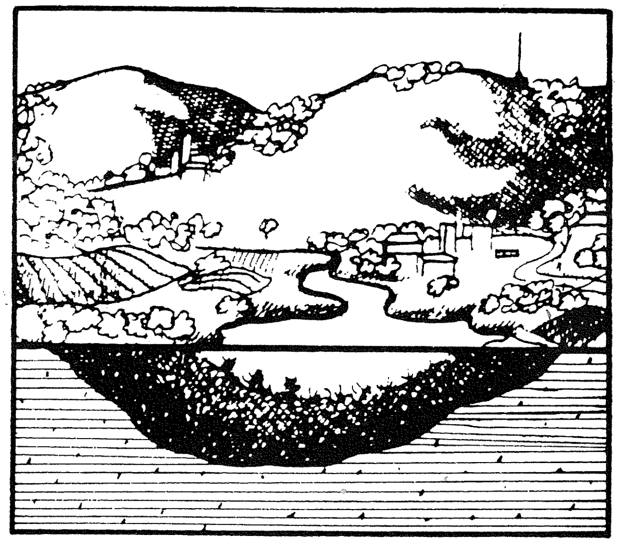

LAKE DEVELOPMENT

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LAKE DEVELOPMENT

How Much Is Too Much? How Much Is Too Much? How Much Is Too Much? How Much Is Too Much?

1987

Minnesota Department of Natural Resources
Division of Waters

Much Is Too Much?..... How Much Is Too Much?...... How Much Is Too Much?

LAKE DEVELOPMENT
HOW MUCH IS TOO MUCH?

By: Wayne Barstad
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1987
St. Paul, Minnesota

Minnesota Department of Natural Resources
Division of Waters
Floodplain/Shoreland Management Section

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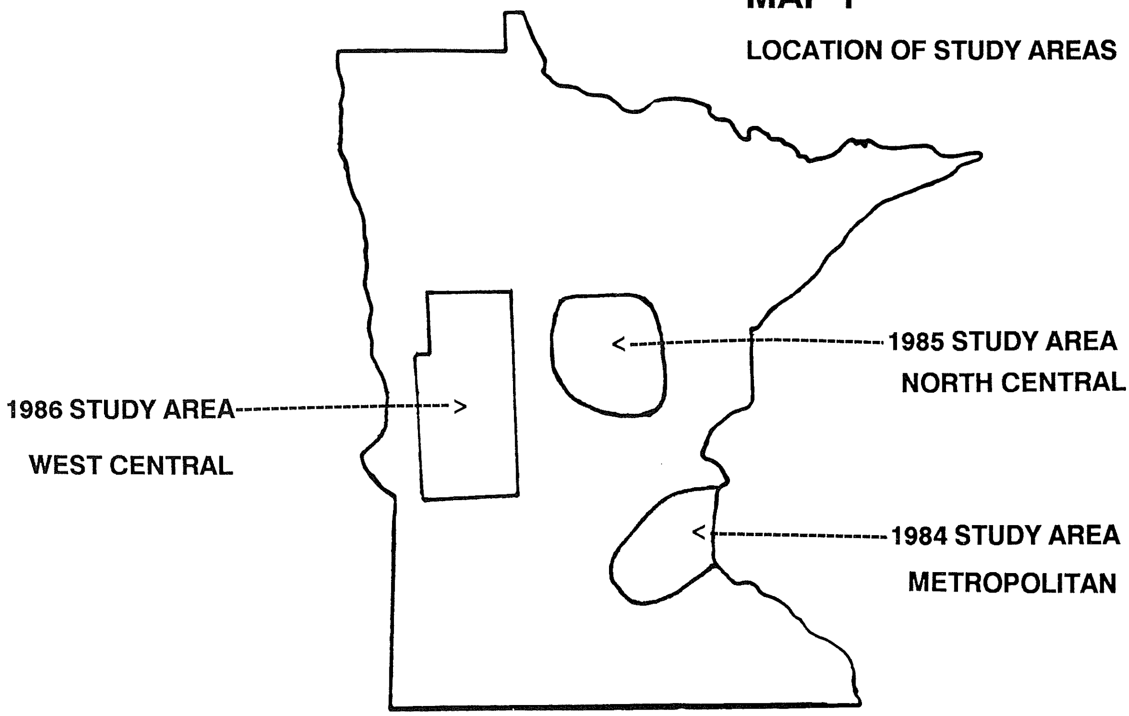
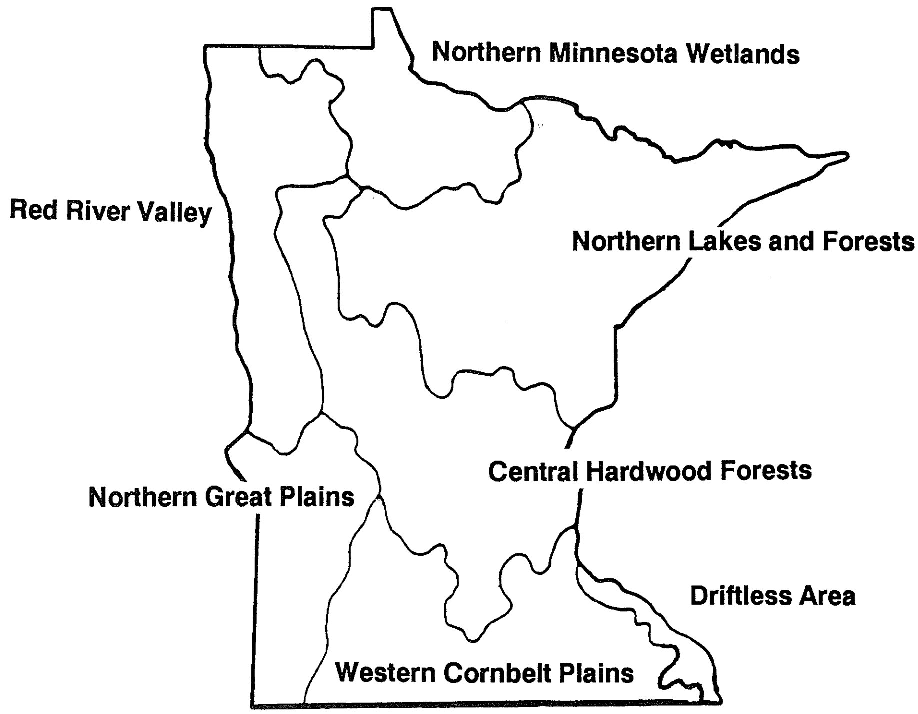
MAP 1

LOCATION OF STUDY AREAS



MAP 2

MINNESOTA ECOREGIONS



INTRODUCTION

The Concept of Resource Capacity

Lake carrying capacity can be defined as the ability of a lake to adapt to particular types of uses and a given number of users within defined levels of ecological disturbance and user conflict. Carrying capacity may be viewed from either an ecological standpoint that reflects the biological, chemical, and physical characteristics of a lake system or a social standpoint that considers human use of the resources.

The purpose of this handbook is to introduce the use of models to communities concerned about their lake's carrying capacity. There is no single figure that describes the amount of development or use a lake can accommodate. Much depends on the type of lake, the nature of present development (in the watershed as well as on the shoreland), and the objectives of the local community. Using water quality models, a community may effectively evaluate individual lakes in relation to the effects of cumulative development.

Lakes, like other ecological systems, do not have an unlimited capacity to incorporate changes due to increases in recreational activities, housing development, and other human endeavors. At some level of development, lake resources will become strained to their limit. Beyond that point, the resources, along with user satisfaction, will begin to decline. Intuitively, the shoreland user may recognize that limits do exist. Evidence of deterioration is readily apparent, portrayed in weed-choked lakes, crowded, poorly maintained shoreland development, and declining fishing success, among other things.

The potential for exceeding resource limits is inherent in the lake watershed as well as in the lake. The soil characteristics of the watershed and the size of the lake in relation to the watershed are among the factors that govern the amount and quality of runoff flowing into the lake. The depth of the lake, water quality, and hydrologic residence time all mitigate the impact of added pollution. In general, as depth decreases and retention time increases, the lake can tolerate less nutrient loading. For example, lakes in western and southern Minnesota, where runoff rates are low, usually have lower flushing rates and, therefore, require longer periods of time to recover from most types of pollution than do lakes in the northeastern portion of the state.

Effects of Excessive Development

Because each lake has its own development capacity, the issue of limits may not be well addressed by statewide minimum standards. Current shoreline regulations govern certain features of development such as sanitary and waste disposal facilities, the frontage of lots, the placement of structures, the alteration of vegetative cover, and the subdivision of shoreland areas. These regulations are intended to prevent the immediate and dramatic effects of erosion and pollution runoff. They do not, however, focus on the actual amount of development that a specific lake can accommodate. Indeed, current shoreland standards may allow development that exceeds a lake's resource limit.

Excessive lake development has been shown to have a negative impact on local economy. There are only a few studies that have specifically examined the effects of water quality change on residential property values or lake-oriented businesses. In St. Albans Bay State Park on Lake Champlain, Vermont, the decline in visitors due to water quality deterioration led to the closing of the park. A study of the situation led to the conclusion that the value of seasonal properties adjacent to the Bay were depressed by approximately twenty percent, compared to the value of similar properties located near the Bay on the cleaner main lake basin. Using an economic model, researchers projected the benefits of water quality improvement. According to the model, improvement of the St. Albans Bay water quality to a level equivalent to the main lake basin could result in a property value increase of approximately two million dollars (an average of $4500 per property).

The above figures reflect only the benefits to individual property owners. Any improvement in the water quality would also be expected to increase the number of visits to the park, benefiting lake-oriented businesses. According to the St. Albans Bay study, visits would increase by 4932 per year, including both current users and users who might recreate in the Bay if the water quality were improved. In a similar study, researchers using a demand price model concluded that if Pike Lake, Wisconsin were improved, annual benefits from increased visits would be $38,964.

The principal water quality problems of excessive development result from sedimentation and nutrient loading. Poor agricultural cropping practices and the exposure of raw earth during land development and road construction can cause sediment infilling. Nonpoint sources of nutrients include rainfall, septic systems, lawns, runoff from agricultural land, logging operations and construction sites, and runoff from rooftops, driveways, roads, or other impervious surfaces. These pollution problems are intensified as shoreland densities increase and more land is made impermeable.

Pollution problems may be further aggravated by nonconforming or inadequate sewage treatment systems. Failing or improperly designed, installed, or maintained septic systems can be a major source of nutrients to a lake. The original capacities of the sewage treatment systems may not be enough to accommodate large numbers of visitors or conversions to more intensive developments.

Water quality models use existing water quality to establish trends and assess the impacts of future development. Using water quality models, a community may estimate the amount of nutrients being contributed by activities in the watershed and may evaluate the need to control development, not only on the lakeshore, but throughout the entire watershed.

It should be noted that a solid understanding of the individual factors affecting capacity requires more than a one-time appraisal of lake and watershed characteristics. Lake ecosystems are in constant flux and water quality problems are compounded by multiple use. Identifying a lake's resource limits can be a lengthy procedure, though not an impossible one.

Resource Capacity and Recreational Use

Every lake has both an ecological and a social carrying capacity. The social carrying capacity is a measure of the amount of recreational use that people will tolerate. Use or development limits are defined on the basis of user perceptions (of crowding) and safety factors. While this handbook does present approaches oriented to these social factors, their subjectivity makes them somewhat suspect as a basis for limiting development. The perception of crowding, in many instances, has more to do with the behavior of users or the nature and quality of the development than with any easily definable amount of use that is considered excessive. It should be emphasized that a community's resources and efforts would be better directed toward assessment of ecological limits and prevention of water contamination or habitat loss.

Models and Community Objectives

A model is not an end in itself. As a representation that is used to analyze and predict the behavior of a system such as a lake/watershed, a model is only a tool to use in seeking solutions to problems. Models are part of a continuing process of monitoring lake and watershed activities. They do not make decisions regarding a lake's use and character, nor do they replace management efforts necessary to insure a lake's quality. They are simply an aid to decision making.

Models can be used only to estimate the point at which intended uses of the lake are no longer possible. The community itself must determine whether its priority is to maintain particular water quality standards, types of fish populations, or characteristics of the shoreland habitat. It is important to remember that water quality requirements differ depending on the objectives of the lake users. For instance, swimmable water, generally unproductive and free of vegetation, does not make good fishing water.

All of this suggests the need for a community to clarify its objectives and then analyze the current state of the lake and any existing water quality and user trends in light of these objectives. It is possible that the assessment of a situation will reveal that no problem exists. If the current status meets the requirements of the objectives, then no action need be taken. If, however, lake carrying capacity is being exceeded, either the objectives will have to be changed or development limits which eliminate particular sources of pollution or user conflict, affect water quality changes, and improve existing lake and shoreland quality will have to be considered.

A discussion of this strategy, using the more promising models available is in the lake modeling section of this handbook. Evaluations of the models are based on the data required, the availability of that data in Minnesota, the usefulness of the results, and the applicability to Minnesota's lake problems.

RECREATIONAL CARRYING CAPACITY

The idea of recreational carrying capacity applies to lake surface use in a manner apart from the impact of recreation on the physical features of a lake watershed. The amount of recreational use a lake receives directly influences user satisfaction. Implied in the term are user safety and the level of pleasure that users attain from the lake resource. Because both safety and pleasure are, to a great degree, matters of individual perception, recreational carrying capacity is difficult to quantify and define by set rules. This section is a review of possible recreational limits presented within the context of user perception.

A Selective Look At Boating Patterns And Boater Attitudes In Three Minnesota Lake Regions

Knowledge of existing conditions and trends can be used to identify possible problems in lake use. The following is condensed from a report prepared by the DNR Office of Planning. It gives baseline information, along with regional variations, on current boating use on Minnesota lakes and provides an idea of how development trends translate into lake use trends. This study was based on regional boating surveys, which were conducted for the DNR Boating Safety Program and Trails and Waterways Unit, and which were paid for out of boating gas tax receipts. Further information about this study or about the regional boating surveys may be obtained by contacting the Office of Planning, Research Unit.

Regional Patterns of Boating Use

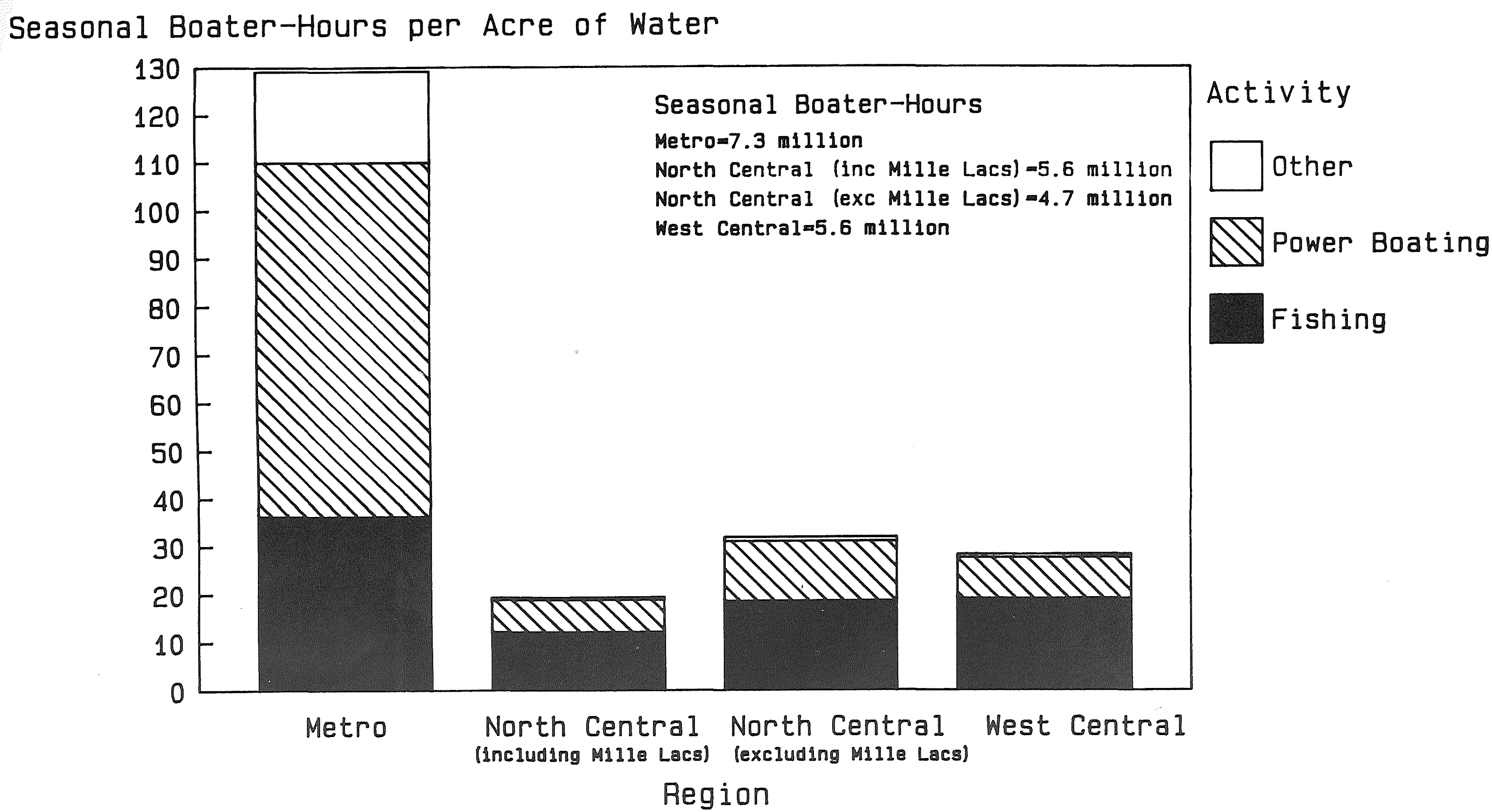
Metropolitan lake use differs from non-metropolitan lake use. The intensity of metropolitan boating exceeds that of other regions by at least a factor of four (Figure 1). High boating densities in the north and west central lake regions are low by metropolitan standards (See Map 1 for location of lake regions).

Metropolitan use is dominated by power boating (Figure 1). Fishing dominates lake use in the north and west central regions. Even though fishing is a secondary activity on metropolitan lakes, metropolitan fishing pressure is about double that of the other regions. The two outstate regions exhibit similar patterns, both in terms of intensity of boating use and in terms of mix of activities.

Boaters gain access to metropolitan lakes in about equal portions from public accesses, marinas and riparian residences (Figure 2). Public access users spend just over half their boating time fishing. Their contribution to metropolitan fishing pressure exceeds that of marina and riparian residential users combined. Power boating is, by far, the predominant activity of riparian residents. Marina users exhibit a comparatively even mix of activities among fishing, power boating and other activities, primarily sailing.

FIGURE 1 Regional Density of Seasonal Boating Use on Lakes by Activity

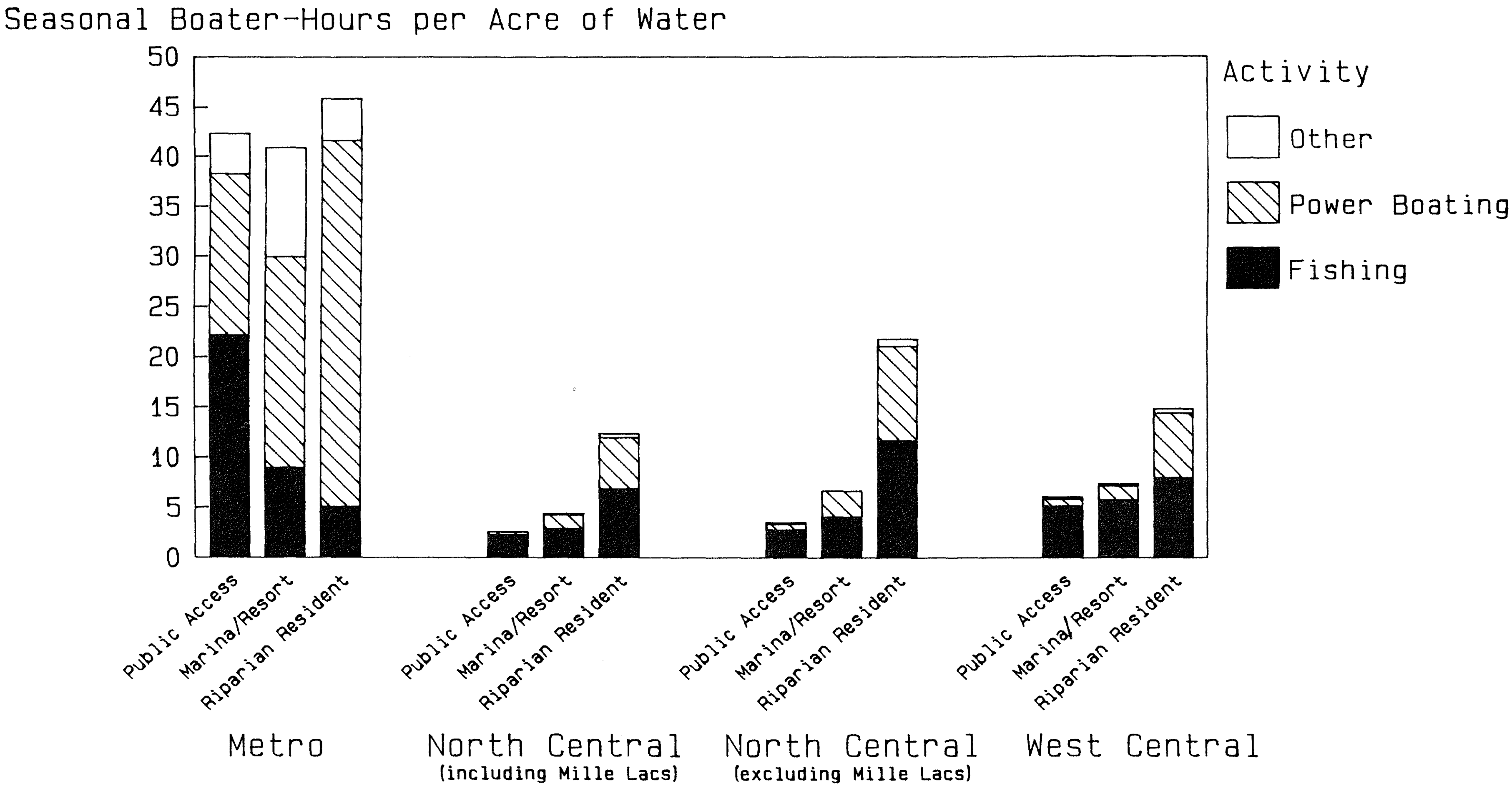
(Season extends from the Saturday of Memorial Day weekend to Labor Day)



Source: An Evaluation of Water Surface Use of Lakes in the Seven County Metropolitan Area (1984), in North Central Minnesota (1985), and in West Central Minnesota (1986). Evaluations conducted by Biocentric, Inc. under contract with the MN DNR.

