Techniques for Estimating Boating Carrying Capacity: A Literature Review

Prepared for:
Catawba-Wateree Relicensing Coalition

Prepared by:
Holly E. Bosley
North Carolina State University
Department of Parks, Recreation & Tourism Management

August, 2005

Techniques for Estimating Boating Carrying Capacity:
A Literature Review

INTRODUCTION

This document is a review of the existing literature on techniques for estimating recreational carrying capacity on a lake, in terms of number and types of watercraft. There are many existing definitions of carrying capacity in a recreation context; however, one would be remiss not to include the definition provided by two of the premier scholars in the recreational carrying capacity literature. Bo Shelby and Thomas Heberlein (1986) define carrying capacity as "the level of use beyond which impacts exceed levels specified by evaluative standards" (p. 18).

The concept of carrying capacity was developed in the fields of biology and ecology, where it was applied to wildlife management to ascertain "the number of animals that can be maintained in a given habitat before undue biological or ecological impacts occur" (Manning, Lime, & Hof, 1996, p. 118). Carrying capacity was then applied to park management when increasing numbers of visitors became a concern. The added human component broadened the concept of carrying capacity from a purely biological one to a complex issue with both biological and social components.

Carrying capacity determination is not a matter of computing and rigidly enforcing a single, explicit maximum value. Instead, carrying capacity includes an element of perception from recreation area users and managers, who add the human component to recreational carrying capacity. For this reason, the carrying capacity determination is never purely objective. As such, capacity is often reported in the form of a range of estimates as opposed to an optimum or maximum value. Capacity will vary from site to site in accordance with visitor behavior and preferences, as well as management goals.

This document will examine a variety of literature on recreational carrying capacity. Emphasis is placed on boating density methodology and other factors pertinent to lake carrying capacity estimation. The boating carrying capacity studies that were reviewed contained the following categories of analysis: use characteristics, usable lake area, boating density, lake use rate, and boaters' perceptions of crowding. These categories are summarized below, followed by in-depth reviews of all seven selected studies.

Use Characteristics

Use characteristics are those data which indicate how the lake is being used, and by whom. Carrying capacity studies use various techniques to estimate the total number of boats, the number and types of boats in use at peak and non-peak times, and the distribution of use between shoreline residents and visitors. Studies reviewed in the present document utilized the following methods to estimate use:

- On-the-water surveying
- On-the-ground surveying, contact surveys
- Mail-back surveys
- Aerial fly-overs
- Parking lot vehicle counts

Usable Lake Surface Area

The most common way to calculate usable lake surface area is to subtract a *shoreline buffer zone* of predetermined width from the total acreage of the lake. These buffer zone widths typically range from 100 to 200 feet. Jaakson, Buszynski, and Botting (1990) also recommended buffer zones around emergent aquatic vegetation (100 feet) and marinas and public swimming beaches (400 feet).

In several studies, the issue of *depth fluctuation* was also addressed with regard to surface area determination, since a lake with a lower depth will have a smaller total surface area. For the most conservative usable surface area calculation, the lowest lake depth should be used in conjunction with a shoreline buffer zone.

Boating Density

Boating density, measured in surface acres per watercraft, could be viewed as the most systematic component of the carrying capacity estimation process. Even so, optimum densities vary depending on users' preferred setting types and site-specific attributes. Additionally, some studies provide aggregate densities, applicable to the entire lake, while others specify a density for each type of watercraft. This literature review includes a number of boating density standards. These acreage specifications range from 1.3 acres per watercraft for fishing from a boat or canoeing/kayaking (Warren & Rea, 1989) to up to 3,200 acres per boat for a primitive recreational boating setting (Aukerman et al., 2004).