FIGURE 2 Regional Density of Seasonal Boating Use on Lakes by Source of Use and Activity

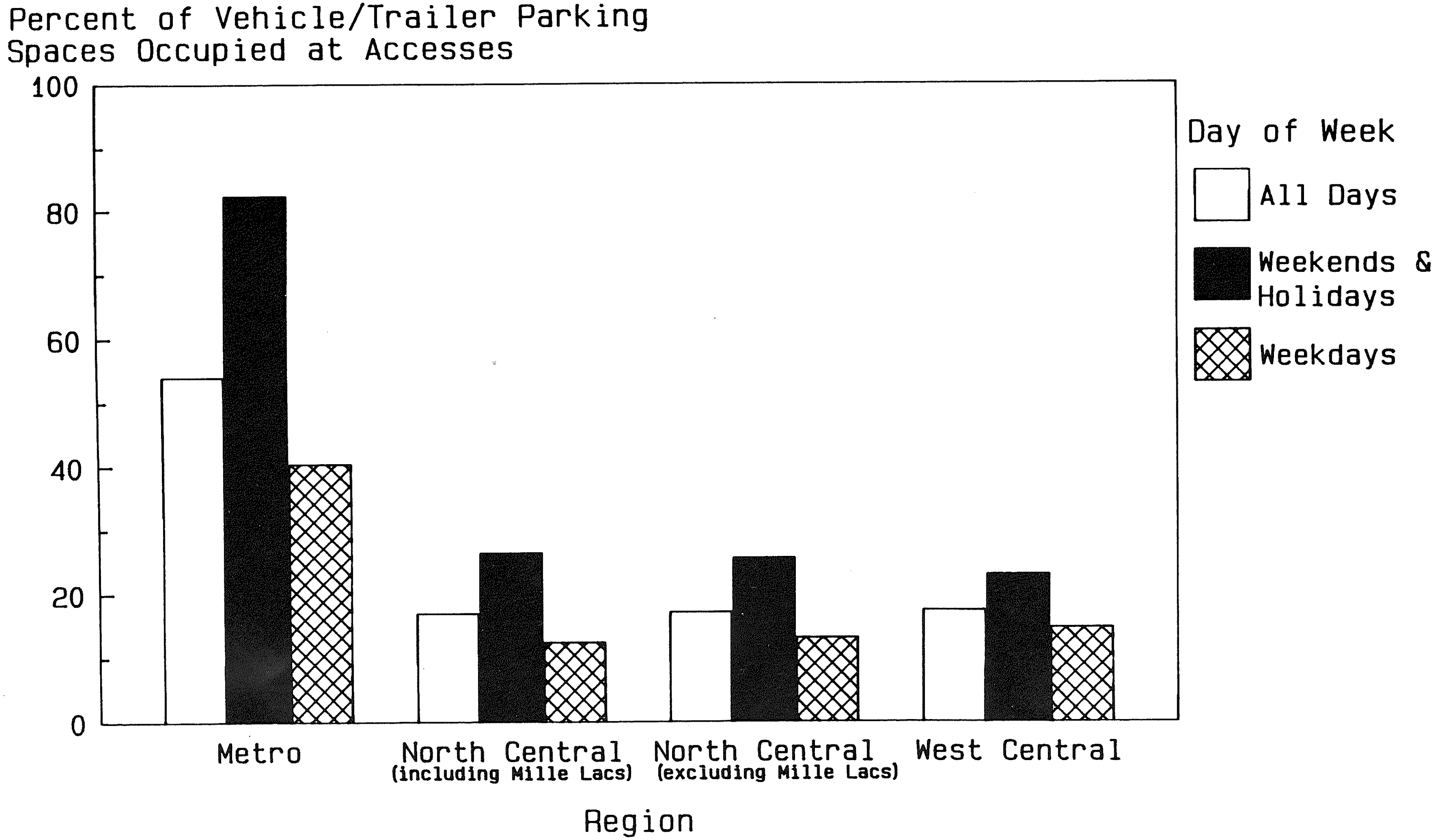
(Season extends from the Saturday of Memorial Day weekend to Labor Day)



Source: An Evaluation of Water Surface Use of Lakes in the Seven County Metropolitan Area (1984), in North Central Minnesota (1985), and in West Central Minnesota (1986). Evaluations conducted by Biocentric, Inc. under contract with the MN DNR.

FIGURE 3 Summer Afternoon Occupancy Rates of Public Water Access Parking Lots by Region and Day of Week

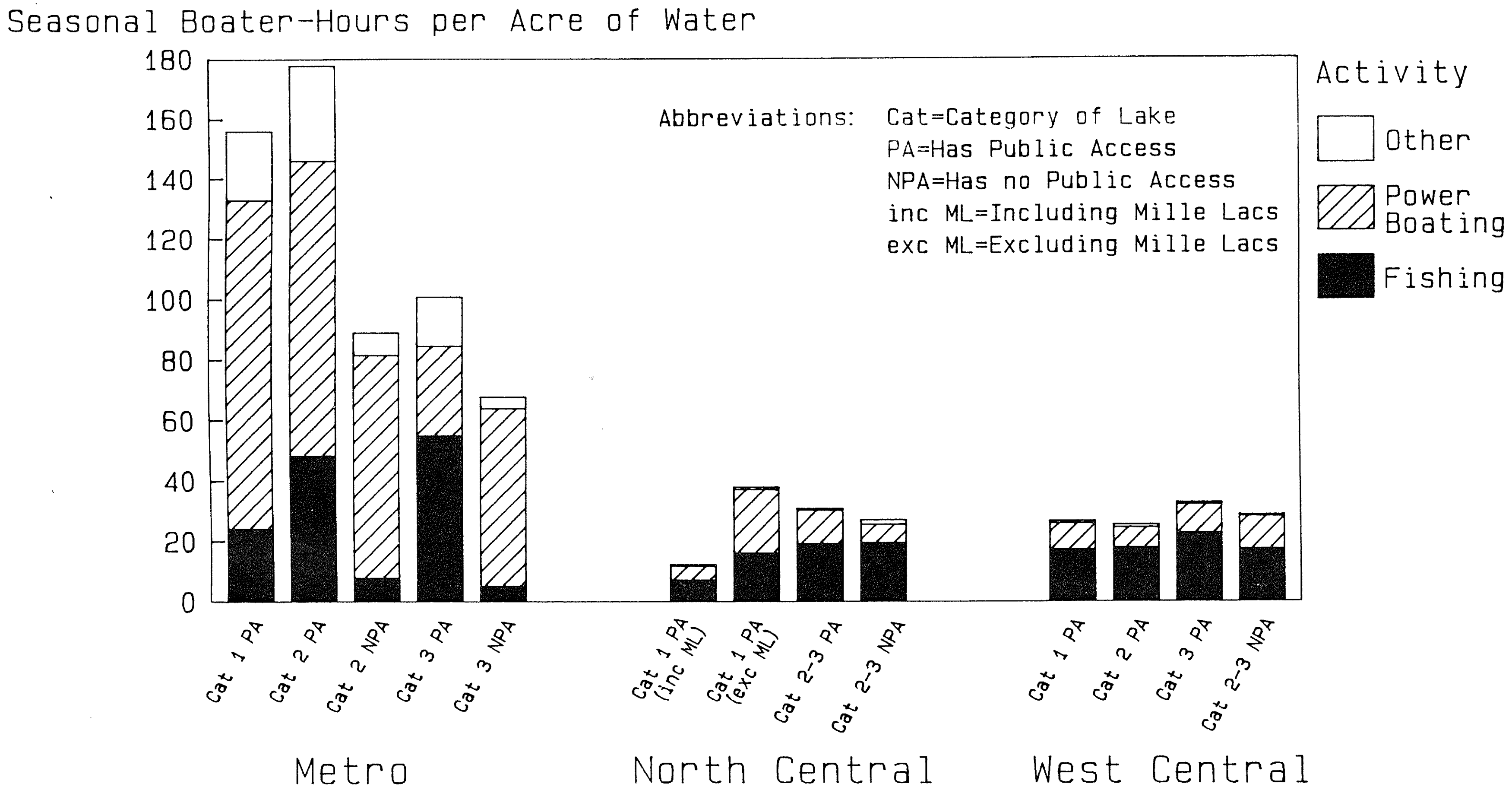
(Summer extends from the Saturday of Memorial Day weekend to Labor Day)



Source: An Evaluation of Water Surface Use of Lakes in the Seven County Metropolitan Area (1984), in North Central Minnesota (1985), and in West Central Minnesota (1986). Evaluations conducted by Biocentric, Inc. under contract with the MN DNR.

FIGURE 4 Regional Density of Seasonal Boating Use on Lakes by Category of Lake and Activity

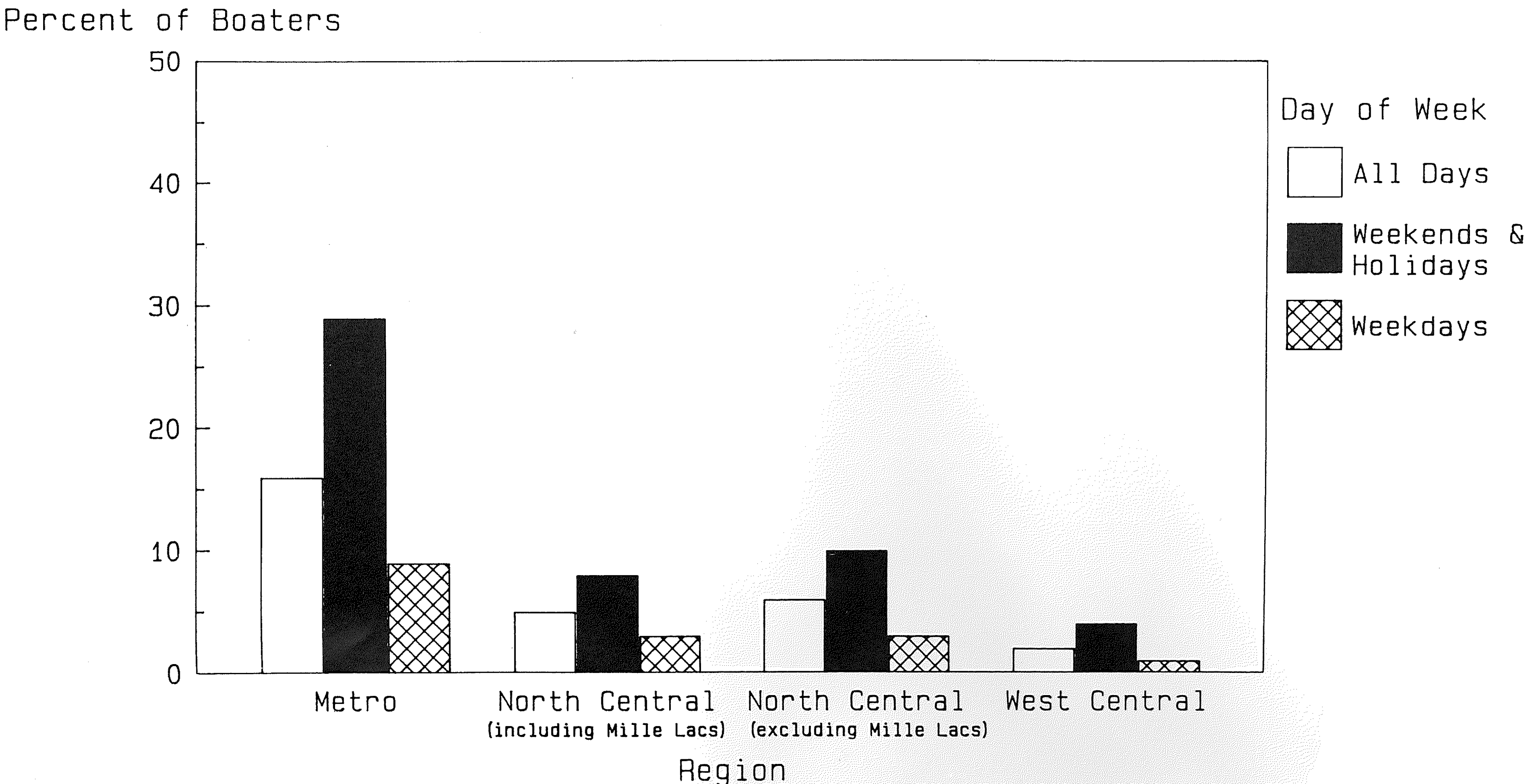
(Season extends from the Saturday of Memorial Day weekend to Labor Day)



Source: An Evaluation of Water Surface Use of Lakes in the Seven County Metropolitan Area (1984), in North Central Minnesota (1985), and in West Central Minnesota (1986). Evaluations conducted by Biocentric, Inc. under contract with the MN DNR.

FIGURE 5 Percent of Summer Boaters Judging the Number of Boats on the Lake as "Crowded" or "Too Crowded" for Safety by Region and Day of Week

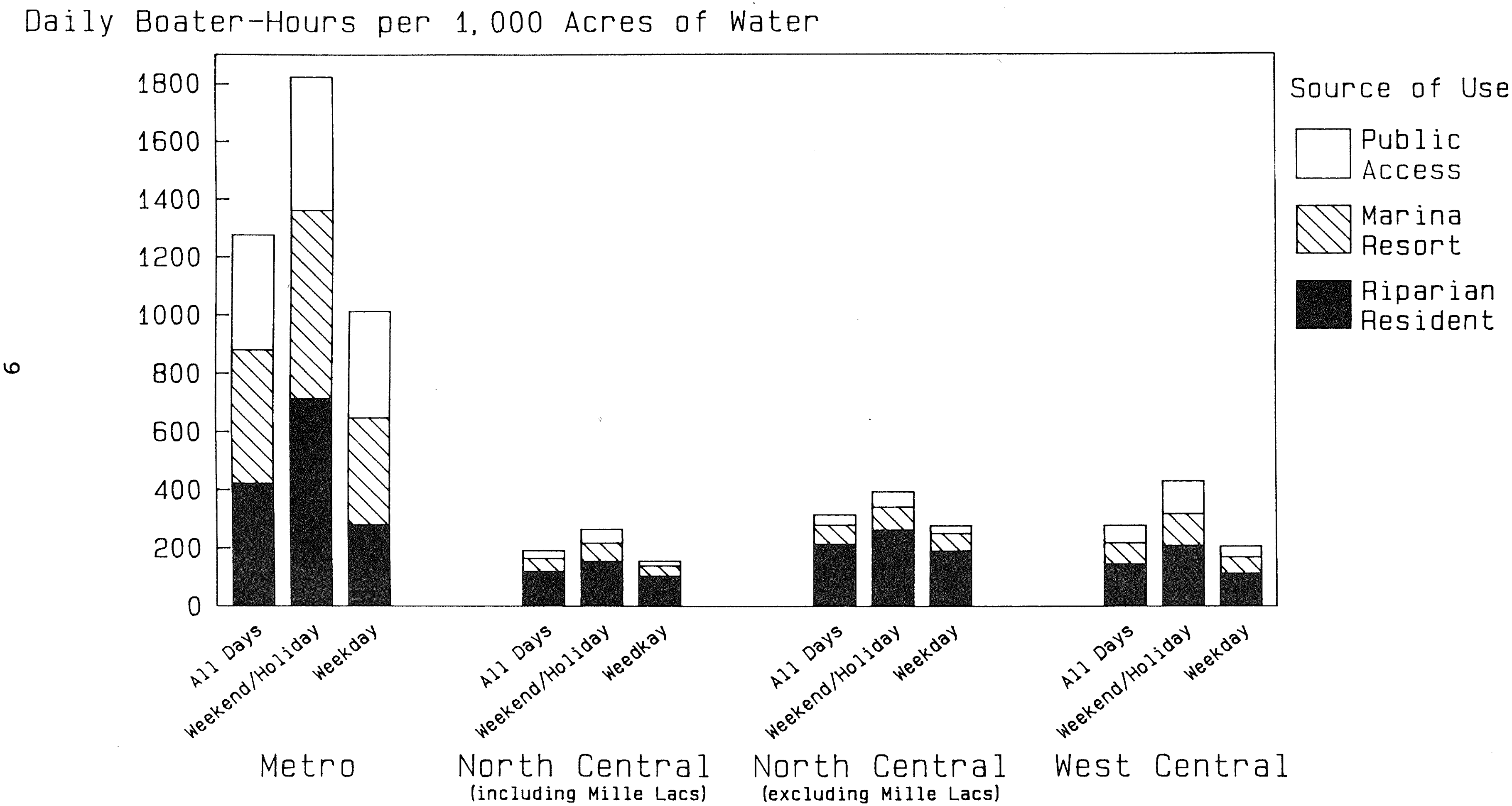
(Summer extends from the Saturday of Memorial Day weekend to Labor Day)



Source: An Evaluation of Water Surface Use of Lakes in the Seven County Metropolitan Area (1984), in North Central Minnesota (1985), and in West Central Minnesota (1986). Evaluations conducted by Biocentric, Inc. under contract with the MN DNR.

FIGURE 6 Regional Density of Seasonal Boating Use on Lakes by Day of Week and Source of Use

(Season extends from the Saturday of Memorial Day weekend to Labor Day)



Source: An Evaluation of Water Surface Use of Lakes in the Seven County Metropolitan Area (1984), in North Central Minnesota (1985), and in West Central Minnesota (1986). Evaluations conducted by Biocentric, Inc. under contract with the MN DNR.

Patterns are different among sources of users in the non-metropolitan lake regions. There, riparian residents are the primary source of boating use, accounting for a least half of total use (Figure 2). Riparian residents split their activity time about equally between fishing and power boating, making them the principal source for each activity. The second largest source of boaters is marinas and resorts (including private campgrounds). Public accesses are the smallest source of boaters. Both public access and marina/resort users allocate the bulk of their activity time to fishing.

The relatively small contribution of public access to boating use in the north and west central regions is not due, in any region-wide sense, to a shortage of public access facilities. Existing public accesses are not typically crowded. There are sufficient public accesses in each of the outstate regions to accommodate greater use. If public accesses in the north and west central lake regions were used at metropolitan intensities, boating through public accesses would about triple (Figure 3).

Because of the high usage rates of public accesses in the metropolitan area, lake boating levels increase when adequate public access is provided. The average increase in boating due to public access is about 100% for lakes in the urbanized area of the metropolitan region (on Figure 4, compare Category 2 PA lakes with Category 2 NPA lakes), and about 50% for lakes in rural parts of the metropolitan region (on Figure 4, compare Category 3 PA lakes with Category 3 NPA lakes). Fishing accounts for the major share of increased use due to the provision of public access.

In contrast to the metropolitan region, intensity of surface use is not noticeably affected by public access availability in the north and west central lake regions (on Figure 4, compare PA with NPA lakes in the same category of lakes). Any effect of public access is washed out, apparently, by low access usage rates and the concomitant elevation in the influence of marina/resort and riparian residential sources on determining lake use levels.

Also in contrast to the metropolitan region, there are no major variations in use intensity among categories of lakes in the two outstate regions. Because of the correspondence between outstate lake categories and shoreland zoning classes, changes among zoning classes, by themselves, have no noticeable effect on lake use intensity.

Boater Perception Of Water Surface Crowding

The three lake region studies included a question that incorporates an aspect of the social limits to water surface use. Boaters were asked how crowded they felt the lake was for boating safety during their most recent outing. Response categories were "few boats," "about the right number of boats," "crowded," and "too crowded."

Results from the crowding question are consistent, in a general fashion, with patterns of boating density:

- Boaters in the metropolitan area, where boating densities are higher (Figure 1), are much more likely than boaters in the north and west central lake regions to perceive the number of boats as "crowded" or "too crowded" for boating safety (Figure 5).
- Within each region, boaters on weekends -- when boating densities are higher (Figure 6) -- are much more likely to perceive "crowded" or "too crowded" conditions than boaters on weekdays (Figure 5).

It needs to be stressed that most boaters, especially those in the north and west central regions, do not perceive lakes as overused from a safety standpoint. Even for metropolitan weekend boaters, the large majority of users do not perceive "crowded" or "too crowded" conditions for boating safety (Figure 5). On outstate lakes, over 90% of boaters perceive the number of boats as "few boats" or "about right" on weekends and weekdays.

Water Surface Use Restrictions

To measure boater awareness of water surface use restrictions, boaters were asked the question "What special boating use restrictions are there for this lake?" Responses indicated that boaters were most likely to have correct knowledge of a specific restriction when that restriction was of the wake or lake area type which is generally of high visibility and regularly posted on signs. Time restrictions were the least correctly identified type of restriction.

Demand for surface use restrictions was determined by analyzing boater responses to the question "What special boating use restrictions do you feel are needed on this lake?". Responses were analyzed by lake region, source of use, activity, day of week, boating density, and boater's perception of crowding.

Fifty-two percent of the metropolitan boaters and 36% of the north central boaters wanted specific use restrictions. Only 10% of the west central boaters requested use restrictions. In the metropolitan and north central regions, lakeshore residents and marina/resort users were more likely to ask for use restrictions than were public access users. In the west central region lakeshore residents, marina/resort users and public access users were similar in their requests for use restrictions. In all three regions, boaters who perceived the lake as being "crowded" or "too crowded" for safety were more likely to request use restrictions than boaters who perceived the number of boats on the lake as "few" or "about right" (Figure 7). It should be noted, concerning Figure 7, that only a small minority of boaters perceived conditions as "crowded" or "too crowded", which is why the first two bars for each region are nearly the same height. In all three regions there was little difference in requests for use restrictions based on activity (fishing, power boating, other), day of week (weekday, weekend/holiday), or "typical" boating density.

For all three regions, frequently requested restrictions were speed/wake, boat type/size, horsepower, and area of the lake (Figure 8). In the metropolitan region, increased enforcement of existing restrictions was also frequently requested. Time was frequently requested in the north central region. Skiing was frequently requested in the west central region. Other restrictions requested included distance from shore/docks/other boats, drinking, noise, and boat operator licensing and education courses.

Simulation Model: Impact Of Riparian Development On Water Surface Use In Non-metropolitan Areas

The lake region studies collected the information needed to develop a model to simulate water-surface use levels from different types and quantities of riparian development in non-metropolitan Minnesota. The specific question the simulation model is designed to answer is: How much water-surface use is generated by a specified amount of public water access development, resort/private campground development, and shoreland residential development? Through application of the model, which is written as an interactive computer program, the user can gain a perspective on boating levels that would result from fully developing a lake according to different shoreland zoning standards and public access policies.

The principal strength of the model is that it is based on the observed (not assumed) use by boaters of different types of riparian development to gain access to the lake. This basis for the model is problematic, too, because it means that the model's range of applicability is implicitly specified by the conditions in which the model was developed. Those conditions are not well known, except that they existed and operated during the two outstate studies. Care, therefore, should be taken to ensure that the model is not applied to times or places markedly different from those in which it was formulated.

To develop the simulation model, information was pooled from the north central (excluding Mille Lacs) and west central studies because there were no major differences between the regions. Major differences, however, were found between riparian development types and between weekends/holidays and weekdays (See Figure 9). The values on figure 9 are the foundation of the model.

The simulation model is an interactive computer program written in BASIC and currently on an IBM XT. It asks the user for the following items (see Table 1: "Sample Run of Simulation Model"):

1. Shoreland Zoning Class: this is used to inform the user of the number of housing units the shoreline could have at the zoning minimums.
2. Lake Acres: this is used to normalize boating amounts and to inform the user of the maximum number of parking spaces public access policy tries to provide.
3. Shoremiles: used with item 1.
4. Public access vehicle/trailer parking spaces.
5. Resort lodging units and private campsites with private water access.
6. Riparian housing units.

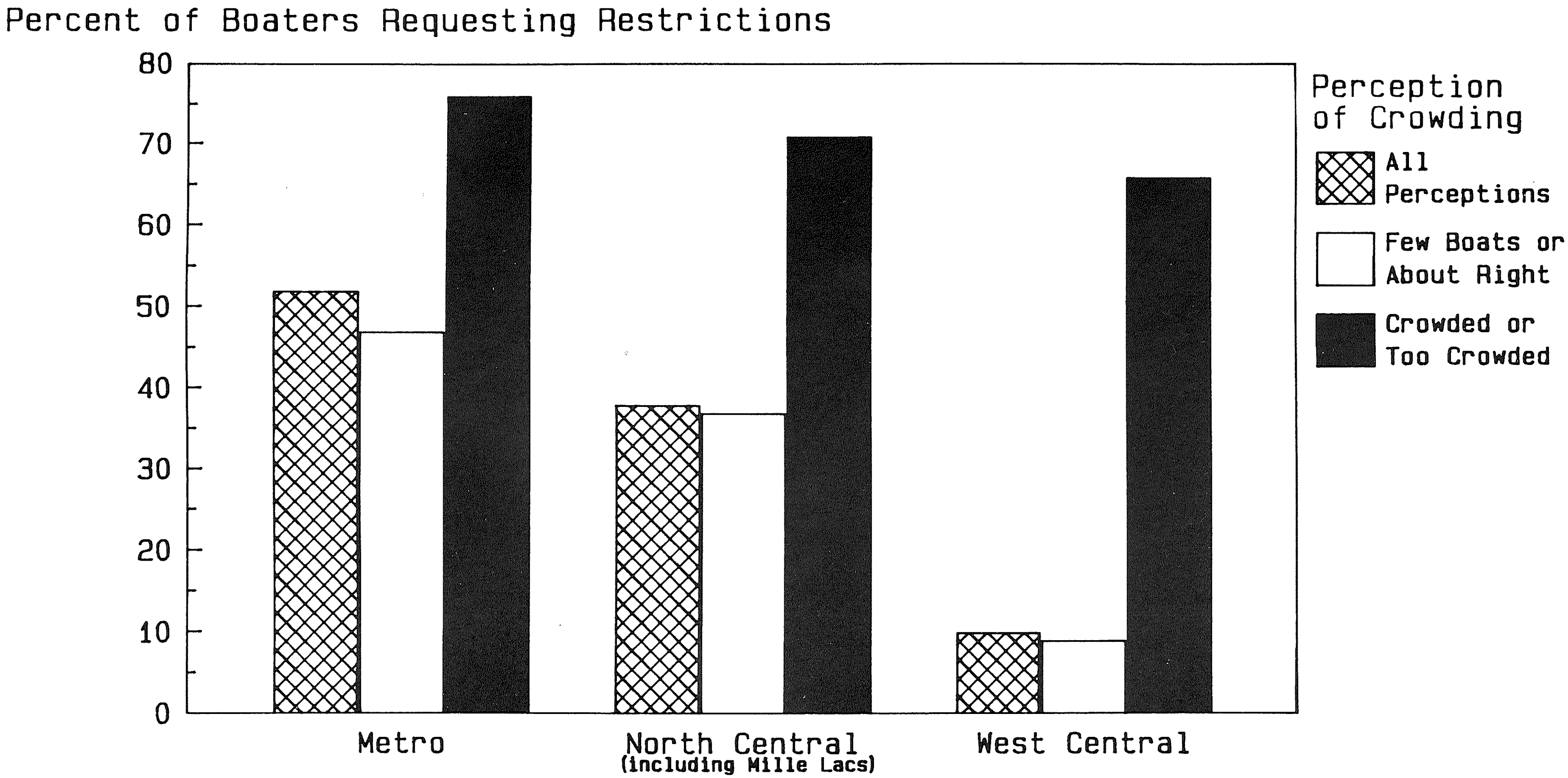
In the model, development items 4, 5, and 6 are multiplied by corresponding average daily boat-hour values on Figure 9, and then distributed by hour according to profiles for each type of riparian development and day ow week. High and low values, one-third above and below the Figure 9 averages, are carried along in the computations to provide high and low estimates. Next, boat-hours are multiplied by the number of boat occupants for each type of riparian development and day of week. This gives boater-hours, or people-boat-hours. Last, boater-hours are distributed according to profiles of major activities (fishing, power boating, other) for each type of riparian development.

Seasonal amounts are produced from the preceding daily amounts by multiplying the weekend/holiday figures by the number of summer weekend/holidays (=33) and the weekday figures by the number of summer weekdays (=68).

There are 3 screens of output from the simulation model (see Table 1). The first screen displays hourly boat totals per 10 acres of water surface for a typical summer weekend, weekday and average day. It can be inspected for peak times and amounts of boating. Screen 2 displays daily boater-hours by source of use and day of week, normalized by thousands of acres, and seasonal boater-hours, normalized by acres. Screen 3 is the activity equivalent of Screen 2.

FIGURE 7 **Requests by Summer Boaters for Water Surface Use Restrictions by Region and Boater's Perception of Crowding for Boating Safety**

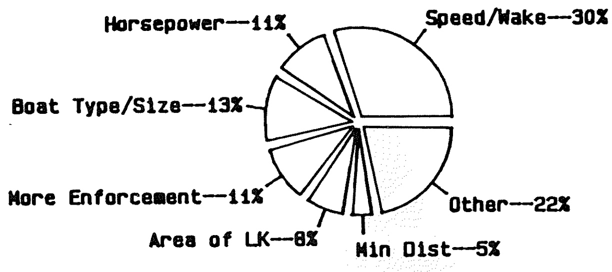
(Summer extends from the Saturday of Memorial Day weekend to Labor Day)



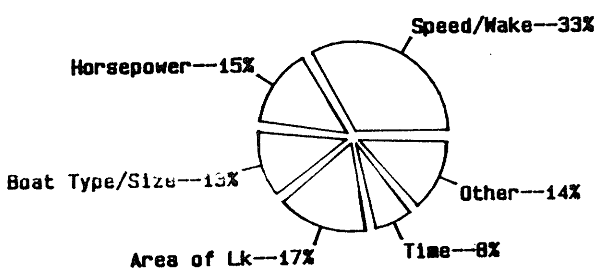
Source: An Evaluation of Water Surface Use of Lakes in the Seven County Metropolitan Area (1984), in North Central Minnesota (1985), and in West Central Minnesota (1986). Evaluations conducted by Biocentric, Inc. under contract with the MN DNR.

FIGURE 8 **Requests by Summer Boaters for Water Surface Use Restrictions by Region and Type of Restriction**

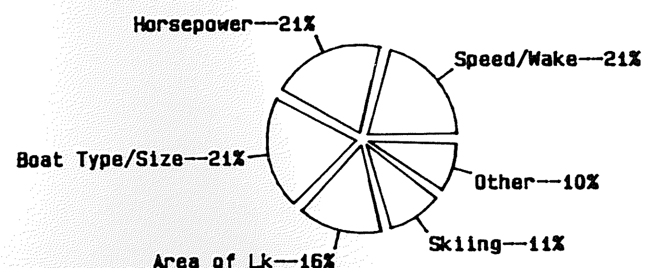
(Summer extends from the Saturday of Memorial Day weekend to Labor Day)



Metro
(52% requested restrictions)



North Central
(including Mille Lacs)
(38% requested restrictions)



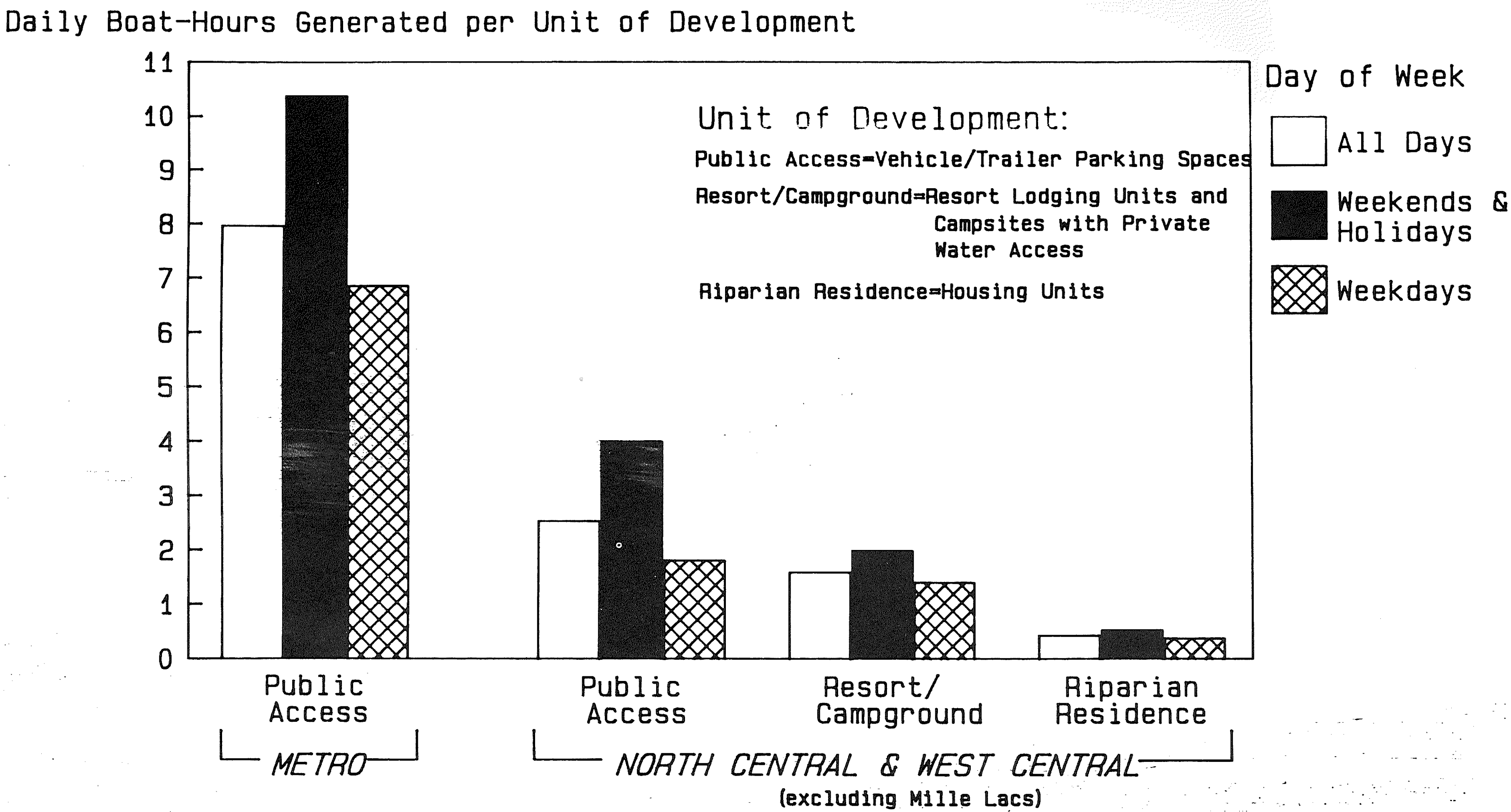
West Central
(10% requested restrictions)

Source: An Evaluation of Water Surface Use of Lakes in the Seven County Metropolitan Area (1984), in North Central Minnesota (1985), and in West Central Minnesota (1986). Evaluations conducted by Biocentric, Inc. under contract with the MN DNR.

Note: Restrictions labelled individually were specified by at least 4% of boaters who requested restrictions; remaining restrictions are in the 'Other' category.

FIGURE 9 **Average Daily Boat-Hours Generated Per Unit of Development During Summer by Region, Type of Development and Day of Week**

(Summer extends from the Saturday of Memorial Day weekend to Labor Day)



Source: An Evaluation of Water Surface Use of Lakes in the Seven County Metropolitan Area (1984), in North Central Minnesota (1985), and in West Central Minnesota (1986). Evaluations conducted by Biocentric, Inc. under contract with the MN DNR.

TABLE 1 SAMPLE RUN OF SIMULATION MODEL

```
RUN
                    ***** RUNNING *****
Zoning class (1=GD,2=REC,3=NE)? 1
Acres? 500
Shore miles? 5
Public access spaces (max =  25 )? 25
Resort units / campsites with private water access? 0
Riparian resident housing units (max =  264 )? 264
```

USER RESPONSES TO MODEL QUERIES

BOATS PER TEN ACRES

HR	WEEKENDS HIGH	WEEKENDS MED	WEEKENDS LOW	WEEKDAYS HIGH	WEEKDAYS MED	WEEKDAYS LOW	AVERAGE DAY HIGH	AVERAGE DAY MED	AVERAGE DAY LOW
6	0.05	0.04	0.03	0.03	0.02	0.01	0.04	0.03	0.02
7	0.12	0.09	0.06	0.08	0.06	0.04	0.10	0.07	0.05
8	0.20	0.15	0.10	0.16	0.12	0.08	0.17	0.13	0.09
9	0.27	0.20	0.14	0.23	0.17	0.11	0.24	0.18	0.12
10	0.36	0.27	0.18	0.29	0.22	0.15	0.31	0.24	0.16
11	0.44	0.33	0.22	0.32	0.24	0.16	0.36	0.27	0.18
12	0.45	0.34	0.22	0.30	0.23	0.15	0.35	0.26	0.18
13	0.53	0.40	0.26	0.28	0.21	0.14	0.36	0.27	0.18
14	0.66	0.50	0.33	0.31	0.23	0.15	0.42	0.32	0.21
15	0.70	0.53	0.35	0.34	0.25	0.17	0.46	0.34	0.23
16	0.64	0.48	0.32	0.33	0.25	0.17	0.43	0.32	0.22
17	0.52	0.39	0.26	0.28	0.21	0.14	0.36	0.27	0.18
18	0.46	0.34	0.23	0.28	0.21	0.14	0.34	0.26	0.17
19	0.45	0.33	0.22	0.31	0.23	0.15	0.35	0.26	0.18
20	0.37	0.28	0.18	0.26	0.20	0.13	0.30	0.22	0.15
21	0.23	0.17	0.11	0.16	0.12	0.08	0.18	0.14	0.09
22	0.09	0.07	0.05	0.05	0.04	0.03	0.07	0.05	0.03

Strike any key to continue

OUTPUT SCREEN 1

***** RUNNING *****

PEOPLE-BOAT-HOURS

SOURCE	WEEKEND HOURS / 1000 ACRES - HIGH-	MEDIUM	- LOW -	PERCENT (HIGH, MED, LOW)
PUBLIC ACCESS	701	526	351	38.4
MARINA/RESORT	0	0	0	0.0
RESIDENT	1127	845	563	61.6
TOTAL	1828	1371	914	100.0

SOURCE	WEEKDAY HOURS / 1000 ACRES - HIGH-	MEDIUM	- LOW -	PERCENT
PUBLIC ACCESS	314	236	157	31.1
MARINA/RESORT	0	0	0	0.0
RESIDENT	696	522	348	68.9
TOTAL	1010	757	505	100.0

SOURCE	SEASONAL HOURS / ACRE - HIGH-	MEDIUM	- LOW -	PERCENT
PUBLIC ACCESS	44	33	22	34.5
MARINA/RESORT	0	0	0	0.0
RESIDENT	84	63	42	65.5
TOTAL	129	97	64	100.0

Strike any key to continue.

OUTPUT SCREEN 2

*****RUNNING*****

PEOPLE-BOAT-HOURS

ACTIVITY	WEEKEND HOURS / 1000 ACRES - HIGH-	MEDIUM	- LOW -	PERCENT (HIGH, MED, LOW)
FISHING	1094	821	547	59.9
BOATING	664	498	332	36.3
OTHER	69	52	35	3.8
TOTAL	1828	1371	914	100.0

ACTIVITY	WEEKDAY HOURS / 1000 ACRES - HIGH-	MEDIUM	- LOW -	PERCENT
FISHING	700	525	350	69.3
BOATING	293	220	147	29.1
OTHER	16	12	8	1.6
TOTAL	1010	757	505	100.0

ACTIVITY	SEASONAL HOURS / ACRE - HIGH-	MEDIUM	- LOW -	PERCENT
FISHING	84	63	42	64.9
BOATING	42	31	21	32.5
OTHER	3	3	2	2.6
TOTAL	129	97	64	100.0

Strike any key to continue.
Ok

OUTPUT SCREEN 3

Social Limits

Defining social limits to carrying capacity is problematic. It is difficult, first, because limits defined by social preferences are not as easily defended as limits defined for ecological reasons. People are likely to disagree about the appropriate types and densities of development and also about recreational use limits. Conflict exists among recreational users. Resolution of the conflict through use limits generally prevents unrestricted use by any particular group such as boaters, shoreland owners, or public access users. Some recreational models are based on the existing mix of uses or the dominance of certain uses. Other models alter existing patterns of use according to equity or economic criteria. This usually means allocating the maximum allowable number of boats among different types of users.

Secondly, social limits are defined on the basis of debated research. To a great extent, recreational conflict arises from the different expectations and tolerances of individual users. Examples of the survey techniques used to examine these perceptions of crowding will be presented in the body of this section. These models are largely experimental and their value to the decision-making process has yet to be proved. Furthermore, the perception of crowding may be tied more to personal opinions about appropriate behavior and development than to actual user densities.

Limits based on notions of safety, rather than perception of crowding, have not been established. Standards for safe boating capacity vary greatly and were developed without consideration of important individual factors that affect safety such as patterns of use, shape of the lake, or types of use regulations. They also require that assumptions be made concerning the proportion of the boating capacity to be allocated to public users and shoreland owners.

It is unclear how development limits based on use patterns can be institutionalized. Current legislation sets broad terms for safe lake use such as boat equipment requirements, rules of the road, or prevention of negligent operations. Communities may have difficulty defending their decisions to interpret enabling legislation in ways that would prohibit incompatible mixing of uses, allocate all or parts of the lakes to the most appropriate use, or restrict the intensity of use.

Recreational capacity is, necessarily, a social, not a technical issue. Communities cannot base decisions on objective models of social limits in the same way that they can with models of physical limits. Physical limits also involve social objectives or priorities, but recreational capacity models are much more encumbered with qualifications which must be discussed completely before using the models.

It is quite possible that a crowding problem does not really exist. For example, one conclusion of the boating pattern study presented earlier was that public accesses in the regions studied were generally used below capacity, contrary to the commonly-held impression. Public accesses on lakes in the north and west central regions of Minnesota contribute a relatively small amount to the total boating use in those areas. This is not due to the lack of public access facilities; there is sufficient access outstate to accommodate greater use. The study concludes that the intensity of surface use outstate is "not noticeably affected by public access availability." However, this situation is not the same for metropolitan area lakes where lake boating levels increase substantially when adequate public access is provided.