Lake Use Rate

Lake use rate is a measure of the estimated proportion of moored boats on the lake at any given time, plus the estimated percent capacity of public access sites. For boats moored at existing shoreline developments, research studies have estimated peak use rate to range from 3.6% (ERM, 2004) to 25% (Jaakson et al., 1990). If historical data on lake use rate exist, those figures should be used instead of generic peak use rate recommendations. Percent capacity of public access sites is only mentioned in one of the reviewed studies, and the recommended percentage for lake use rate is 50%, unless existing data or park staff indicate otherwise (ERM, 2004).

Boaters' Perceptions of Crowding

Boaters' perceptions of crowding on the water are measured via on-site and mail-back surveys. Visitors responding to on-site surveys report their perceptions of crowding for a specific day, while residents responding to mail-back surveys report their overall perceptions of crowding. Crowding is often measured on either a 5- or 9-point Likert-type scale. Shelby and Heberlein's (1986) 9-point scale is commonly used (cf. EDAW, 2004b; Falk et al., 1992). Crowding is typically perceived to be highest on holiday weekends, but no significant relationships have been found between perceived crowding and boater satisfaction. Digitally enhanced photographs have also been used to gauge users' perceptions of crowding.

1. Four Township Recreational Carrying Capacity Study: Pine Lake, Upper Crooked Lake, Gull Lake, Sherman Lake (Michigan)
Authors: PAE

Estimating Recreational Carrying Capacity on a Lake

The authors of this study, a consulting firm by the name of Progressive Architecture Engineering (hereafter referred to as PAE), acknowledge that there is no universal formula for calculating recreational carrying capacity, since the human elements of judgment and perception are inextricable pieces of the carrying capacity puzzle. Consequently, "there is no single boating density standard that will satisfy all lake users in all situations" (PAE, 2001, p. 1).

While there is no singular "magic number," useful estimates of recreational carrying capacity *can* be constructed. PAE lists the following items as key factors to evaluate when estimating the recreational carrying capacity of a lake: "lake physical characteristics, use characteristics (i.e., the number of lakeside homes, moored boats, the number and type of access sites, and current boating activity), environmental impacts, usable lake area, boating density, and lake use rate" (p. 2). These six factors are explained below.

Lake Physical Characteristics

In terms of lake physical characteristics, PAE states that a lake's "size, shape, and depth strongly influence recreational carrying capacity" (p. 3). They describe a size-independent measure of lake shape, known as *shoreline development factor* (SDF), which is defined as "a measure of the degree of irregularity in the shape of the shoreline" (PAE, p. 3). SDF compares the actual length of the shoreline around a lake to the minimum shoreline length of a lake with the same area (i.e., if the lake were a perfect circle). See Equation 1.

Equation 1
Shoreline Development Factor (SDF)

$$\text{SDF} = \frac{\text{Length of shoreline around lake}}{\text{Circumference of circle with area equal to that of lake}}$$

A higher ratio indicates a more irregular shoreline. Irregular shorelines, with their coves and inlets, "may serve to isolate impacts…[but] also imply greater safety risks as well as ecological consequences" (Wagner, 1991, as cited in PAE, p. 3).

Use Characteristics

Use characteristics are those data which indicate how the lake is being used, and by whom. To evaluate lake use characteristics, PAE performed field surveys to count the number of moored boats, lakeside homes, marinas, and other facilities (e.g., university research stations; camp facilities).

In conjunction with on-the-ground surveying, two aerial fly-overs were conducted. Distributions of the number and types of boats in use as well as moored boats were determined for the following boat types: boats with motors greater than 25 HP, boats with motors less than or equal to 25 HP, personal watercraft, sailboats, and non-motorized boats. The researchers recognize the inherent limitation to fly-over data, since it only captures information on use characteristics at one specific moment in time. Their technique, however, is more powerful than other aerial surveying methods because it distinguishes among various boat types.

To differentiate between boats launched from public access sites and those launched from private lakefront properties, PAE also counted the number of vehicles with trailers that were parked in the public access parking sites at the time of the fly-overs.