In the same study, boaters were asked how crowded they felt the lake was for boating safety. The majority of surface users, even in the high boating density metropolitan area, do not perceive conditions that are "crowded" or "too crowded" for boating safety. The study also suggests that riparian residents are more likely to perceive crowding on the lake than do non-riparian users.

The boat density standard (or boating capacity of the lake) is one answer to access and use conflicts. The solution must also include an inventory of public and private access use, policy decisions about the proportional use from private, public, and commercial sources, review of enforcement, and an assessment of ancillary facilities for the boating public. Actual use conflicts, water surface zoning, and patterns of lake use (peak times, origin of boaters, and use of other lakes) must be monitored and evaluated.

The Lake Minnetonka Conservation District has completed a preliminary study aimed toward developing a comprehensive lake management plan for Lake Minnetonka. The study addresses ten separate areas of interest , identifies issues related to each area, and suggests further work necessary to alleviate surface use problems. Topics of interest covered in the study are:

1. Lake access
2. Lake use
3. On-shore related facilities
4. Public safety
5. Shoreland aesthetics
6. Upland environmental protection
7. Water quality
8. Intergovernmental relations
9. Institutional arrangements
10. Funding alternatives

The Lake Minnetonka study is a good starting point for making management decisions because it clarifies the current lake status relative to user objectives. The next step is to estimate the amount of use that can be permitted on the lake. Once determined, that figure may be equated with a level of development in the lake watershed.

The DNR boating patterns information was used to develop a model to estimate water-surface use levels which would result from different types (i.e. public water access, resort/private campground, or shoreland residential) and quantities of shoreland development in non-metropolitan Minnesota. The model is based on the observed behavior of boaters relative to development and has been described in greater detail in the previous section.

Recreational Safety

In clarifying the relationship between boating accidents and density, it is necessary to look at types of accidents and their causes. The Department of Natural Resources, Boat and Water Safety Section, annually compiles boating accident statistics, dividing them into two groups: fatal accidents and nonfatal accidents (occurrence of bodily injury or property damage).

Generally, most boating fatalities occur in small, open boats powered by outboard motors less than 40 horsepower or in nonpowered canoes. Fatalities on lakes commonly happen on calm water in clear weather and generally involve only one boat in a capsizing or fall overboard accident.

Most nonfatal boating accidents involve higher-powered craft (over 40 horsepower). Fires or explosions occur on inboard or stern drive craft when proper safety equipment maintenance or proper fueling procedures are not followed. Collisions occur between boats when operators do not pay attention to where they are going. Dock areas and narrow and difficult stretches of lakes are frequent locations of accidents.

One finding of the Lake Minnetonka Conservation District study was that unfamiliarity with rules of the road and the lake itself may be a cause of many public safety problems. Similarly, the DNR boating study indicated that 40-50% of metropolitan lakes' boaters were unaware of existing restrictions and that this percentage was even higher outstate.

The DNR discovered other relevant points about boating accidents. The use of alcohol was involved in a large percentage of boating accidents. In most cases, lifesaving devices were on board the craft but were not in use at the time of the accident. Half of the fatal accidents occurred when the water temperature was cold (less than 70 degrees F). Finally, the majority of boat operators involved in accidents had considerable experience using their craft, but had never taken a formal boating safety course.

A community concerned with safe water surface use should begin by developing an understanding of the known causes of accidents. It should be noted that behavioral factors are generally more responsible for causing boating accidents and injuries than is boat density. First and foremost, the community must strictly penalize alcohol use, disregard of safety procedures, and violations of rules and regulations for watercraft use. These are primary concerns that need to be addressed before strategies such as zoning can be effective in alleviating congestion and use conflicts.

Water Surface Use Management

Zoning is one of the most widely used but least understood management tools for water oriented recreation. The frequency of reported boat collisions, the injury of swimmers by boats, the competition of anglers and water skiers for use of the same area, and the expressed frustrations of canoers seeking quiet waters free of powerboat intrusions all reflect a lack of effective use of zoning.

Technological advances have compounded the problems of water resource administrators and users. Outboard motor and other marine engine manufacturers are packing more horsepower into lighter engines. Boats with lighter hulls move across the water at speeds comparable to automobiles on roads. The faster and larger boats become, the more surface acreage they require.

Minnesota statutes authorize county boards and cities to regulate by ordinance the surface use of lakes. Proposed ordinances must be approved by the Commissioner of Natural Resources (see Appendix). Factors to consider in preparing ordinances include the size and shape of the lake, accidents which have occurred, obstructions or hazards to navigation, existing lakeshore development, and current watercraft use patterns. Communities considering regulating surface use also may refer to surveys of crowding perception, examples of which are included in the next section. After analyzing their particular lake situation, communities may then consider one or more controls from the range specified in the regulations.

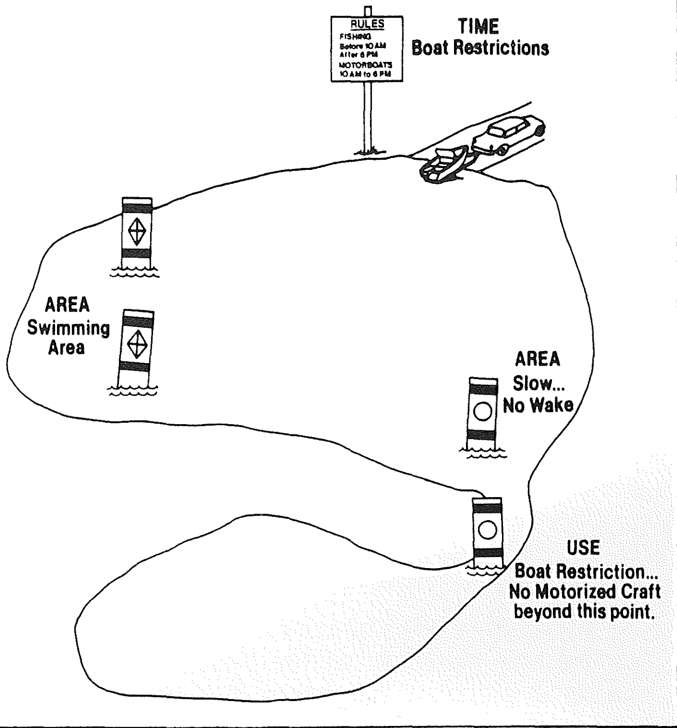
The Minnesota Water Surface Use Statutes and Rules detail three types of zoning: area, time, and use. Area zoning includes such diverse strategies as buoying off lakeshore swimming beaches and dedicating geographic areas such as the Boundary Waters Canoe Area (a unique example). Round Lake in Hennepin County has a designated ski zone. Foot Lake, Kandiyohi County, has a "no motorboats" area. Chanhassen's lakes in Carver County, certain lakes in Crow Wing and Murray Counties, and Bancroft Bay and Fountain Lake in Freeborn County are among those lakes which have speed zones in certain channels (See Figure 10).

Area zoning is most effective in small bays less than one mile long with a mouth less than a half mile wide. A line of demarcation can be made with markers on shore and buoys across the mouth. Marinas can be given adequate protection from wakes by the designation of "no wake" zones in small bays. Buoys are effective for indicating lake swimming areas.

Used improperly, area zoning can create more problems than it will solve. The purchase of markers, boats, buoys, signs, and literature, and the payment of salaries to enforce zoning regulations may be too expensive for the community. Also, even though maps may show lines of demarcation, people usually cannot estimate distances well enough to know exactly where the boundaries are.

Time zoning involves the allocation of portions of the day, night, or year for designated activities. For example, fishing and water skiing are conflicting uses. To eliminate friction, anglers may be required to use the lake in the morning and evening when the fish are usually active and water skiers may be limited to use during the day. Lake Marion in Dakota County has specified hours for water skiing. Time zoning is most effective on small lakes under conditions of strict control by law.

Figure 10. Types of Zoning.



The third type, use zoning, is frequently combined with area zoning. Many lakes prohibit certain activities or limit the boat size or engine horsepower. Several lakes in Anoka County, North Lake in Stearns County, and Lake Owatonna in Steele County do not permit motorboats. Little Bass Lake in Beltrami, Fish Lake in Le Sueur and certain lakes in Woodbury, Washington County, have a horsepower limit on motors. This type of zoning may be effective in eliminating some conflicting uses of water and providing users with a better experience. However, other lakes should be available within the region before use zoning is considered, since people desire a variety of water recreation opportunities.

Enforcement of speed limits may be difficult. The effectiveness of radar depends on its position relative to boats being monitored and also on the configuration and hull material of the boat. For instance, fiberglass, the principle material in most fast boats, does not reflect radar well. Accurate readings usually require that these boats be monitored from the rear. Speed is also a factor. Speeds greater than 10-20mph can be read accurately and readings in the range below 10mph are questionable.

Although considered to be only a temporary deterrent to resource overuse, zoning, for the reasons outlined above, may be the most socially feasible one. Zoning has, however, its limitations. For example, zoning can inadvertently create a false impression of poor fishery management by causing unequal fishing pressure. Zoning also requires that communications be established with the users. This can be done through boat registrations, issuance of boating regulations, brief written tests, and interpretive signs and talks. According to the DNR Office of Planning survey of boating patterns and boater attitudes, metropolitan public access users, marina users, and lakeshore residents are about equally aware of restrictions on the lakes they use. In the non-metropolitan region surveyed, public access users and marina users appeared to be much less aware of existing restrictions than were lakeshore residents. This suggests an inadequacy of information reaching non-riparian users outstate.

Zoning involves planning. Resources must be inventoried, zoning objectives clearly defined, land uses identified, the public educated, and political influences considered. Zoning also requires public input. One of the findings of the DNR boating survey was that boaters who requested restrictions on lake uses preferred speed/wake, horsepower, and boat type/size restrictions (see Figure 8). The perception of a need for zoning will vary, depending on the location of a lake and its amount of use. Boaters in the metropolitan region, where there is a high density of use, more frequently requested restrictions than did boaters in the north central and west central regions. With adequate knowledge and proper planning, zoning can be a powerful means for providing a variety of higher quality recreation, eliminating conflicting uses, reducing the ecological impact of recreationists, and promoting safe use of lakes.

Recreational Use Models

This section is a presentation of recreational use models intended for limiting future development, with an emphasis on the reservations about them. The work related to recreational capacity is far less unified than that related to aquatic modeling and differs according to the current recreational use of the lake and the objectives of the authoring agency. In most instances, the motivation of the agencies involved was to justify public access construction or the funding of federal reservoir development. In addition, the vagueness of riparian law contributes to the confusion concerning public access, therefore making the application of recreational models very difficult.

The Boat Limit System

The Boat Limit System uses space standards to determine the safe boating capacity of a lake. Each lake activity requires a certain amount of space to occur safely and avoid conflict with other activities. Recreational researchers have tried to standardize the average amount of space for a boat; others further distinguish between types of boats or between motorized and nonmotorized boats.

Using this method, a community may restrict new development to safe use levels; in this case, the maximum allowable use would be compared to the projected demand from different types or scenarios of development. Or, as many agencies using this approach assume, each boat may represent one development unit, which translates the boating capacity into development capacity.

The central idea of this method is to divide the usable surface area of the lake by a space standard. Determination of usable surface area of the lake is accomplished by deducting certain areas of water from the gross area, for example:

a) a 60-meter band around the shore
b) a 120 meter band in front of marinas, public beaches, and access points
c) a 30-meter band around all navigation hazards
d) the center portion of the lake more than 1.6 km from the shore (optional)

The method is generally quite easy to use and much of the analysis can be done in the office with the aid of topographic maps and aerial photographs.

Two problems exist with this method: the boat standards vary widely and subjective decisions must be made concerning the amount of the boating capacity to be allocated between public users and shoreland owners.

Boat standards found in the literature, some of which are listed in Table 2, vary from one boat per acre to one boat per twenty acres. Some were developed from recorded observations of actual use. Most, however, are staff estimates or are borrowed from other studies.

Table 2. Boating Standards (in acres per boat)

	Single Standard	Anchored Fishing	Trolling Fishing	Non-power	10 hp or less	Sailing boating	Water skiing
Army Corps of Engrs.+	1						
Calif. Recr. Comm.+	1						
Soil Conserv. Serv.+		.2	.3		3	3	5
Ohio Dept. Nat. Resour.+		5.5	5.5	5.5	5.5	5.5	5.5
Park Plng. Guidelines+		.2	1	.3	1	.4	
Allegh. Res. Mgmt. Plan (1972)		1	1	1	5	1	20
Eberwein+		2	2.2	2.4	3	2.6	
Sirles (1968)	.8-1.78						
Tichacek (1975)		8	8	1	10-20	2	40
Bur. Outdr. Recr.(1970)		3.6-8	3.6-8				20-40
Wisc. Dept. Nat. Resour.+	20						
Mn. Dept. Nat. Resour.(1979)	10						
Ontario Min. Hsg.*	10						
Manitoba*	50						

+listed in Eberwein (1984)
*listed in Manitoba (1984)

The standards vary, particularly in accordance with the management objective for the lake and the intensity of use that the objective implies. Eberwein, for instance, used a standard of two to three acres per boat. This standard is consistent with Pennsylvania's recreational objective which is to provide "high intensity day-use recreation for areas close to urban centers while still maintaining a pleasurable and safe recreational use."

In addition to their wide variation, standards ignore a number of important factors. These include: the number of boats in use at any time, the existence of any type of informal concentrations, the compatibility with other uses, and the size of the lake.

Some researchers have tried to address these deficiencies, for instance, by repeating the capacity evaluation for each area of the lake where separate types of boats congregate. These "improvements" only serve to reinforce the artificial and static nature of the standards. They are based on stipulations which become more and more complicated, if not arbitrary.

The same conclusion applies to the second problem with the boat limit system. In translating the boating capacity into development capacity, public access use must be considered. Often, average use levels from public accesses are simply deducted from the overall boating capacity. In the past, the Metropolitan Council and the Minnesota DNR have simply assumed that public access users had the right to half of the available area. The DNR boating study, however, shows that public access accounts for only about one third of the total boater use in the metropolitan lakes region. In the non-metropolitan regions, public access is the smallest source of boaters while riparian residents are responsible for at least half of the boating use.

Kusler, in a 1972 study of recreation carrying capacity controls, developed a sliding scale formula in which consideration was given to the amount of riparian land in private ownership and the proportions of public and riparian use. This formula could provide a good starting point for planning purposes, but should not be applied too rigidly because of exceptions that will not realistically fit the equation.

Surveys of User Attitudes

Commonly, local communities survey user attitudes on crowding (also called user preferences) to determine whether their lake is near a social "threshold". Depending on the conclusions of this analysis, the community may consider controlling the use access or increasing the convenience and publicity of underused lakes in the area. Also, they may wish to restrict further development based on the projected use resulting from that development.

The study of user attitudes includes those studies which incorporate economic measures of the attitudes and those which do not. Both approaches, in essence, compare some measure of user satisfaction to different use densities (or to "packages" of different types of activities). Noneconomic indices simply summarize interviews in which respondents indicate whether or not they had a favorable boating experience. An unfavorable experience could be related to a general sense of crowding or to conflicts with other uses. Economic measures are designed to put a dollar value on a site's level of desirability to a user. As part of the sampling routine, users might be questioned about their travel costs or about the amount they would be willing to pay for certain conditions.

The major deficiencies of reliance on user attitudes arise from the design of the user surveys. These include: 1) the self-selection of interview respondents according to their tolerance to crowding, 2) bias introduced by respondents to protect their self-interest, and 3) a level of measurement inadequate to detect variance within gross categories of "satisfied" and "unsatisfied."

The first problem is well illustrated by the unspectacular results of a study of heavily used lakes in Oakland County, Michigan. Although successfully applied to heavily used urban lakes, these methods, when applied to less frequently used lakes farther north, showed a minimal effect of changing densities on levels of satisfaction. Boaters who were intolerant of crowding were, to a certain extent, already selected out of the sample of interviewees. Therefore, no expressions of dissatisfaction could be expected.

Second, both shoreland owners and public access users are likely to perceive that the study is being carried out to determine the acceptable number of users. Knowing this, the shoreland owners might exaggerate their negative response to overcrowding, hoping that the agency will limit lake public access and not riparian access use. Public access users, using the same logic, might understate their negative response to crowding in order to protect themselves from access limitations.

The tendency to protect one's right to access might bias reports of conflicts as well. Boaters may report conflicts with other kinds of users but not with users of the same kind. Thus, water skiers might report too many sailboats, but not too many skiers, while sailboaters would report the opposite.

The third factor that creates problems with attitude surveys is the poor level of resolution of the measurements failing to identify sufficient variance to permit adequate statistical analysis. If users are knowledgeable about their alternatives, they will choose to recreate where they are going to be most satisfied. What is needed, some researchers have suggested, is a more precise measure of what happens when crowding levels increase. Communities would need to measure the level of satisfaction necessary to just make the recreation day worth the expense and trouble involved.

An economic technique (Clawson and Knetsch, 1966) has been proposed as an alternative measure of user attitudes. However, this economic index of attitudes responds only to the third deficiency with user surveys and remains extremely controversial. It was developed to estimate the value of a recreational resource in the absence of a competitive market price. The capacity of a lake resource would be an optimal combination of types of uses at certain use levels (optimal here referring to the maximum aggregate value that users would experience).

The premise underlying this technique is as follows. As a lake becomes more crowded, a critical density level is reached beyond which individual user satisfaction declines as each new user is added. At first, the added satisfaction experienced by the new users will more than compensate for the reduced satisfaction of other users. As new users continue to arrive, however, the difference will become smaller and smaller. A point will be reached at which the satisfaction experienced by the newcomer just equals, or is exceeded by, the loss (reduced value) experienced by those already using the resource. At that point, the carrying capacity of the lake will have been reached or slightly exceeded. This relationship between use levels and user satisfaction (as measured by her or his willingness to incur the costs for travelling to that site) can be used to derive a demand curve.

Procedures for measuring satisfaction (or willingness to pay) are based, essentially, on a mathematical function that relates the cost of making a visit to the resource to the number of visits made. Various densities and mixes of uses can be observed over time on a set of lakes. Information on willingness to pay can be gathered from users who choose to recreate under those various densities and mixes. From this data, a set of equations relating mix and density to satisfaction can be established for each type of user. A separate equation would be required for each type of use: water skiing, bank fishing, etc. Total satisfaction would be the sum of these equations. As always, it should be kept in mind that the value of this survey depends entirely on the method of application and the degree of confidence in the objectivity of the interview responses.

PHYSICAL LIMITS

For people living within a lake and watershed system, the understanding of lake biological and chemical processes is crucial to the management and development of that system. There is a limit to the amount of use a lake can accommodate without affecting its basic character and recreation quality. A lake's carrying capacity is determined to a great extent by the physical and biological characteristics of the lake and the surrounding watershed. By identifying the relationships between development and water quality and recreational experiences, local governments will be better able to properly manage and preserve lake and shoreland resources while meeting the needs of the community. Residents should become involved in a well-thought-out management effort, which includes self-education and a willingness to understand how human activity affects the surrounding environment. Depending on community needs and the current state of the lake, such an effort could be fairly simple or it could require the gathering and analysis of much information.

Determining physical limits, in most lake models, is an evaluation of the amount of phosphorus introduced into the lake. When nitrogen (N) and phosphorus (P) are present in excess amounts, they may accelerate aquatic plant and algal growth and artificially "age" a lake. This is commonly known as cultural eutrophication. Of these two nutrients, phosphorus is considered more important for several reasons. In the aquatic environment, phosphorus is generally the nutrient in shortest supply. Nitrogen is available from the atmosphere, whereas no gaseous source of phosphorus exists. Therefore, in culturally impacted lakes, the proportion of the total supply of phosphorus directly attributable to development is typically higher than that for any other growth-limiting element. Furthermore, phosphorus reduction is technologically more feasible. For example, phosphorus generated from nonpoint sources may be reduced with proper land use practices.

Phosphorus concentration is directly related to the amount of chlorophyll-a in the lake, Chlorophyll-a is a common algal pigment which serves as an estimate of algal biomass and, therefore, is a direct measurement of eutrophication. The phosphorus loading level is generally accepted as a reliable indicator of water quality. Therefore, phosphorus concentration is used in many models as the basis for establishing the lake's existing trophic state and, when used in conjunction with morphometric and hydrologic data, the permissible phosphorus loading levels.

Physical limits must be seen within a total modeling strategy, devised by a community and based on its resources, commitment, lake problems, and water quality goals. The major objectives of such a strategy are divided between those that describe lake water quality interactions and those that describe watershed and runoff interactions. A community should understand that each modeling strategy will fulfill particular objectives but will not address all management questions.

Physical limits may be thought of in terms of four model objectives: 1) assessing the existing trophic state (or lake sensitivities), 2) assessing the lake processes that regulate phosphorus concentration, 3) relating the total amount of phosphorus entering the lake to land uses in the watershed, and 4) evaluating future scenarios, both of development and of altered land use practices.

The first two objectives, which deal with water quality interactions, may be approached in a static or dynamic manner. Neither the simple trophic state classification based on water quality samples nor the indices of lake sensitivity based either on morphological characteristics or coefficients substituting for lake processes is intended to allow the simulation of changes in phosphorus loading which would result from development. Yet these schemes are easier to apply than nutrient loading models which predict the in-lake phosphorus concentrations.

The second group of objectives, which deal with watershed and runoff interactions, also may be approached in a static or dynamic manner. Land cover classifications and fairly straightforward formulas may be used to assess the pollution contribution of watershed activities and, by implication, any change in land cover. However, more elaborate simulations of runoff and sedimentation in the watershed are feasible. Also, nutrient loading models may be modified to simulate and estimate loading from future development. All approaches should be capable of targeting problem areas in the watershed which are contributing high levels of nutrients or which may contribute high levels if developed.