Environmental Impacts

PAE's section on environmental impacts of recreational boating was quite comprehensive. Some of the more common impacts of boating activity are "fuel emissions from boat motors, suspension of bottom sediments, decreased water transparency, shoreline erosion, destruction of fish spawning areas, and loss of valuable fish and wildlife habitat" (PAE, p. 10).

Portions of the lake less than 5 feet deep are most susceptible to environmental impacts. As such, PAE introduced a second ratio, called the *shallowness ratio*, which is calculated as follows:

Equation 2
Shallowness Ratio (SR)

$$SR = \frac{\text{Area of lake less than 5 ft. deep}}{\text{Total area of lake}}$$

The shallowness ratio represents the proportion of the lake bottom likely to be affected by motorized watercraft. A ratio less than 0.10 is considered low, while a ratio greater than 0.50 is considered high.

Usable Lake Area

PAE states that "most environmental problems associated with boating activity occur in shallow waters" (p. 13). Thus, in addition to considering a shallowness ratio for the lake as a whole, PAE recommends a minimum 100-foot shoreline safety/environmental protection zone. Usable lake area is then calculated as the difference between total lake area and the shoreline safety/environmental protection zone. A Michigan state law is in place to enforce no-wake zones within 100 feet of the shoreline and in water less than three feet deep.

PAE also raises an important point regarding water level fluctuations. When the water level drops, the usable lake area is reduced. Carrying capacity would thus be lower during periods of low lake level. The study does not provide any methodological suggestions for accounting for this fluctuation when estimating usable lake area.

Boating Density

Boating density is a recommended spatial requirement, measured in acres per boat, for various types of watercraft. PAE provides a useful table summarizing five studies on optimum boating densities. Most densities in this table are aggregate, giving only a suggested density for all boating uses combined. The table is reproduced below.

Table 1
Summary of Optimum Boating Densities

Source	Suggested Density	Boating Uses
Ashton (1971)	5 to 9 acres/boat	All uses combined in Cass Lake
	4 to 9 acres/boat	All uses combined in Orchard Lake
	6 to 11 acres/boat	All uses combined in Union Lake
Kusler (1972)	40 acres/boat	Waterskiing - All uses combined
	20 acres/boat	Waterskiing
	15 acres/boat	Coordinated waterskiing
Jaakson et al. (1989)	20 acres/boat	Waterskiing and motorboat cruising
	10 acres/boat	Fishing
	8 acres/boat	Canoing, kayaking, sailing
	10 acres/boat	All uses combined
Wagner (1991)	25 acres/boat	All recreational activities
Warbach et al. (1994)	30 acres/boat	All motorized (> 5 HP) uses

Note. From "Four Township Recreational Carrying Capacity Study: Pine Lake, Upper Crooked Lake, Gull Lake, Sherman Lake," by, PAE, 2001, p. 13.

The Jaakson et al. (1989) study appearing in Table 1 will be reviewed below (see p. 9).

Based on these previous studies, PAE determined that 10 to 15 acres of water surface per boat would be a conservative, aggregate estimate of optimum boat density. High-speed watercraft (PWC and boats with motors greater than 25 HP) require more space, so this density estimate was then adjusted for each of the four lakes in the study area, depending on the proportion of high-speed watercraft. The *boating density adjustment equation* is calculated as follows:

<u>Equation 3</u>
Boating Density Adjustment Equation

Boating density (in acres) = 10 + 5*(proportion of high-speed watercraft)

Hence, if there were no high-speed watercraft on a particular lake (i.e., proportion of high-speed watercraft = 0.00), then its optimum boating density would be 10 acres per boat. Conversely, if all boats on a lake were high-speed watercraft (i.e., proportion of high-speed watercraft = 1.00), then the boating density would be 15 acres per boat.

Lake Use Rate

Lake use rate is defined as the proportion of the total number of moored boats on the lake at any given time. Based on historical data collected at the study site, PAE was able to estimate a peak use rate of 10%. That is, at peak usage times, 10% of the riparian boats (i.e., boats moored at existing shoreline developments) will be on the lake. However, when empirical data on lake use rate is not available, a more conservative peak use rate of 15% is suggested (Warbach et al., 1994, as cited in PAE, 2001).