Whatever modeling strategy a community chooses, it should be aware of the limits of the model. A model is simply a representation of an object or situation. Because real lake situations are difficult to deal with directly, models, which go beyond intuitive judgement and consider available quantitative information, are substituted. When using models, lake managers will always be faced with some degree of uncertainty. Each lake is a unique system. Therefore, general formulas may produce highly variable results when used in different settings, requiring careful analysis to ensure that proper management decisions can be made.

Preliminary Steps

The assessment of lake water quality can be carried out in two parts: 1) the determination of lake trophic status, and 2) the evaluation of the relationship between water quality and watershed land use. A community or lake association should begin its investigation by gathering basic information concerning the present trophic status and the interactions that occur in the lake. This may involve a simple water monitoring routine which may be carried out in cooperation with a state agency. The measurements taken are compared with existing water quality indices to roughly determine the current degree of eutrophication. A single summer's worth of data can provide basic information for classifying the trophic status of a lake. Several years of sampling, on the other hand, will be necessary to distinguish between permanent change and year-to-year fluctuations in water quality. The basic information eventually may be combined with additional data to run more complex models which pinpoint problem areas in the lake watershed or estimate development limits.

Trophic Status

The "trophy" of a lake is the rate at which organic matter is supplied by or to the lake. The effects of organic input are generally expressed on a scale from nutrient poor to nutrient rich. Nutrient poor or oligotrophic lakes are often characterized by low rates of organic input and low production, while for nutrient rich or eutrophic lakes, the input of nutrients, and resulting production, is generally relatively high.

In common usage, trophic refers to the open water, the area of the lake in which primary production is dominated by phytoplankton, e.g., algae. Sampling necessary for classification according to trophic status is normally carried out in this area. When determining trophic status, three special cases must be kept in mind: brown water lakes colored by organic matter from the watershed, bog lakes receiving input primarily from littoral vegetation, and shallow, highly eutrophic lakes dominated by littoral vegetation. Conditions in these lakes may not be reflected by trophic state indices and, therefore, must be considered separately.

Lake trophic status models categorize lakes on a scale ranging from oligotrophic to eutrophic. The scale used indicates water quality conditions in a lake based on factors pertaining to the eutrophication process. The trophic scale typically indicates how increases in the concentration of phosphorus influences chlorophyll-a concentration, which is a direct measure of lake productivity. Chlorophyll-a and total phosphorus are also related to transparency, the ability of the lake water to transmit light, as shown in Figure 11. This relationship makes possible the substitution of Secchi disc transparency as a measurement of water quality. Of the three factors, Secchi disc is most easily monitored and, in most cases, provides usable information on the other two factors. When setting water quality goals, lake managers should be aware of their lake's position on these scales and the amount of nutrient reduction

FIGURE 11

RELATIONSHIP OF THREE PARAMETERS PERTAINING TO TROPHIC STATUS

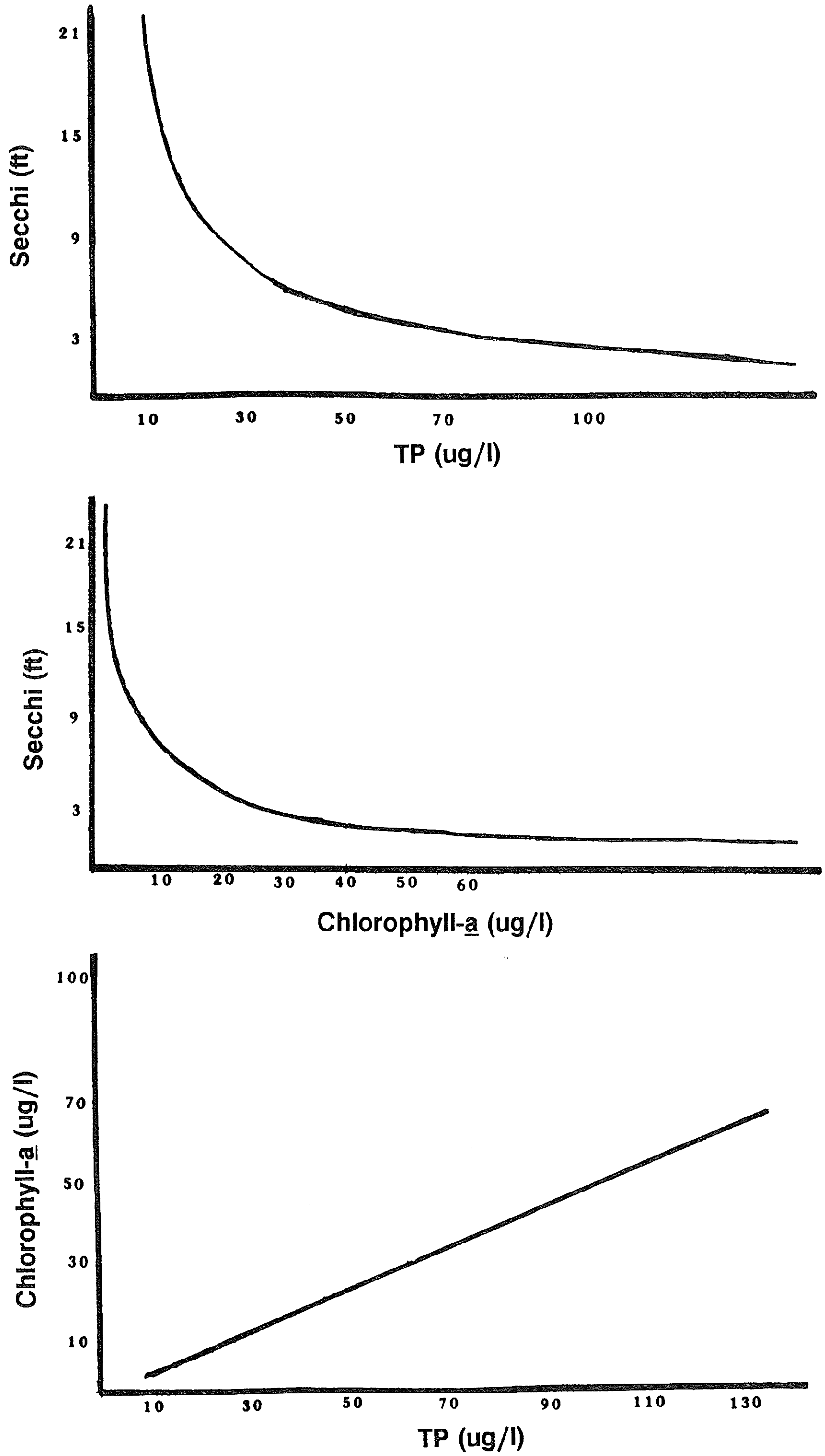
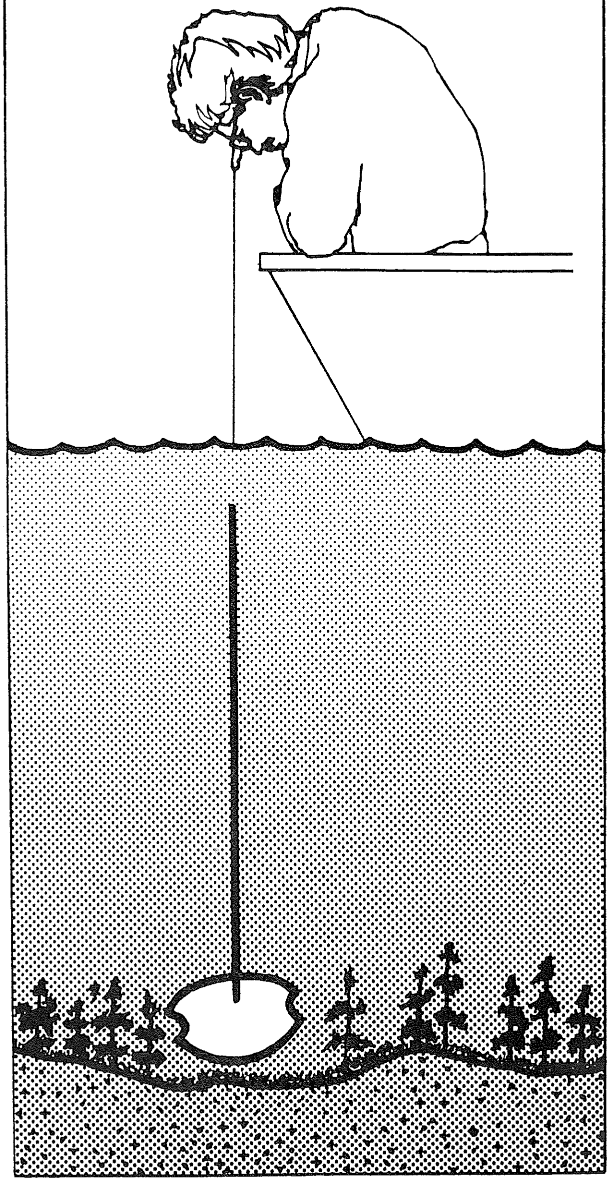


Figure 12. SECCHI DISC



that may be necessary to reach a projected goal. For instance, Secchi disc transparency in a lake with very high total phosphorus and high chlorophyll-a may not improve significantly even if total phosphorus (TP) is reduced greatly.

A significant understanding of lake water quality can be acquired through use of the Secchi disc, a weighted white disc which, when lowered into the water, disappears at a depth related to the amount of dissolved and particulate organic matter in the water (See Figure 12). This measurement of transparency is an estimate of the density of phytoplankton (algae) populations, in other words, the nutrient richness or trophic state of the lake. Figure 12 (DIAGRAM OF SECCHI DISC)

Tables 3 and 4 illustrate values for Secchi disc, total phosphorus (TP), and chlorophyll-a and their relationships to trophic state. Table 3 expresses the traditional classification ranging from oligotrophic to hypereutrophic (four trophic status) while Table 4 allows for 100 trophic states, providing a clearer resolution for rating lakes in relation to each other.

Trophic state index (TSI) values are calculated as follows:

$$TSI_{TP} = 4.14 + 14.43 \ln(TP)$$
$$TSI_{CHL} = 30.56 + 9.81 \ln(CHL)$$
$$TSI_{SD} = 60 - 14.43 \ln(SD)$$

where TP (ug/L), CHL (ug/L), and SD (m) are the measured average values for the lake. In reality, trophic state differences often exist among the three values, leading to apparently conflicting conclusions concerning the assignment of trophic status to a lake. These differences can, however, provide valuable information to the lake manager concerning interactions in the lake.

Table 3 General Trophic Classification of Lakes and Reservoirs

Parameter	Oligotrophic	Mesotrophic	Eutrophic	Hypereutrophic
Trophic state index	≤ 40	41-50	51-70	>70
Total phosphorus (ug/L)	≤ 12	13-25	26-99	≥ 100
Chlorophyll-a (ug/L)	<3	3-7	8-54	≥ 55
Secchi transparency depth (m)	>13	13-6.5	6.5-1.5	<1.5

(Modified from Wetzel, 1983, and Maloney, 1979)

Table 4 Carlson's Trophic State Index

TSI	Secchi disc (m)	Surface phosphorus (ug/L)	Surface chlorophyll (ug/L)
0	64	0.75	0.04
10	32	1.5	0.12
20	16	3	0.34
30	8	6	0.94
40	4	12	2.6
50	2	24	6.4
60	1	48	20
70	0.5	96	56
80	0.25	192	154
90	0.12	384	427
100	0.062	768	1183

(Taken from Reckhow, 1978)

The Minnesota Pollution Control Agency has classified over 1000 Minnesota lakes using both Secchi disc transparency and total phosphorus data. The lakes surveyed are a fairly good representation of Minnesota lakes. Data on the lakes studied is available from MPCA or the State Planning Agency, Land Management Information Center (LMIC).

The MPCA also sponsors a Citizen Lake-Monitoring Program (CLMP). Through this program, Minnesota citizens assist in collecting baseline data to determine lake trophic status and assess changes in water quality over time. The MPCA provides equipment and instructions for measuring water clarity and volunteers from the lake community take the Secchi disc readings each week throughout the summer. This monitoring program is an excellent and inexpensive ($10 initial cost) way for lake residents to increase their knowledge of lake principles. For information contact the MPCA at (612) 296-7373.

Additional information may be acquired through the MPCA's Lake Assessment Program (LAP), which was designed to assist lake associations with the collection of baseline lake water quality data including Secchi disc, water chemistry analysis, and watershed analysis. Data collection involves the MPCA and lake associations in a cooperative arrangement. Through the assessment of the collected data, lake trophic status can be determined. Much understanding of lake-watershed processes also can be gained simply through observation and the study of topography and land use.

The evaluation of trophic status is simply a beginning. By itself, the trophic status of a lake says nothing about possible sources of nutrient pollution, the knowledge of which is necessary to the decision-making process. Once it has been determined that problems do exist, other models can be used to identify the cause of the problems.

Lake Vulnerability

Another approach to understanding a lake's status is to develop an indicator of the lake's relative vulnerability to cultural eutrophication by analyzing morphological data. The model presented here considers some watershed effects as well as effects of the structure of the lake itself. All of the necessary information is easy to collect. Five characteristics comprise this index:

1) The ratio of watershed area to lake volume. The larger this ratio, the more vulnerable the lake because the amount of nutrients and sediments loaded into the lake varies directly with the size of the watershed.

2) Shoreline configuration. This figure can be obtained by dividing the total shoreline length by the circumference of a circle with an area equal to the area of the lake. The greater this figure, the higher the number of bays retaining nutrients. Bays tend to be more shallow than the rest of the lake and, thus, more productive.

3) Mean depth. Deeper lakes have a greater capacity to assimilate nutrients and trap them in the sediments where they are not available for growth.

4) Shoalness ratio. This is the percentage of lake bottom area with a depth of less than 15 feet, which is approximately the maximum depth of light penetration and plant growth. A lake with a high percentage of bottom at depths greater than 15 feet is less likely to be vulnerable to human-caused eutrophication. Lake contour maps developed by the Minnesota Department of Natural Resources include a measurement of the littoral area (shoreline to the 15 foot contour).

5) Water transport. Mean hydrologic residence time is the amount of time necessary for a volume of water equal to the volume of the lake to flow through the system. It indicates the rate at which a lake is flushed. Nutrients are flushed more quickly through a lake with a short residence time and, therefore, have less effect on lake processes. Related to residence time is the means available for water to enter and leave the lake. Lakes may be ranked on the basis of the manner that water and nutrients are removed from the lake:

> A flowage lake, commonly a reservoir or part of a river system (i.e. Lake Pepin), may have a short residence time, possibly as little as two or three weeks. A drainage lake has an outlet present and, therefore, may not be highly vulnerable from a flushing standpoint.
>
> Two other types of lakes have long residence times. Lakes with inlets but no outlet receive water from their watershed but have no immediate means of release and are referred to as inflow lakes. Seepage lakes generally have relatively small watersheds and lack inlets and outlets. Seepage lakes receive and lose groundwater through the basin walls. Lakeshore activities are especially critical to the well-being of these lakes.

Assign an index number to each characteristic: 1 for lowest vulnerability, 2 for medium, and 3 for high vulnerability. The sum of the index numbers is the total vulnerability index which can either be interpreted on its own or compared with other lakes in the area. As with other trophic state indices, the lake vulnerability index requires comparative data on other lakes and the use of judgement in the evaluation of the total vulnerability points. If data on other lakes is not available, the suggested values provided in the following table may be useful. It may be necessary to have someone in the Department of Natural Resources or the University of Minnesota evaluate the information.

Table 5 Lake Vulnerability Index for Rating of a Single Lake

Factor	Parameter Measured	Index Points 1	2	3
Drainage: lake area relationship	Ratio: watershed area (acres) to lake volume (acre-feet)	<0.3	0.3-1.0	>1.0
Shoreline configuration	Ratio: shoreline length/circumference of a circle with area equal to a lake area	<1.5	1.5-2.0	>2.0
Mean depth >30	Ratio: volume (ft^3) /lake area (ft^2) in feet	<10	10-30	>30
Shoalness	Ratio: lake area whose depth is less than 20ft/total area	0-40%	40-80%	80-100%
Water transport	Lake type based on structure	flowage	drainage	seepage or no outlet
	Vulnerability index (total pts)		____	

Adapted from Sargent (1976)

Most of the information necessary for the Lake Vulnerability Index can be computed from topographic maps or provided by the State Planning Agency or Department of Natural Resources. For topographic maps, call the Minnesota Geological Survey map sales, (612) 627-4782.

Evaluating Lake Processes

Following the preliminary steps, a community should begin to understand the extent to which lake processes regulate the concentration of phosphorus within the lake. These processes are portrayed in nutrient loading models or in general indices which use a few of the most important factors (flushing rate, mean depth, and phosphorus retention). The data requirements are similar for both approaches.

Lake Sensitivity

Sensitivity to water quality degradation due to nutrient pollution differs for each lake depending on the lake's ability to flush phosphorus from the system or trap it in the sediments. The ranking of lakes on the basis of sensitivity can be done quickly and may be useful in appointing certain lakes a management priority. The data used in this model can also be used in more complex nutrient loading models which simulate the lake response to changes in nutrient input.

Data required to develop a sensitivity coefficient includes: lake surface area, mean depth, a lake retention coefficient (the percentage of total phosphorus loading retained in the lake), and the lake flushing rate (the number of times per year a volume of water equal to the lake volume flows through the lake.

The retention coefficient is defined as $R = 1/(1\text{-}p)$ and the flushing rate, p = (watershed area x annual runoff)/(mean depth x lake surface area). Annual runoff can be calculated from soil infiltration rates available from LMIC or the USGS Annual Summary. Lake sensitivity can then be calculated as $S = (1\text{-}R)/(z \times A \times p)$.

Sensitivity can be used to evaluate changes in phosphorus concentration that would result from increases in loading to the lake. Table 5 is a relative rating system based on a 10 kg/year increase in phosphorus loading. Increases in loading due to land use changes (discussed later in this chapter) can be viewed in terms of trophic status as shown in tables 3 and 4.

Table 6 Criteria for rating lake sensitivity.

Lake sensitivity	Criteria
Extreme ($S*10 \geq 20$)	Ten kg increase in annual P loading results in a 20 ug/L or greater increase in lake water P concentration.
High ($10 \leq S*10 \leq 20$)	Ten kg increase in annual P loading results in a 10 to 20 ug/L increase in lake water P concentration.
Moderate ($3 \leq S*10 \leq 10$)	Ten kg increase in annual P loading results in a 3 to 10 ug/L increase in lake water P concentration.
Low ($S*10 < 3$)	Ten kg increase in annual P loading results in less than a 3 ug/L change in lake water P concentration.

(From Gilliom, 1983)

Nutrient Loading

Realistic lake use goals must take into account the natural condition of the lake. Nutrient levels characteristic of certain types of lakes are simply not attainable in other lakes. Geology, water chemistry, and other factors that affect lake processes limit the reduction of lake nutrient levels. Restoration of lake water quality to former levels may be possible; in many cases, however, maintenance of current levels is the only alternative. Protection of current water quality levels is very important in lake systems which presently exhibit good water quality.

Ecologically, no two Minnesota lakes are exactly alike. However, the state can be divided into seven aquatic regions based on ecological similarities (See Map 2). This ecoregion approach takes advantage of patterns in watershed characteristics, lake trophic status, fisheries composition, and lake mixes to simplify the task of data gathering in developing lake management strategies. The MPCA suggests total phosphorus levels that may be attainable for lakes within each of the seven ecoregions. When determining lake management strategies, communities or lake associations should consider their lake's geographic location, and may find it helpful to assess their lake relative to other lakes in the region.

Certain models predict changes in trophic status in response to increases or decreases in nutrient loading which result from land use changes. These models may be used to reveal the proportions of the total phosphorus load contributed by different land uses and to simulate cumulative impacts of development within watersheds or sub-basins. Permissible loading rates of phosphorus may be determined and equated to amount and type of development. Management aimed at the maintenance of an existing trophic state, or even the reduction of productivity, may then be formulated.

It has been recognized that critical levels of nutrients in a lake (usually measured at the time of spring turnover), if exceeded, will result in nuisance populations of algae during the growing season. Nutrient loading rates and their expected effect on trophic status have been described and are graphically shown in Figure 13. This particular figure represents the expected condition of lakes of various depths as a function of annual phosphorus loadings. The lower line in the figure designates what has been termed permissible loading; at or below this loading rate the lake will not develop beyond the oligotrophic state. Beyond the critical loading level (upper line) the lake can be characterized as eutrophic. The graph provides a quick estimate of phosphorus loading rates that will maintain or develop a particular trophic status. The predicted status generally matches the observed status based on Secchi disc, chlorophyll-a, and phosphorus loading data.

Figure 13 Vollenweider's (1968) phosphorus loading showing areal loading vs mean depth.

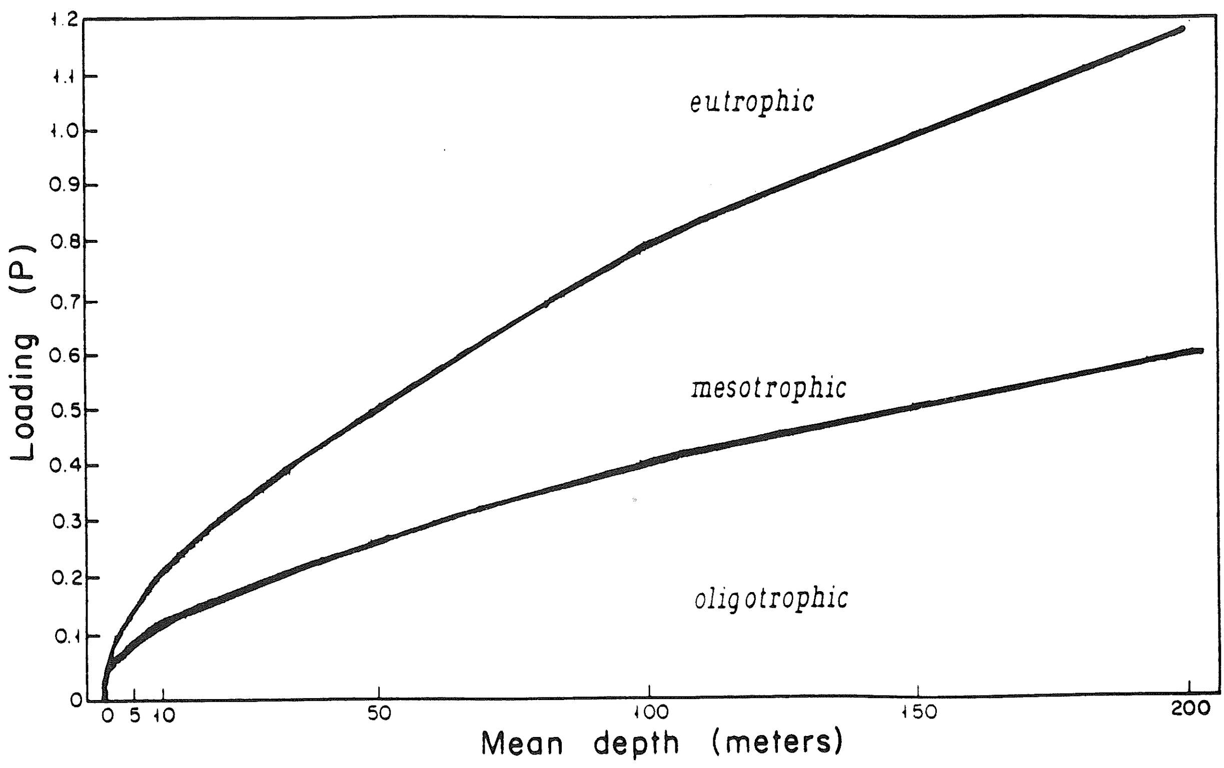


Table 7 provides approximate phosphorus loading rates required to maintain lakes in a steady state; these are the same figures represented in Figure 13.

Table 7 Provisional Loading Levels for Total Phosphorus in $g/m^2/year$.

Mean Depth (m)	Permissible Loading	Dangerous Loading
5	0.07	0.13
10	0.10	0.20
50	0.25	0.50
100	0.40	0.80
150	0.50	1.00
200	0.60	1.20

(After Vollenweider, 1968)

The issue of water quality goals is relevant to all the approaches discussed in this handbook. Models that predict phosphorus concentrations from new development refer back to these permissible and dangerous levels in order to evaluate the predictions. A number of development situations can be compared simply by altering factors such as phosphorus export coefficients or numbers of lake residents and running the model with the new values.

Several nutrient loading formulas have been proposed, all of which are based on the mass balance of a nutrient between its sources and its losses. The general equation takes the following form:

nutrient gain or loss = the external nutrient load
minus loss by lake outflow
minus loss to the lake sediments
plus nutrient reloading from the sediments.

Under steady-state conditions, the nutrient concentration does not change. Although steady-state conditions do not actually exist in lakes, lake response to loading may remain fairly constant over a period of years. This relative steady state (or average condition) is usually defined by the nutrient concentration as measured at spring turnover (and is generally applicable only in dimictic lakes in the oligo-mesotrophic range). Mass balance equations generally characterize steady-state conditions.

Loading rates and lake response to nutrient loading depend very much upon lake morphometry, i.e. mean depth, surface area, and volume; also water chemistry, water input and output, and watershed characteristics such as area and land use. Several fairly complex trophic status models have been developed to consider these aspects of nutrient loading. These models may be usefully employed in management approaches aimed at limiting a lake's phosphorus supply with the goal of maintaining, or possibly improving, lake water quality. In the general form of the model, input expressed as phosphorus loading is acted upon by climate, geology, lake hydrology, watershed land use, and vegetation. The resulting model output (lake phosphorus concentration) can be expressed in terms of trophic status or related to intended lake use. Table 8 shows these relationships.

Table 8 Proposed relationships among phosphorus concentration, trophic state, and lake use.

Phosphorus conc. (ug/L)	Trophic state	Lake use
<10	Oligotrophic	Suitable for water-based recreation and propagation of cold-water fisheries, such as trout. Very high clarity and aesthetically pleasing.
10-20	Mesotrophic	Suitable for water-based recreation but not for cold-water fisheries. Clarity less than for oligotrophic lakes.
20-50	Eutrophic	Limited total body contact suitability, based upon either loss of aesthetic properties or possible health hazards. Generally very productive for warmwater fisheries.
>50	Hypereutrophic	A typical "old aged" lake in advanced succession. Some fisheries, but high levels of sedimentation and algae or macrophyte growth may be diminishing open water surface area.

(From Reckhow and Simpson, 1980)

Table 8, while conveniently showing lake uses that can be expected for each trophic status, does not portray either total phosphorus values or regional expectations of use suitable for Minnesota lakes. The trophic state index values in Table 3, though still fairly restrictive, more accurately reflect the trophic status of Minnesota lakes.

The model presented here (developed by Reckhow and Simpson, 1980) estimates the total annual mass flow of phosphorus into a lake by summing the annual contribution from each of the nonpoint sources plus any additional point source contributions. Data requirements include watershed area, total annual runoff, lake surface area, mean annual net precipitation, a phosphorus export coefficient for each land use, area of each land use, soil retention coefficients, and the measurement of any point source input.

Export coefficients (See Table 9) estimate the expected annual amount of a nutrient such as phosphorus transported per unit of its source to a lake. In all cases, direct measurement of nutrient concentration and hydraulic loading provides a more accurate picture of a lake's dynamics than do modeling estimates. However, direct measurement adds greatly to the expense and may be a difficult and time-consuming task. Users of estimates must be aware that the coefficients have been developed for specific geographic areas and may not accurately reflect land cover, precipitation, and soil conditions in their own area.

Table 9 Phosphorus Export Coefficients

	*high	Phosphorus ($kg/km^2/yr$) mid	low
Urban	500	80-300	50
Rural/Agriculture	300	40-170	10
Forest	45	14-30	2
Precipitation	60	20-50	15
		Phosphorus(** kg/capita-year)	
Septic Tank	1.8	0.4-0.9	0.3

* High, mid, and low values are calculations of high, most likely, and low total loading estimates, which represent model uncertainty.

** A capita-year = the average number of persons per living unit times the number of days spent at the unit per year/365 times the number of living units. This figure is computed for both seasonal and permanent residential units.

(From Reckhow and Simpson, 1980)

Present land use and proposed changes can be modeled for purposes of comparison. If the predicted value for the present use compares well with a measured lake phosphorus concentration value, then the model can be used to predict P changes due to land use changes. Use of the high, most likely, and low values provides a range of possible loading figures rather than a single figure, thereby providing statistical confidence limits around the result. The MPCA has begun using this model to test possible impacts of land use change as part of its Lake Assessment Program. Lake associations may find this model useful for identifying areas in which development would greatly degrade lake water quality.

Andrews and Pickering (1978) applied a water quality model as a component of a mathematical model designed to analyze different land use developments. The nutrient loading equation represented an environmental constraint to development with phosphorus loading reflecting changes in water quality. Various development alternatives were compared with respect to 1) economic consequences in terms of both public and private sector income and costs, 2) water quality changes estimated using the nutrient loading model, and 3) projected lake use and boating figures. Phosphorus loading levels were weighed against the economic benefits for each development scenario.

Each development scenario was generated with a different primary objective: instituting a type of minimum lot zoning, limiting the number of tiers, maximizing the net public revenue, and designating only commercial development. Specific acreage limitations and economic constraints were also considered. From the alternatives, the best mix of uses which would reduce lake crowding, maintain lake nutrient levels, and provide optimal revenue was chosen.

Several results of the case study underline the fact that certain types of development may just not be economically feasible. One scenario, for example, called for two-tier development with two-acre zoning. Second tier users, the authors predicted, would require additional public services at a higher rate than the rate of increase of public revenues. The increased revenue to the town, in other words, would not offset the cost of services, let alone the loss in environmental quality.

For communities interested primarily in the economic value of their lake, this model may be very useful, although not without some disadvantages. The model is essentially a mathematical program and adequate understanding of linear programming is necessary. But use of the approach has indicated that nutrient loading models can be combined with other types of analyses in a broad decision-making process.

Nutrient loading models appear to be the most comprehensive predictive tool for evaluating future development, encompassing processes of both nutrient loading and lake assimilation. They also can be quite expensive where monitoring is necessary. This is especially the case on lakes with numerous inlets or complicated shapes, which would require increasing the number of sampling sites.

Watershed Analyses

Watershed models, while not as widely applicable as nutrient loading models, have significant cost and management advantages. Being able to examine the runoff within a watershed is important to lake management decisions. Lake residents will want to pinpoint marginal land, areas of possible erosion, and land uses that do or could cause sedimentation and polluted runoff. Existing land uses, the percent of impervious cover, the soil and vegetation, and the drainage efficiency of sub-basins are all factors that affect the development capacity of a lake's watershed. Watershed models, when based on good geographic information, may also prove indispensable to lake communities for short-term decisions about the location of development.

Two types of watershed analyses are possible. Since neither type consider lake response, they both need to be combined with lake indices or nutrient retention equations. Watershed classifications assess the watershed conditions in a qualitative, static manner. Alternatively, AGNPS, a computer program, simulates runoff processes, providing quantitative estimates of water volume and quality. Both types rely on runoff coefficients based on soil type and land cover (as do some variations of the nutrient loading models). Thus, their meaning is a direct function of the scale and accuracy of this data. One may evaluate future development or modified land practices in a general way by altering these land cover coefficients.

Watershed Classification

Marsh and Borton (1975) developed a simple, noncomputerized method for quantifying runoff in the lake's watershed beyond the shoreland. The watershed is divided into sub-basins, individual land areas linked to the lake by streams or other flow systems. Quantity and quality of surface water provided to the lake are the primary concerns.

Quantity of runoff (discharge) can be estimated as $Q=cIA$, where c=the coefficient of runoff, the percentage of rainfall that runs off the surface, I=intensity or amount of rainfall, per hour, A=area of the sub-basin. Because the coefficient of runoff is related to land cover, conversion of land use can change the coefficient drastically. On the basis of cover alone:

c_{forest} = 0.1 to 0.2 (10-20%)
$c_{residential}$ = 0.4 to 0.5
$c_{cultivated}$ = 0.5 to 0.6
c_{urban} = 0.9 to 1.0.

Soil texture and slope also affect runoff and should be considered when estimating the coefficient of runoff. Table 10 gives coefficients for some common rural surfaces based on cover, soil, and slope.

Table 10 Runoff Coefficients

Topography and vegetation	Open sandy loam	Clay and silt loam	Tight clay
Woodland			
Flat (0-5% slope)	0.10	0.30	0.40
Rolling (5-10% slope)	0.25	0.35	0.50
Hilly (10-30% slope)	0.30	0.50	0.60
Pasture			
Flat	0.10	0.30	0.40
Rolling	0.16	0.36	0.55
Hilly	0.22	0.42	0.60
Cultivated			
Flat	0.30	0.50	0.60
Rolling	0.40	0.60	0.70
Hilly	0.52	0.72	0.82

(From Marsh and Borton, 1975)

Runoff quality decreases as land use intensity increases. Human activities produce wastes and create impervious surfaces that carry those wastes into the lake. The relative influence of a sub-basin is a factor of its capability to generate large discharges of low quality and move the discharge to the lake with little water loss.

Sub-basins can be ranked on the basis of discharge, flow efficiency, and water quality. Flow efficiency is an indicator of the efficiency of the drainage linkage between the sub-basin and the lake. A storm sewer link to the lake is the most direct and efficient while a sub-basin lacking a drainage system is the least efficient. Table 11 lists some flow efficiency and water quality values.

Table 11 Water Quality Coefficients

Land Use	Coefficient
Urban (either industrial, commercial institution or a mixture of all three)	1.0
Urban Residential (mainly medium and high density residential)	0.8
Suburban (low density residential with 25% or less open and wooded)	0.6
Agricultural (mainly cultivated with 25% or less fallow and wooded)	0.6
Rural Non-Cultivated (mixed vacant, wooded, pasture and residential)	0.2
Forest (75% or more wooded)	0.1

Flow Efficiency Values

Drainage Network	Coefficient
Storm Sewers	1.0
Improved Channels	0.8
Perennial Streams	0.7
Intermittent Stream Channels	0.5
Wetlands	0.3
Diversified	0.1

(From Marsh and Borton, 1976)

The relative influence of each sub-basin is determined by the equation $I = Q \times W \times E$ in which:

I = influence factor
Q = discharge
W = Water quality coefficient
E = flow efficiency coefficient.

Sub-basins with the largest factors can be given immediate attention for planning and management.

In a study of development around Owasco Lake, New York, Gordon (1977) demonstrated how watershed and water quality models may be integrated to evaluate future development. Two types of development scenarios were evaluated based on a demographic projection. In scenario I, development was dispersed throughout the watershed and in scenario II, development was concentrated in one place.

The simulation of runoff and erosion was based on watershed geographical data (each grid of 5.5 acres), using the universal soil loss equation and the Soil Conservation Service's runoff formula. The two, five, ten, twenty-five, fifty, and one hundred year probability storms were used as variable information for the simulation. Alternative erosion simulations assumed that all the land was cleared of vegetation during development, that only 25% of the land was cleared, that all development in the basin occurred at once, that development was spaced evenly over 25 years, or that no erosion control measures were enforced.

The simulation of eutrophication was based on the response of phytoplankton to the addition of nutrients. Like other lake sensitivity indices discussed, the formula used existing nutrient concentration, lake volume, hydraulic retention time, and annual nutrient loading figures. The levels of soluble phosphorus that would induce eutrophication were drawn from Vollenweider's critical loading curves. By simulating development of different locations, Gordon was able to compare various levels of impact. Despite the crude nature of the model, it provided an understanding of the impacts of dispersed versus concentrated development and of the impact of slope, of the necessity for performance controls in some areas, and of the adequacy of slope guidelines for concentrated development.

Agricultural Nonpoint Pollution Source Model

A promising model for Minnesota agricultural areas is AGNPS, the Agricultural Nonpoint Pollution Source Model. Developed by the U.S. Department of Agriculture and the Minnesota Pollution Control Agency, AGNPS provides basic water quality information for prioritizing nonpoint (and also point) source pollution problems in agricultural watersheds. AGNPS may be used to predict the runoff volume and peak flow, amount of erosion, and nutrient concentrations in the runoff and sediment for single storm events for all points in the watershed. Outputs can be simulated for single cells or for the entire watershed. The model is also being adapted to analyze water quality impacts of small urban areas within agricultural watersheds.

The basic components of AGNPS are hydrology, erosion, sediment transport, and pollutant transport (phosphorus, nitrogen, and chemical oxygen demand in both runoff and sediment). AGNPS does not analyze in-lake parameters, but is useful for prioritizing cells within a subwatershed and providing a rough estimate of the quality of water flowing into a lake. Data necessary for use in the model may be collected either manually or from existing data sources, especially the Minnesota Land Management Information Center (LMIC). Most of the parameters in the model are interpretations of basic soil and topographic data. These interpretations are drawn from tables and graphs in the AGNPS manual or are available from SCS.

The developers of the model suggest the time required to input the data will be approximately one person-month for larger watersheds (up to 23,000 acres) and approximately three person-days for watersheds less than 500 acres.

Model information comes in the form of two reports entitled "AGNPS: A WATERSHED ANALYSIS TOOL: A GUIDE TO MODEL USERS," and "AGNPS MODEL DOCUMENTATION." For further information about the model, contact the University of Minnesota, Minnesota Extension Service Distribution, Room 3 Coffey Hall, 1420 Eckles Avenue, St. Paul, MN 55108.

Since almost two-thirds of shoreland development in Minnesota is located in areas with some agricultural activity and since agricultural runoff is one of the major water quality considerations in many counties in the state, this model may be very useful for identifying potential impacts of various kinds of land use in this type of watershed. The model encourages lakeshore homeowners and county officials to view lake water quality within the broader context of watershed management. It could also be a very valuable supplement to use with other water quality models by providing simulated results on changes in nutrient loadings that can be used to determine impacts on lake water quality.

For example, AGNPS has been used as part of a Clean Lakes project to restore Big Stone Lake in western Minnesota. AGNPS identified critical areas in 3 sub-watersheds. Land use changes were then simulated for approximately 10% of the cells and comparisons were made with current land use. As a result, several Best Management Practices were recommended to reduce sedimentation and nutrient loading to the lake. The watershed district now promotes chisel plowing and has purchased a no-till drill which is available to district farmers on a lease basis.

Shoreland Capability

Analysis of shoreland development capability (or site suitability) is another, immediate step for short-term objectives. These analyses limit development on the shoreland only where site conditions suggest erosion potential or excessive septic field seepage. The analysis is limited to considerations of topography and drainage. It uses no water quality data.

A community should not assume that evaluations of suitability can be directly translated into development policy. We cannot, in other words, propose the maximum development of every suitable section of shoreline and call the resulting level of development the lake's capacity. At the same time, the method does support the provisions for suitability analysis in current and expanded shoreland regulations. For example, it uses information necessary to establish land use districts and their conditional development or subdivision densities.

Marsh and Borton (1975) proposed a simple shoreland classification scheme to complement the sub-basin model described earlier in this chapter. Shoreland is described as the areas that drain directly into the lake between sub-basins. For small watersheds, which have a large ratio of shoreland to watershed area, the consideration of the shoreland is relatively more important than it is for larger watersheds.

This model is designed to establish three orders of development suitability, based on soil, topography, and drainage. Five types of shoreland are described in terms of topography and drainage:

1) wetlands	Situated close to or below the water table, these areas offer the greatest limit to development. Usually, landfill is required, destroying the ecological role of the wetland which is necessary to the proper functioning of the lake system.
2) berm	A ridge, usually situated between the lake and a wetland. Berms, if they are high and wide, are more suitable for development than wetlands. Small, low berms present the same problems as wetlands and also are often sandwiched between the lake and a road placing houses and septic tanks too close to the lake.
3) bluff	Any area where the average slope of the land is greater than 30 percent as measured over horizontal distances of 50 feet or more. The steep slope makes these sites subject to rapid runoff, erosion, and sedimentation. Septic fields may drain directly into the lake.
4) lake slope	Similar to a bluff but having less than a 30 percent slope.
5) terrace	Relatively level ground situated above the water table.

These last two classifications are usually well suited to development.

The shorelands are then grouped into three orders:

1) No improvement of the site is necessary for development. This group may include terrace, lake slope, and high berm.
2) Proper planning and design is necessary to overcome topographic and drainage limitations.
3) Much improvement is necessary before development. Wetlands and low berms fall into this group.

Certain general rules are then applied to assess a shoreland's development capacity. For example, if all first order sites are occupied, development capacity is reached. The use of some second-order sites is possible if limitations are compensated for and if runoff from the upland parts of the watershed, which also drain into the lake, is not excessive. If third-order sites are being developed, then carrying capacity has been exceeded. The idea of suitability deals only with the feasibility of developing a site or the amount of improvement that would be necessary before a lot can be developed.

Minnesota Department of Natural Resources shoreland regulations consider shoreland types similar to the types described above. Information for this model will come from on-site observation, aerial photographs, and topographic and soil maps.

Table 12 Sources of information for models discussed in this section.

Model	Information	Source
CLMP	Secchi disc	MPCA (program info). Lake monitoring by the lake association
LAP	Secchi disc	Lake association
	total phosphorus total nitrogen chlorophyll-a solids pH color oxygen profile temperature profile	Collected by MPCA or lake association; analyzed by MPCA
	lake morphometry	MPCA or lake association
	definition of watershed	Lake contour map
	identification of: tributaries, storm sewers, agricultural tiles, etc.	Lake association
	map land use	MPCA or lake assn. (use LMIC information)
	assess and update land use	Lake association (SCS, SWCD)
	number of homes, sewage disposal	Lake association

table continued on next page

Table 12 Continued

Model	Information	Source
Lake Vulnerability	lake surface area	LMIC (Lake Summary Data Base) or Topographic map
	drainage basin area	LMIC or topographic map
	shoreline length	Topographic map
	mean depth	LMIC (Lake Summary Data Base)
	area below 15' depth	Lake contour map or DNR
	hydrologic residence time	
	lake outflow	Measured by lake association
	lake volume	Lake surface area x mean depth
Lake Sensitivity	lake surface area mean depth	Measured by lake association
	phosphorus retention coefficient	
	watershed area	Measured by lake association
	annual runoff	SCS
Nutrient Loading	total phosphorus	PCA or measured by lake association
	watershed area annual runoff lake surface area	Measured by lake association
	annual precipitation	SCS
	phosphorus export coefficient	Table 9
	point source input	Measured by lake association
Sub-basin Analysis	coefficient of runoff	Table 10
	rainfall intensity	SCS Handbook
	area of watershed	Topographic map
	water quality coeff.	Table 11
	flow efficiency coeff.	Table 11
AGNPS	slope aspect soils	SCS
	land use	SCS or on-site observation
Shoreland Classification	shoreland type	On-site observation, topographic maps, photographs

LAKE MANAGEMENT PLANNING

Unguided development has the potential to degrade the environment and deplete or destroy our limited natural resources. This handbook is intended to be an aid to lake communities in planning lake development that will create and maintain a desirable environment while promoting public health, safety, welfare, and convenience. This section describes various planning strategies, beginning with a discussion of forms of organization that are available to lake communities. This is followed by a listing of agencies that can provide technical assistance, information, funding, and necessary permits. The final subject considered is the possible costs of data collection. Much of work of lake management can be carried by the lake community itself, although the level of investigation will be determined by the cost the community is willing to incur.