For boats launched from public access sites, it was assumed that facilities would be at 50% capacity during peak use periods, unless existing data demonstrated otherwise. For example, at one particular study area facility, park staff reported a peak use rate of 100%. PAE does not justify their decision to use 50% capacity as the use rate for public access sites.

The total estimate of the number of boats on a lake during peak use periods is found by summing these two lake use rate estimates, as shown below in Equation 4.

Equation 4
Estimated Number of Boats at Peak Use

Total number of boats = 0.10*(# of riparian boats) + 0.50*(max. capacity at public access site)

Carrying Capacity Calculation

Equations 5 and 6 below are used to calculate carrying capacity in terms of the optimal number of boats on the lake. First, the optimal number of boats is calculated, as shown in Equation 5.

Equation 5
Optimal Number of Boats on Lake

$$\text{Optimal number of boats} = \frac{\text{Usable lake area}}{\text{Optimum boating density}},$$

where usable lake area is the adjusted lake area (subtracting a 100-foot shoreline safety/environmental protection zone) and optimum boating density is between 10 and 15 acres per boat (based on the adjustment equation defined in Equation 3 above).

The resultant estimated carrying capacity is expressed in terms of percentage at peak use, and it is calculated as follows:

Equation 6
Percentage at Peak Use

$$\textbf{Carrying Capacity} = \frac{\textbf{Estimated number of boats at peak use}}{\textbf{Optimal number of boats}}$$

Carrying capacity is exceeded when the percentage at peak use (see Equation 6) is greater than 100%.

Two of the factors described above – lake physical characteristics and environmental impacts – are not included in the carrying capacity estimate. PAE does not provide a system for incorporating shoreline development factor or shallowness ratio into the carrying capacity equation.

2. Carrying Capacity and Lake Recreation Planning, Parts I & II
Study Area: North-Central Saskatchewan, Canada
Authors: Jaakson, Buszynski, and Botting (1989, 1990)

Carrying Capacity Spectrum Model

Jaakson et al. (1989) write that "[o]ne weakness that is common to most of the past recreation carrying capacity methods is that each model has tended to result in a separate, isolated lake management guideline…However, lake recreation planning should be flexible enough to include several alternative approaches to management, since in environmental matters generally, ultimatum-type decisions are difficult to justify" (p. 12). Consequently, Jaakson et al. describe a *carrying capacity spectrum model*, consisting of four capacity calculations. Providing these options is important since every management scenario has different priorities and intended outcomes. The four capacity calculations are:

1. **Natural shoreline reserve calculation:** What percentage of the shoreline should be preserved in its natural, undeveloped state?

2. **The shoreline capability calculation:** How many shoreline residences are desirable for development? How many new residences can the shoreline physically sustain?

3. **The theoretical boat-density calculation:** How does the number of boats that theoretically could be active on a lake at a given time compare with the number of boats introduced to the lake from existing shoreline developments and public access points?

4. **The observed boat-density calculation:** What are the actual boating conditions on a lake?

Most relevant to the present literature review are theoretical and observed boat-density calculations. The difference between theoretical and observed boat-density is explained as follows: "the theoretical densities provide a constant index of what past research has shown to be generally accepted standards for safe boating, while the observed densities – which may vary over time as recreation patterns change – provide a current detailed index of actual boating conditions on a lake" (Jaakson et al., 1990, p. 8).

Theoretical Boat Density Assumptions

The following assumptions were made regarding theoretical boat-density calculations:

- Shoreline protection zones: 200 feet for the lake in general, 100 feet around emergent aquatic vegetation and navigation hazards, and 400 feet around marinas and public swimming beaches

- Lake use rate: 25% of the total number of boats may be on the water on a peak day

- Aggregate density: 10 acres of water per boat is required for safe boating (Schneberger & Threinen, 1964, as cited in Jaakson et al., 1990)

It is important to note how these assumptions contrast with those in the above study review. The shoreline buffer zone is more comprehensive, providing a more conservative carrying capacity estimate. The estimated lake use rate of 25% is also more conservative than PAE's 10%.

Observed Boating Densities for Various Watercraft

Then, based on previous standards and field observation (the details of which are not provided), Jaakson et al. (1990) determined that, for the study area, the following acreage specifications were appropriate:

- 20 acres per boat for motorboat cruising
- 20 acres per boat for water skiing
- 10 acres per boat for fishing from a boat
- 8 acres per boat for canoeing and kayaking
- 8 acres per boat for sailing

Jaakson et al. emphasize that their conclusions were value judgments based on field observations. Such findings, then, are not readily transferable to other lakes, but should be adjusted according to "the morphology of a lake, cultural tolerances of density, and safety considerations of the manner in which water-oriented recreation activities are carried out" (p. 8). The density recommendation for water skiing, however, would remain relatively stable since the activity does not vary much from lake to lake, nor from skier to skier. This conclusion is supported by the waterskiing density recommendation from Kusler (1972) contained in Table 1.

Overall Carrying Capacity Calculation

Overall carrying capacity for a lake can then be expressed in terms of an overall average of the four carrying capacity calculations, or as a range of estimates (i.e., specifying the minimum and maximum capacity calculations).

3. Deep Creek Lake (Maryland) Boating and Commercial Use Carrying Capacity Study Authors: ERM

Purpose of the Study

This study was conducted as follow-up to a 1988 recreational carrying capacity study of Deep Creek Lake. The 1988 study, funded by the Maryland Department of Natural Resources (MDNR), was spurred by an increase in recreational boat traffic on the lake. Further increases in demand for lake-related recreation brought about a recognition that an update to the 1988 study was in order. The consulting firm hired to conduct this study was Environmental Resources Management, henceforth referred to as ERM.

Three Survey Methods

In order to gauge recreational use, ERM utilized three types of surveys:

- Contact surveys
- Mail-back surveys
- Phone surveys

Contact surveys were administered both on shore (at the boat ramp) and on the lake (by boat). The study does not explain whether there was any randomization applied to the administration of these surveys, but a total of 263 surveys were collected. The breakdown of on-shore versus on-the-lake surveys was not provided.

Mail-back surveys were sent to "all approximately 1,900 buffer strip use permit holders who have direct private access to Deep Creek Lake, and approximately 10 percent of the common dock slipholders…[P]ermit holders were divided into three equal sets and one third of the permit holders were each surveyed in June, July, and August. This approach controlled for weather-related effects on recreational use and other factors that have the potential to skew the results of the study" (ERM, p. 7). Response rate was moderate; 910 surveys were returned.

ERM provided no additional information on their administration of a *telephone survey*.

Spot Counts

Spot counts were used to collect "information on the number and type of watercraft on the lake during peak and non-peak periods" (ERM, p. 4). Holiday weekends, other weekends, and weekdays were all sampled. Three types of spot counts were used:

- Boat spot counts
- Ramp spot counts
- Aerial spot counts (none conducted on weekdays)

For *boat spot counts*, researchers surveyed the lake by boat. They divided the lake into three sections and toured each section two or three times each survey day, counting all boats in use and noting their types.

For *ramp spot counts*, "all boats launched over a 10-hour period (approximately 8:00 am to 6:00 pm) were counted and the time boats were launched and returned was noted (boats launched before 8:00 am were counted as they returned). The number of vehicles, boat trailers, personal watercraft (PWC) trailers, and rooftop carriers (for canoes and kayaks) at the parking lot were recorded and the number and type of boats launched were tallied. In addition, the length of time people waited to launch their boat was recorded" (ERM, p. 4).