The state legislature has authorized the regulation of the use of land bordering lakes to preserve water quality and maintain the economic and environmental value of the land resources (Minnesota Statute 105.485 and Minnesota Rules Chapter 6120). The Shoreland Management Act authorized the Department of Natural Resources to establish minimum zoning standards for local governments to use in regulating development and use of the shoreland. Communities are required to adopt local shoreland controls that meet or exceed the minimum standards. In many cases local feeling may be that the standards are not strict enough to adequately protect the lake resources. The models presented in this handbook are intended to aid communities in determining, as closely as possible, the impact of development so they may justify passing local controls that go beyond the minimum state standards.

Community objectives are affected by the aims, goals, values, and ambitions of the people. Proposed alterations in lake and watershed use will result in changes in water quality, flooding and erosion potential, recreational facilities, the tax base, and job opportunities, etc. The question of future development is really many-faceted, depending upon the area of concern and the necessity for short-term or long-term decisions. Should a particular development proposal be approved? What will be the consequences if development continues? Should a particular type of development be restricted by zoning? Is it necessary to direct the location of development? Are performance controls necessary for new development? Each of these questions is related to future development; each is answerable, based on information provided by one of the models discussed in this handbook. Yet, before a community initiates a data-gathering and modeling effort, it must have clearly defined its own objectives and questions. Once that is accomplished, the community may begin to approach government agencies and other sources of information and assistance.

To establish their objectives, lake communities should describe both the existing resource and the overall goals of the community. Resource features to be considered include water quality characteristics (including trophic status), drainage system components such as streams, ditches, storm sewers, and subwatersheds, and the present land uses of the watershed (forestry, agriculture, urban development).

Lake watersheds often lie within two or more political jurisdictions, confusing management responsibility and creating conflict among groups with recreational or economic interests in the watershed. To avoid conflict and to most effectively manage the available resource, it is necessary that lake communities recognize all interested private parties and governmental agencies (local, state, and federal) and involve them all, as much as possible, in the decision making process. Adversarial relationships, resulting from lack of communication, petty jealousies, and imagined and real insults, can quickly undermine otherwise good planning and waste valuable time and energy. Therefore, local planners should coordinate their efforts with the relevant local, state, and federal agencies wherever possible.

Organizing

The lake association is a common form of local organization, evolving from the informal lake committee or social group. At this level of organization, lake problems are discussed and analyzed. Determination can be made as to whether problems are land-use or lake-use related, and possible solutions can be discussed. Lake associations may operate informally without designation as a legal entity. However, incorporation as a non-profit corporation will better facilitate the accrual of funds through the membership, the hiring of contractors, and interaction with governmental units. Incorporation requires the submission of articles of incorporation as a non-profit corporation under Minnesota Statutes 394 to the Secretary of State. Application for 501(c)3 tax exempt status may be made with the Internal Revenue Service.

The scope of lake management problems can be examined at the lake association level. Local understanding and support can be developed and state and local agencies can be contacted for guidance. Among other things, make certain that plans are compatible with existing plans and regulations. Current county or watershed district plans may prohibit certain activities. Analyze possible conflicts among goals. For instance, do the recreational goals conflict with water quality goals? What tradeoffs will have to be made?

A negative aspect of lake associations is the difficulty of recruiting 100% of the lake's residents. Commonly, a number of lake residents benefit from the efforts of a lake association without paying any dues. As an alternative, lake communities may wish to form a lake improvement district (LID) which would be supported by county taxation authority. A tax levy would possibly be the same amount as the association membership fee, but could be collected from everyone in the district. A lake improvement district can also receive grants from state and federal agencies and private foundations.

A lake improvement district (see Minnesota Statutes Chapter 378) is a special purpose local governmental unit established by resolution of a county board to provide the opportunity for greater landowner involvement in lake management activities by actions initiated at the local level of government. Each lake improvement district may be delegated different levels of authority by the county board depending upon existing problems and proposed activities. A LID allows landowners closest to the situation to directly seek solutions to their problems. A county board may grant powers to a LID to, among other things:

acquire, construct and operate a dam or other lake control structure;
undertake research projects;
conduct programs of water improvement and conservation;
construct and maintain water and sewer systems;
serve as local sponsors for state and federal projects or grants; and
provide and finance governmental services.
implement a water monitoring program.

A LID may undertake a number of activities, including regulating water surface use, providing public water and sewer service, constructing and maintaining public docks, beaches or fishing piers, and controlling and improving runoff from the watershed. Proposed district boundaries should reflect the objectives of the LID and should include a sufficient area of the lake's watershed for the LID to develop and implement solutions to identified problems. If the concern is about flooding or water quality problems on a lake with a small contributing drainage area, forming a lake improvement district or sanitary sewer district may be considered. Sanitary sewer districts such as the Alexandria Sewer District are formed to develop ways to dispose of residential sewage and garbage and industrial waste.

A watershed district may be a useful government authority for managing a large watershed that does not conform well to political boundaries A watershed district provides a local organization which coordinates all water management decisions in the watershed. The powers of a watershed district include the implementation of measures to control land and soil erosion and siltation of watercourses and the regulation of improvements by riparian landowners of the beds, banks and shores of lakes, streams, and marshes. Existing watershed districts in Minnesota vary in size from less than 60 square miles to over 6000 square miles (Map 3). The area of a proposed district should include the entire contributing watershed. The area's tax base should also be considered. State law currently allows a watershed district to establish an annual administrative budget of up to $125,000. However, the ad valorem tax levy for the administrative fund cannot exceed 1.0 mills. A small watershed district with a small tax base will be able to raise only a small administrative fund. This could hamper a small district's ability to function effectively.

Establishment of a watershed district requires development of an overall plan, adoption of formalized rules for operation of business and preparation of yearly reports. If the area is adjacent to an existing watershed district, the option of enlarging the existing district is available under the law and should be discussed with the district's board of managers.

To reduce conflicts among jurisdictions and increase local capabilities, the state provides for the establishment of joint powers agreements through which two or more governmental units (cities, towns, counties) may jointly or cooperatively exercise power common to both or all parties. The Mississippi Headwaters Board is a joint powers agreement signed by eight counties in northern Minnesota to formulate plans for the area under its jurisdiction and protect the Upper Mississippi River from uncontrolled and unplanned development through the preparation and adoption of a comprehensive management plan for the river and adjacent lands. The plan provides for adoption of strong local control, recreational use of the river, donation or purchase of critical lands, and sound cooperative management of public lands along the river. The Mississippi Headwaters Board was formed under the authority granted in Minnesota Statutes 471.59. The board prepares grant applications to secure state and federal funding.

The North Shore Management Board is a joint powers agreement consisting of three counties, four cities, and two townships. Funding has been provided by the state legislature to develop a set of shoreland management standards as set forth by Minnesota Statutes 105.485. The board was formed to develop strategies for environmental protection and orderly growth of the North Shore of Lake Superior, and has the power to accept and disburse funds and to apply for state and federal funds. To meet its needs, the board has appointed a Technical Advisory Committee consisting of representatives of various local, state, and federal agencies, as well as the University of Minnesota.

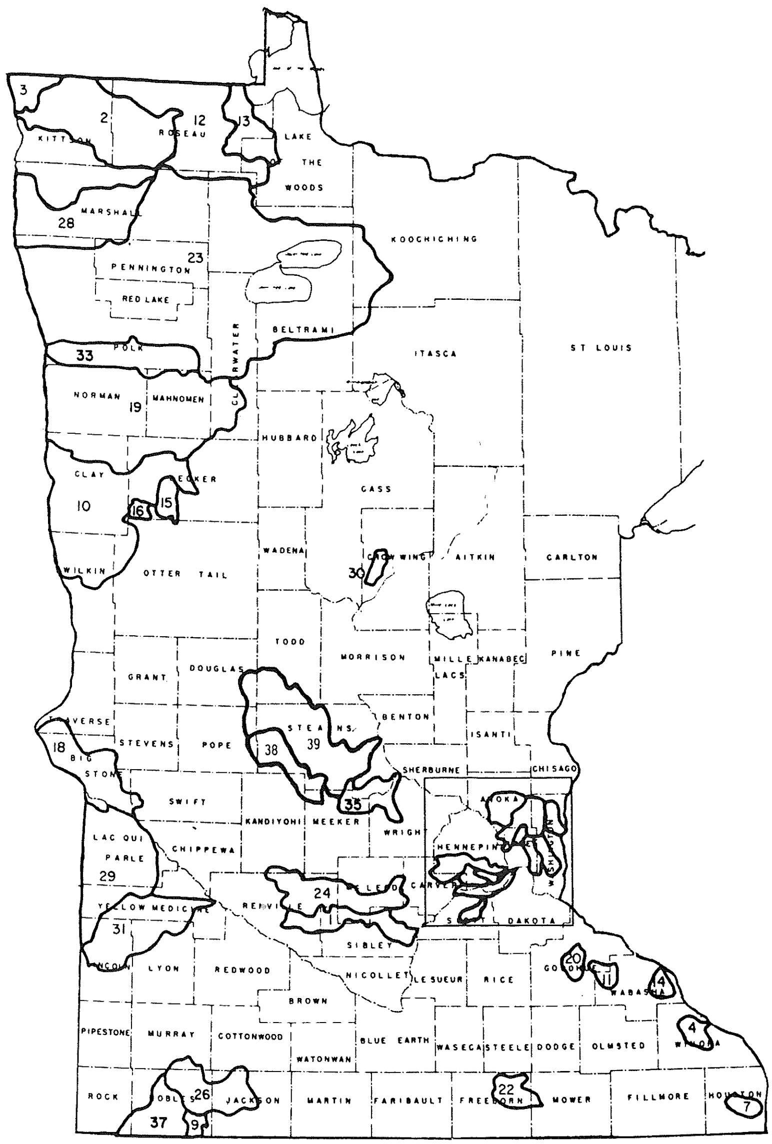
Regional Development Commissions (see Minnesota Statutes 462.381-462.396) provide intergovernmental cooperation on a regional basis as a means of pooling the resources of local government to resolve common economic, social, physical, and governmental problems and to secure the assistance of the state in making use of local, state, federal, and private programs to benefit these regions. A regional development commission is authorized to receive state and federal grants for regional purposes for resource, conservation, and development districts. A commission is required to adopt a comprehensive plan for the region consisting of policy statements, goals, standards, programs, and maps prescribing guides for the economic development of the region. Thirteen regional development commissions were established in Minnesota.

Economic realities may dictate that a community must provide much of the organization and labor itself. If possible, tailor the program so that the community can handle the work and expense itself. Encourage public participation. Always remember that it is important to show public support for the plan; this is viewed positively by funding agencies. Lake associations should inventory community resources. Examine the strengths and weaknesses of the community. Who are the local "experts?" What groups, i.e. sports groups, civic organizations, scout troops, high school science clubs, etc., could meet their own diverse goals by becoming involved with other community members in some facet of the management of their environment. A goal inherent in any lake development strategy is environmental awareness. The more the community is involved, the greater is the educational opportunity and the chance for the project to succeed over the long term.

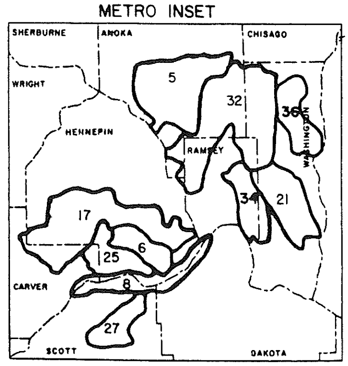
MAP 3 WATERSHED DISTRICTS OF MINNESOTA (1986)

WATERSHED DISTRICT

1 High Island
2 The Two Rivers
3 Joe River
4 Stockton-Rollingstone-Minnesota City
5 Coon Creek
6 Nine Mile Creek
7 Crooked Creek
8 Lower Minnesota River
9 Okabena-Ocheda
10 Buffalo-Red River
11 Bear Valley
12 Roseau River
13 Warroad
14 Cooks Valley
15 Pelican River
16 Cormorant Lakes
17 Minnehaha Creek
18 Upper Minnesota River
19 Wild Rice
20 Belle Creek
21 Valley Branch
22 Turtle Creek
23 Red Lake
24 Buffalo Creek
25 Riley-Purgatory Creek
26 Middle Des Moines
27 Prior Lake-Spring Lake
28 Middle River-Snake River
29 Lac Qui Parle-Yellow Bank
30 Thirty Lakes
31 Yellow Medicine River
32 Rice Creek
33 Sand Hill River
34 Ramsey-Washington Metro
35 Clearwater River
36 Carnelian-Marine
37 Kanaranzi-Little Rock
38 North Fork Crow River
39 Sauk River



METRO INSET



Assistance

The county may have already developed a comprehensive water plan or may be in the process of formulating one. The purposes of a comprehensive water plan are to identify existing and potential problems and opportunities for the protection, management, and development of water related land resources; and to develop objectives and carry out a plan of action to promote sound management of water and related land resources, effective environmental protection, and efficient management (Minnesota Rules, Chapter 9300). If a plan is being developed by the county, lake residents should take the opportunity to include their own concerns in its formulation. The county is required by law to hold a public informational meeting and solicit information about issues, problems, and opportunities to be considered in the plan. If a plan is already in effect, then it will provide a good source of information concerning the local physical environment, along with current and proposed land use and development.

Water quality and development capacity is only one of many issues within a comprehensive lake management plan. Scenic easement, wetland encroachment, zoning changes, and recreational impact are all areas of interest. The management structure affecting the lake, especially any overlapping of authorities, could hinder the development of a comprehensive plan. Court battles or stalled efforts are probable consequences of conflicting objectives. Therefore, it is imperative that any party interested in lake management consider coordinating their efforts with those agencies concerned with lake surface, shoreland boat docks, water patrol, shoreland park operation, new commercial facilities permitting, public access, or other funding and review matters.

The 92 Soil and Water Conservation Districts (SWCDs) in Minnesota conduct research, implement conservation programs, construct and operate conservation practices, develop resource plans, and assist private landowners. State funds distributed to SWCDs through the Minnesota Board of Water and Soil Resources (BWSR) go to, among other things, cost-sharing programs, resource conservation planning, watershed management, agricultural pollution control, and environmental education.

The Clean Water Partnership Program (see Minnesota Laws of 1987, Chapter 392) exists to protect and improve surface and ground water in Minnesota through financial and technical assistance to local units of government to control water pollution associated with land use and land management activities. The program is administered by the MPCA which may provide grants for up to 50 percent of the eligible costs of a project and technical assistance with the development and implementation of projects.

A Clean Water Partnership may be initiated by residents' groups such as lake associations, but the grantee must be a local unit of government, i.e. municipality, town, county, watershed district. Soil and Water Conservation Districts may be part of a project through joint powers or contract with other local units of government.

The Agricultural Conservation Program is a joint effort by agricultural producers and federal and state agencies to protect land and water resources. This program is administered by the Agricultural Stabilization and Conservation Service (ASCS) of the USDA. The SCS, the U.S. Forest Service and the Department of Natural Resources are responsible for providing technical guidance. Educational support is provided by the county extension. Through this program, the federal government may share up to 75 percent of the cost to install measures to reduce soil erosion and water pollution. Funds are authorized annually by Congress.

Quite possibly, landowners may wish to install conservation measures or retire marginal lands to reduce erosion within the lake watershed. Various local, state, and federal programs exist to assist in this process. These programs include the Reinvest in Minnesota (RIM) Reserve Program designed to retire marginal agricultural land through conservation easement and the Streambank, Lakeshore, and Roadside Erosion Control Program (SLR) which provides financial assistance to local units of government for the control of erosion along streambanks, lakeshores, and roadsides. The Conservation Reserve Program (CRP) pays farmers to discontinue growing crops on highly eroding cropland and plant it to grass and trees. Information about these and other programs is available through local SWCDs, the Board of Water and Soil Resources, and the Minnesota Department of Natural Resources.

In the metropolitan area, the Metropolitan Council is a good source of information concerning the physical environment, land use, and development, as well as information on metropolitan lake management programs. Metro Council has studied approximately 120 metropolitan lakes since 1980, collecting lake morphometric and water quality data.

Many private consulting firms are available to assist lake communities. Lake associations should contact their parent association, the Minnesota Lake Management Federation, or the North American Lake Management Society for information concerning lake management consultants.

Information

It is important to remember that governmental agencies, when working on their own projects, catalog information that may be very useful and otherwise costly for lake communities to obtain. At the state level, the Department of Natural Resources and the Pollution Control Agency are responsible for gathering much of the lake information that lake associations will need for their studies. Water quality and fisheries data, and lake morphological information are already available for many lakes in the state. These agencies can also provide guidance in data acquisition. Make use of these valuable information resources. Tables 13 and 14 list local, state, and federal agencies which have carried out research in the the area of lake management or which may be able to provide information or technical assistance to lake communities.

Table 13 Agencies providing information or technical assistance.

Local
Counties
Soil and Water Conservation Districts
Watershed Districts
County Extension
State
Pollution Control Agency
Department of Natural Resources
Department of Agriculture-Board of Water and Soil Resources
Department of Transportation
Department of Health
University of Minnesota-Agricultural Extension Service
Metropolitan Council
Federal
Environmental Protection Agency
Department of Agriculture-Soil Conservation Service
Department of Interior-Geological Survey
-Fish and Wildlife Service
Army Corps of Engineers
Department of Transportation

Table 14 Authorities providing information about the physical environment.

a. geology	Minnesota Geological Survey (MGS) United States Geological Survey (USGS)
b. soils	local Soil and Water Conservation Districts (SWCD) USDA-Soil Conservation Service (SCS)
c. land cover	SWCD SCS State Planning Agency-Land Management Information Center (LMIC)
d. land use	SWCD Minnesota Pollution Control Agency (MPCA) local comprehensive plans (counties) LMIC
e. watershed	USGS Minnesota Department of Natural Resources (DNR) topographic maps
f. wetlands	DNR SWCD U.S. Fish and Wildlife Service
g. lakes	DNR MPCA Metro Council
h. rainfall	U.S. Weather Service
i. groundwater	MGS USGS DNR PCA

Funding

The involvement of a local sponsoring authority is necessary to enter into formal arrangements with potential funding agencies. Basinwide strategies require at least one political entity to take the lead role if for no other reason than to secure the necessary funding. The authorities and obligations for implementing these strategies and securing of local or matching funds does not lie solely with municipalities or counties. State legislation has provided for establishing special purpose quasi-governmental districts or special taxing authorities which may be used for implementing mitigation strategies. Table 15 lists possible sources of funding.

Table 15 Funding agencies.

<u>local</u>
Counties
Soil and Water Conservation Districts
Watershed Districts
<u>state</u>
Pollution Control Agency
Department of Natural Resources
Board of Water and Soil Resources
Department of Transportation
Department of Health
<u>federal</u>
Environmental Protection Agency
Soil Conservation Service
Agricultural Stabilization and Conservation Service
Farmers Home Administration
Army Corps of Engineers
Department of Transportation

Municipal and county government can appropriate general funds for mitigation measures and act as a local sponsoring agency. Counties can establish "subordinate service districts" pursuant to Minnesota Statutes Chapter 375. Subordinate service districts allow a county to provide additional governmental services only within that service district. Importantly, the revenues to fund these additional government services come only from within the subordinate service district. These districts may be initiated either by a resolution of the county board or by petition to the county board signed by ten percent of the qualified voters within the portion of the county proposed for the subordinate service district.

Under the Clean Lakes Program the MPCA provides federal matching grants to eligible local units of government (watershed districts, lake improvement districts, cities, counties, and other governmental units recognized by state statute). These funds are used to develop and implement methods to control the sources of pollution that impacts freshwater lakes which have deteriorated in water quality. The emphasis of the program is on watershed management and the reduction of external pollutant loading to lakes.

Permits

Certain projects that a lake community may wish to carry out will require a permit from a local, state, or federal agency. Any project constructed below the ordinary high water mark, which alters the course, current, or cross-section of protected waters or wetlands is subject to the regulatory jurisdiction of the Department of Natural Resources. Copies of the DNR Protected Waters map are available for public inspection at all DNR regional and area offices, local Soil and Water Conservation District offices, and the County Auditors' office, or may be purchased from the Minnesota Documents Division. Some projects will not require permits from the DNR if certain conditions are met. However, local units of government and other agencies, such as the U.S. Army Corps of Engineers, may still require permits for these projects. The Corps of Engineers is responsible for regulating all work in navigable waters in the United States and the placement of fill in almost all waters and wetlands. A permit from the Corps may be required by property owners or contractors before any fill is placed in any body of water or wetland.

Data Collection Costs

The cost of gathering water quality information is a considerable planning constraint. Lake communities that collect data unaided by government agencies will by necessity keep their efforts modest; intensity of effort will be dictated by the availability of funding. Some basic costs are listed here to provide an understanding of the data collection possibilities relative to cost.

Lake surface area can be obtained from topographic maps ($4.00), lake maps ($4.50), both available from the Minnesota Documents Division, or from aerial photos on file with the Soil Conservation Service or the U.S. Fish and Wildlife Service. Plastic grids for estimating area can be purchased for about $5.00. Mean depth can be determined at no extra cost if a lake contour map is available from which lake volume can be calculated (mean depth = lake volume/lake surface area).

Two alternatives are available for developing a dissolved oxygen profile:

a. Purchase of a YSI oxygen meter is initially costly but will reduce collection time and, over the years, may prove to be a good investment for a lake community. Costs include the meter ($645), oxygen probe ($157), cables ($100), and a membrane kit ($9), for a total of $911.

b. A dissolved oxygen kit good for 100 tests costs $39.95. This is a small expense compared with the oxygen meter, but is less accurate and not as handy to use.

To determine a temperature profile It is best to use a thermometer that can be lowered into the lake to specific depths and read from the surface. A Thermistor thermometer costs $396 and the probe is about $27 for a total of $423.

A commercially produced Secchi disc costs about $22, but a home-made disc is inexpensive and easy to make. The MPCA-CLMP start-up cost (which includes a disc) is only $10.

The cost of water sampling bottles and apparatus may be minimal. A home-made water sampler can be constructed from readily available materials (Lundquist, 1975). Some commercial water testing facilities provide properly prepared sample bottles as part of their testing service. The expense of transportation or mailing will also have to be considered.

Commercial laboratory analysis of water samples is available to lake communities. The following range of prices reflect current laboratory costs in the metropolitan area.

Total phosphorus	$17-$20
Total Kjeldahl nitrogen	$16-$28
TP and TKN combined	$25
Total dissolved solids	$12-$16
Total alkalinity	$11-$15
Specific conductance	$11-$15
Total dissolved phosphorus	$10
Nitrite and nitrate	$15-$18
Ammonia nitrogen	$9-$20

The cost of a second or third sample (i.e. more than one sample site) may be less than the first sample because the cost of setting up the testing equipment is applied to the first sample. Some arrangement might possibly be made with a local university to do the lab tests at a lower rate.

Water analysis kits are also available. These kits do not provide the precision that a lab could produce. However, the kits are fairly inexpensive and will provide ball park figures. The following is a representative list of 1987 retail catalog prices.

Test	Price	Number of tests
Total phosphorus	$99.75	100
Ammonia nitrogen	$20.00	50
Nitrate	$44.75	50
Nitrite	$11.95	50
Dissolved oxygen	$39.95	100
pH	$57.50	300
Color	$44.00	no limit

Summary

The processes of gathering data and acquiring assistance and funding are not as complicated as they may seem. The work required of single individuals should not be a great burden if the effort can be spread throughout the entire lake community. Citizen involvement cannot be overstressed. It creates a sense of achievement and belonging while providing a tremendous opportunity for learning about the local environment, especially in respect to its human component.

At the federal level, recent and pending legislation may simplify the efforts of lake communities as they seek to maintain or improve lake quality. Congress in 1987 re-funded the Clean Lakes Program, making further money available for lake improvement projects. Minnesota, in the past, has been very successful gathering money from this program. Another federally funded program, the Clean Water Partnership Program also got off to a promising start on the strength of its initial funding, and additional funding will be pursued.

In the near future, the state's enabling statutes may be combined and streamlined to allow all local governmental units to act under the same planning statutes. This would simplify the regulations by reducing redundancy, conflict, and confusion over jurisdiction and statute language. At present the MDNR is in the process of upgrading the state shoreland regulations in an effort to more sensibly regulate development near our water resources. The MPCA sewage regulations are also being reviewed and upgraded.

The emphasis on planning results from an increased concern over the effects of development on our natural resources. Unguided growth has helped create many of the environmental problems we face today. Planning is an attempt to direct future growth in a way that not only reflects a community's goals, but protects the local resources and corrects, as much as possible, past mistakes. The success of a lake management program depends on good planning. It should always be remembered that the cleanup of a degraded lake can be very expensive. Dredging sediments or flushing lakes with fresh groundwater are costly processes that will not solve the overall pollution problems. User expectations, once established, are not easily altered. Plans on the drawing board are much easier to cancel than are the finished products. Cure lake watershed ills where necessary, but plan as much as possible with prevention in mind.

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GLOSSARY

Alkalinity: Capacity of a lake to neutralize acid.

Berm: A nearly horizontal part of a lakeshore, usually formed at the high water line by waves depositing material.

Bluff: Type of shoreland characterized by a steep slope, subject to rapid runoff, erosion, and sedimentation. The DNR Shoreland Management Regulations define bluff as "any area where the average slope of the land is greater than 30% as measured over horizontal distances of 50 feet or more.

Capita-year: An expression of the number of people contributing to the ecological impact on a lake.

Carrying Capacity: The amount of use an area can accommodate without its basic character and recreation quality being affected.

Chlorophyll-a: The primary photosynthetic pigment in plants, a measure of the concentration of algae in lakes.

Critical Loading: The nutrient loading level beyond which a lake may be characterized as eutrophic.

Crowding: A level of use that exceeds the user's definition of capacity.

Development: Growth or advancement of housing, recreational facilities, business, industry, or agriculture.

Ecoregion: An environmental area characterized by a specific land use, soil types, land surface form, and potential natural vegetation.

Ecosystem: A community of interaction among animals, plants, and microorganisms, and the physical and chemical environment in which they live.

Epilimnion: Upper, warm layer of a lake during summer thermal stratification.

Eutrophication: The aging process by which lakes are fertilized with nutrients. Natural eutrophication will very gradually change the character of a lake. Cultural eutrophication is the accelerated aging of a lake as a result of human activities.

Eutrophic Lake: A nutrient-rich lake--usually shallow, "green," and with limited oxygen in the bottom layer of water.

Export Coefficient: An estimate of the expected annual amount of a nutrient transported from its source to a lake.

Flushing Rate: The number of times per year that a volume of water equal to the lake's volume flows through the lake.

Hydrologic Residence Time: The amount of time a volume of water equal to the volume of the lake remains in the lake.

Hydrology: The study of the processes affecting the occurrence and movement of water on the earth's surface, in the soil and underlying rocks, and in the atmosphere.

Hypolimnion: Lower, cooler layer of a lake during summer thermal stratification.

Lake Management: A process that involves study, assessment of problems, and decisions affecting the maintenance of lakes as thriving ecosystems.

Lake Slope: Shoreland characterized by a low rise.

Mass Balance: An equation stating that the average phosphorus concentration in a lake is determined by the amount of phosphorus loaded into the lake minus losses to the sediment and lake outflow.

Mesotrophic Lake: Midway in nutrient levels between the eutrophic and oligotrophic lakes.

mg/L: Milligrams per liter; also parts per million.

Model: A representation of an actual situation.

Morphometric: Relating to description of lake basin size and shape.

Nonpoint Source: Polluted runoff--nutrients and pollution sources not discharged from a single point: e.g. runoff from agricultural fields or feedlots.

Nitrogen: A major nutrient that affects the productivity of fresh waters.

Nutrient Budget: An itemized estimate of nutrient availability (usually for a period of one year), taking into account all sources and losses.

Nutrient Loading: The input of nutrients to a lake.

Oligotrophic Lake: A relatively nutrient-poor lake, it is clear and deep with bottom waters high in dissolved oxygen.

Permissible Loading: The nutrient loading level below which a lake will remain oligotrophic.

pH: A measure of acidity.

Phosphorus: A nutrient necessary for plant growth; commonly the first element to limit biological productivity.

Point Sources: Specific sources of nutrient or polluted discharge to a lake: e.g. stormwater outlets, sewage plant discharge.

Resource Capacity: The level of use of a recreation resource beyond which irreversible biological deterioration takes place or degradation of the physical environment makes the resource no longer suitable or attractive for that recreational use.

Retention Time: The amount of time that a nutrient remains in a lake.

Riparian: Owning property or living on the shore of a lake.

Secchi Disc: A device measuring the depth of light penetration in water.

Sedimentation: The addition of soils to lakes, a part of the natural aging process, makes lakes shallower. The process can be greatly accelerated by human activities.

Shoreland: Land located within 1000 feet from the ordinary high water level of a lake or pond. Within this drainage area, runoff tends to move toward the lake along individual paths formed by gullies, ditches, driveways, and streets.

Social Carrying Capacity: A measure of the amount of recreational use that people will tolerate.

Soil Retention Coefficient: An estimate of how well soil immobilizes a nutrient such as phosphorus.

Spring Turnover: After ice melts in spring, warming surface water sinks to mix with deeper water. At this time of year, all water is the same temperature.

Steady State: An average lake water chemistry condition; it does not reflect fluctuations.

Sub-basin: A small watershed nested within the larger watershed of a lake; most tend to be leaf-shaped with the narrow part (the mouth) at the lake itself.

Terrace: A flat, raised mound of earth having sloping sides and situated above the water table.

Thermocline: During summertime, the middle layer of lake water. Lying below the epilimnion, this water rapidly loses warmth.

Tier: One of a series of rows of development around a lake.

Transparency: Light penetration.

Trophic Status: The level of growth or productivity of a lake as measured by phosphorus content, algae abundance, and depth of light penetration.

ug/L: Micrograms per liter; also parts per billion.Watershed: The surrounding land area that drains into a lake, river, or river system.

Water Budget: The water balance in a lake described by an equation in which the change in storage of water equals the rate of inflow from all sources minus the rate of water loss.

Water Quality: A state of lake water represented by a combination of productivity, chemistry, cleanliness, and recreational potential.

Watershed: The area that drains into a lake; also, drainage basin.

Wetland: Swamps, marshland, or bogs; serve as water storage and purification areas.

APPENDIX

Excerpt from "Minnesota Water Surface Use Statutes and Rules." Minnesota Department of Natural Resources. St. Paul, Mn. 1983.

Minn. Statutes, Section 378.32 WATER SURFACE USE REGULATION.

Subdivision 1. The county board of every county may by ordinance regulate the surface use of any bodies of water situated wholly or partly within the boundaries of the county and not situated entirely within the boundaries of a single city or lake conservation district established by law, except that where a body of water lies in more than one county no such ordinance shall be effective until adopted by the county boards of all the counties in which the body of water lies pursuant to section 471.59 or placed into effect by order of the commissioner of natural resources pursuant to section 361.26. With the authorization of the affected city or lake conservation district, a county board may assume and exercise the powers set forth in this section with respect to bodies of water lying wholly within that city or lake conservation district. The regulation by the county of the surface use of any portion of a body of water situated within the boundaries of a city shall be consistent with any regulations existing on May 25, 1973 of the surface use of that portion of the body of water, by the city. After January 1, 1975, any such ordinance shall be consistent with the provisions of chapter 361 and rules and regulations of the commissioner promulgated pursuant to section 361.25. Any surface use zoning ordinances adopted pursuant to this section by a local governmental unit subsequent to May 26, 1973 is invalid unless it is approved by the commissioner. Proposed surface use zoning ordinances shall be submitted to the commissioner for his review and approval prior to adoption. The commissioner shall approve or disapprove the proposed ordinance within 120 days after receiving it. If the commissioner disapproves the proposed ordinance, he shall return it to the local governmental unit with a written statement of his reasons for disapproval. The county board shall have power:

Subd. 2. To regulate and police public beaches, public docks and other public facilities for access to the body of water, except that a county board may not regulate state accesses and a municipality may by ordinance forbid the exercise of this power within its jurisdiction;

Subd. 3. To regulate the construction, configuration, size, location and maintenance of commercial marinas and their related facilities including parking areas and sanitary facilities. The regulation shall be consistent with state law and the regulations of the department of natural resources, the pollution control agency, and department of health, and with the applicable municipal building codes and zoning ordinances where the marinas are situated;

Subd. 4. To regulate the construction, installation and maintenance of permanent and temporary docks and moorings consistent with state and federal law and sections 105.42, 361.07 and 361.21;

Subd. 5. To regulate the construction and use of mechanical and chemical means of deicing the body of water and to regulate the mechanical and chemical means of removal of weeds and algae from the body of water consistent with the regulations of the department of natural resources;

Subd. 6. To regulate the type and size of watercraft, as defined in section 361.02, subdivision 7, permitted to use the body of water and set access fees;

Subd. 7. To limit the types and horsepower of motors used on the body of water;

Subd. 8. To limit the use of the body of water at various times and the use of various parts of the body of water;

Subd. 9. To regulate the speed of watercraft on the body of water and the conduct of other activities on the body of water to secure the safety of the public and the most general public use;

Subd. 10. To contract with other law enforcement agencies to police the body of water and its shore.

Department of Natural Resources Regulations
For Water Surface Use Management

6110.3000 Policy. It is the policy of this state to promote full use and enjoyment of waters of the state, to promote safety for persons and property in connection with such use, and to promote uniformity of laws relating to such use.

6110.3100 Scope. As part of implementing that policy, Minn. Stat. 378.32 and 459.20 authorize counties, cities, and towns to regulate by ordinance the use of surface waters by watercraft, upon approval of any such ordinance by the commissioner. Minn. Stat. 361.26, subd. 2a authorizes the commissioner to regulate such use by rule, upon request of a county, city, or town, and after the rule is approved by the majority of the counties affected. These rules, however, shall not apply to units of government other than counties, cities and towns, or to counties, cities or towns adopting ordinances identical to and on the same body of water as a lake conservation district ordinance.

6110.3200. Goal. The goal of water surface use management shall be to enhance the recreational use, safety, and enjoyment of the water surface of Minnesota and to preserve these water resources in a way that reflects the state's paramount concern for the protection of its natural resources. In pursuit of that goal, an ordinance or rule shall:

1. Where practical and feasible accommodate all compatible recreational uses.
2. Minimize adverse impact on natural resources.
3. Minimize conflicts between users in a way that provides for maximum use, safety and enjoyment.
4. Conform to the standards set in 6100.3700.

611-.3300 Authority. These rules are required by Minn. Stat. 361.25. They provide procedures for the development and approval of rules and ordinances for resolving water surface use conflict by regulating:

1. Type and size of watercraft.
2. Type and horsepower of motors.
3. Speed of watercraft.
4. Time of use.
5. Area of use.
6. The conduct of other activities of the water body where necessary to secure the safety of the public and the most general public use.

6110.3400 Jurisdiction.

1. The commissioner shall exercise his discretion under Minn. Stat. 361.26, subd. 2 to regulate a water body when so requested by a county, city, or town only when the water body
    a. is traversed by a state or international boundary; or
    b. is within the jurisdiction of two or more counties which cannot agree on the content of ordinances; and
    c. regulation is necessary to achieve the goals in 6110.3200.
2. In all other cases, water surface use regulation shall be by country, city, or town ordinance as specified in Minn. Stat. 378.32 and 459.20. If a body of water is located within the jurisdiction of two or more cities or towns which cannot agree on the content of ordinances, any such city or town may petition the county in which they are located to adopt an ordinance.

6110.3500 Existing ordinances and rules. All existing ordinances and rules adopted on or after January 1, 1975 affecting water surface use shall be brought into compliance with these rules within a reasonable time period after promulgation of these rules.

6100.3600 Assessment of conditions.

A. Factors to consider. The commissioner or any governmental unit formulating, amending or deleting controls for surface water shall acquire and consider the following information, noting factors that are not relevant:

1. Physical characteristics.
    a. Size-normal surface acreage, if available, or the basin acreage listed in the Division of Waters Bulletin No. 25, "An Inventory of Minnesota Lakes."
    b. Crowding potential-expressed as a ratio of water surface area to length of shoreline.
    c. Bottom topography and water depth.
    d. Shore soils and bottom sediments.
    e. Aquatic flora and fauna.
    f. Water circulation-for lakes, the existence and locations of strong currents, inlets, and large water level fluctuations; for rivers and streams, velocity and water level fluctuations.
    g. Natural and artificial obstructions or hazards to navigation, including but not limited to points, bars, rocks, stumps, weed beds, docks, piers, dams, diving platforms, and buoys.
    h. Regional relationship-the locations and the level of recreational use of other water bodies in the area.
2. Existing development.
    a. Private-to include number, location, and occupancy characteristics of permanent homes, seasonal homes, apartments, planned unit developments, resorts, marinas, campgrounds, and other residential, commercial, and industrial uses.
    b. Public-to include type, location, size, facilities, and parking capacity of parks, beaches, and watercraft launching facilities.
3. Ownership of shoreland-to include the location and managing governmental unit of shoreline in federal, state, county, or city ownership as well as private, semi-public, or corporate lands.
4. Public regulations and management-to include federal, state or local regulations and management plans and activities having direct effects on watercraft use of surface waters.
5. History of accidents which have occurred on the surface waters.
6. Watercraft use-to include information obtained in the morning, afternoon, and evening on at least one weekday and one weekend day, concerning the number and types of watercraft in each of the following categories.
    a. Kept or used by riparians.
    b. Rented by or gaining access through resorts or marinas.
    c. Using each public watercraft launching facility.
    d. In use on the waterbody.
7. Conflict perception and control preferences-to include opinions gained by surveys or through public meetings or hearings of riparians, transients, local residents, and the public at large.

B. Written statement. Any governmental unit formulating, amending or deleting controls for surface waters shall submit to the commissioner the following:

1. The information requested in 6110.3600 A., portrayed on a map to the extent reasonable.
2. A statement evaluating whether the information reveals significant conflicts and explaining why the particular controls were selected.
3. The proposed ordinance.

4. A description of public hearings held concerning the proposed controls, including an account of the statement of each person testifying.

C. Commissioner review and approval.

1. The commissioner shall require the ordinance proposer to provide additional information of the kind described in 6110.3600 A., when needed in order to make an informed decision. The commissioner shall approve the ordinance if it conforms with these rules.

6110.3700 Water surface management standards. To promote uniformity in ordinances or rules on the use of watercraft on surface waters of this state, to encourage compliance and to ease enforcement, the commissioner and any government unit formulating such ordinances or rules shall follow these standards. When formulating an ordinance or rule, it is not required that all the standards listed below be incorporated into every ordinance or rule. Rather, the commissioner or governmental unit shall select from the standards listed below such standard(s) as are needed to regulate the surface use of waters.

A. Watercraft type and size. Controls may be formulated concerning the type and/or size of watercraft permissible for use on surface water body(ies) and portions thereof.

B. Motor type and size. Controls, if any, concerning the maximum total horsepower of motor(s) powering watercraft on surface waters shall utilize one or more of the following horsepower cutoffs or motor types.

1. 25 H.P.
2. 10 H.P.
3. Electric motors
4. No motors

C. Direction of travel. Directional controls, if used, shall mandate watercraft to follow a counter-clockwise path of travel.

D. Speed limits. Controls, if any, concerning the maximum speeds allowable for watercraft on surface waters shall utilize one or more of the following miles-per-hour cutoffs:

1. Slow-No Wake. "Slow-No Wake" means operation of a watercraft at the slowest possible speed necessary to maintain steerage and in no case greater than 5 mph.
2. 15 mph.
3. 40 mph.

E. Effective time.

1. Controls must use one or more of the following time periods.
    a. Sunrise-sunset or sunset-sunrise the following day.
    b. 9:00 a.m.-6:00 p.m. or 6:00 p.m.-9:00 a.m. the following day.
    c. Noon-6:00 p.m. or 6:00 p.m.-noon the following day.
    d. All 24 hours. of the day.
2. Controls must be in effect during one of the following calendar divisions:
    a. All year.
    b. Memorial Day weekend through Labor Day weekend.
    c. On all weekends and legal holidays occurring within period b.
3. Controls governing the use of watercraft may be adopted which are placed into effect based upon specific water elevations.

F. Area zoning.

1. Controls shall clearly specify which portion of the water body is affected by such controls.
2. Area controls may be formulated concerning any of the subject matter covered in the water surface management standards A-H.

3. Controls concerning a "Slow-No Wake" shall be established for the entire water body or portion thereof according to the following criteria:

a. Within 100 ft. or 150 ft. from the shore; or

b. Where watercraft speed or wake constitutes a hazard to persons, property or the natural resources; or

c. Where it has been determined that such control(s) would enhance the recreational use and enjoyment of the majority of users.

G. Conduct of other activities on a body of water. Controls formulated by a governmental unit which restricts other activities (such as swimming, or SCUBA diving) shall conform to 6110.3200.

H. Emergencies. In situations of local emergency, temporary special controls may be enacted by a county, city or town for a period of not more than five days without the commissioner's approval. The commissioner shall be notified, however, as soon as practicable during this five day period.

I. A government unit may submit additional evidence if it feels that variance from the afore stated standards is necessary to best address a particular problem. The commissioner will review such evidence and shall grant a variance if there are circumstances peculiar to the body or bodies of water in question of such magnitude as to overshadow the goal of uniformity.

6110.3800 Administrative provisions.

A. Enforcement and penalties.

1. Any government unit adopting ordinances pursuant to Minn. Stat. 378.32 and 459.20 shall provide for their enforcement and prescribe penalties for non-compliance. Rules established pursuant to Minn. Stat. 361.26 shall be enforced by conservation officers of the Department of Natural Resources and the sheriff of each county.

2. Rules or ordinances shall contain a provision exempting authorized resource management, emergency and enforcement personnel when acting in the performance of their assigned duties. They may also provide for temporary exemptions from controls through the use of permits issued by the unit of government adopting the ordinance or rule.

B. Commissioners's approval

1. Any governmental unit formulating ordinances or desiring amendments and deletions to existing ordinances shall submit the written statement required by these rules with the proposed ordinance to the commissioner pursuant to Minn. Stat. 378.32 for his approval or disapproval. Determination of approval or disapproval shall be based upon the written statement and the compatibility of the ordinance with these rules. If the proposed ordinance is disapproved by the commissioner and a satisfactory compromise cannot be established, the governmental unit may initiate a contested case hearing to settle the matter.

2. The commissioner shall notify the governmental unit in writing of his approval or disapproval of proposed ordinances within 120 days after receiving them pursuant to Minn. Stat. 378.32. Failure to so notify shall be considered approval.

C. Notification.

1. Any governmental unit adopting ordinances shall provide for adequate notification of the public, which shall include placement of a sign at each public watercraft launching facility outlining essential elements of such ordinances, as well as the placement of necessary buoys and signs. All such signs and buoys shall meet requirements specified in Minn. Stat. 361 and NR 204-207.

2. The commissioner shall publish and update at his discretion a listing of watercraft use rules and ordinances on surface waters of the state for distribution to the public.