For *aerial spot counts*, "a series of almost vertical (approximately 85 degrees) photographs were taken sequentially over the lake. The photographs were taken at a sufficiently low altitude that the number and type of boats could be readily identified. This allowed an accurate estimate of the boats-at-one-time (BAOT) on the lake during these periods. This methodology was essentially identical to that used by MDNR over the past decade to count boats" (ERM, p. 5).

The methodology described in the previous paragraph was adapted from a 1997 survey conducted by MDNR, in which aerial boat counts "were conducted during the early afternoon, generally between 1:00 pm and 2:00 pm, on clear days when the temperature was 70ºF or warmer. The aerial surveyors followed a standardized route for each of the surveys" (ERM, p.

18). In this 1997 study, boats were counted from the aircraft, while in the present ERM study, boats were counted from aerial photos.

Findings from aerial counts justified the division of the lake into sections, since the distribution of boating traffic across the three sections varied by type of day. Use was similar on weekends, but one of the three sections received much heavier boat traffic on weekdays and holiday weekends.

From the aerial photographs, boat types could be distinguished, except that motor boating could not be differentiated from boat fishing, which was "defined to include all essentially stationary boat uses (e.g., fishing, swimming, picnicking, rafting up)" (ERM, p. 55). Based on survey responses, they assigned 65% of the counted boats to motor boating, and 35% to boat fishing, even though on-the-water counts indicated a split closer to 50/50. While ERM does not provide an explanation for this discrepancy, I suggest that it may come from the fact that these two activities are not mutually exclusive, coupled with the limitation that the aerial photograph depicts lake use at one specific instant. Boaters may partake in both motor boating and boat fishing during a given launch, but it is impossible to capture both activities in a single photograph, since they do not occur simultaneously.

Previously collected data on boating use by time of day suggested that the peak time of day was mid-day (11 am until 2 pm) for weekends and afternoons (2 pm until 5 pm) for holiday weekends. This kind of information would be useful in determining when aerial counts should be conducted.

Basis for Boat Carrying Capacity Assessment

ERM based their boat carrying capacity assessment on the same two references that the Louis Berger Group used in the Catawba-Wateree study: Bureau of Outdoor Recreation's (1977) *Guidelines for Understanding and Determining Optimum Recreation Carrying Capacity* and Warren and Rea's (1989) *Management of Aquatic Recreation Resources*. ERM's carrying capacity estimation included the following types of data:

- **Peak boating use estimate** – from spot counts and resultant BAOT measurement
- **Total usable boating surface area** – a shoreline buffer of 100 feet was subtracted from the total surface area
- **Optimum boating density per boat for each activity type** – from Warren and Rea (1989):
    - Motorboats: 9.0 acres per boat
    - Fishing from boat: 1.3 acres per boat
    - Sailboats: 4.3 acres per boat
    - Canoes/kayaks: 1.3 acres per boat
    - Waterskiing boats: 12.0 acres per boat
    - Distribution of boating activities across all users (e.g., percentage of motor boats, sailboats, PWC, etc.) – from spot counts on each of three lake sectors; also referred to as the *boating use mix*

Criticisms of Warren and Rea's (1989) Methodology

ERM had two criticisms of Warren and Rea's (1989) methodology. First, they proposed that Warren and Rea did not provide clear guidelines for quantitatively evaluating factors other than optimal boat density and distribution of watercraft in various lake zones. Examples of these other factors include: proximity to urban areas, multiple uses of the lake, and shoreline configuration. While I understand this criticism that the methodology is not applicable in a quantitative sense, I would like to note that since carrying capacity estimation is ultimately a management decision, it is acceptable to include an element of qualitative evaluation in the estimation process.

ERM's second criticism relates to the boating use mix, or, in other words, the inclusion of the observed distributions of the various watercraft types into the overall capacity estimate. ERM wrote that Warren and Rea "did not maintain the boating use mix" (p. 9), meaning that when optimum carrying capacity per watercraft type was determined (the sum of which is an optimum BAOT estimate), the observed percentages of each watercraft type were not incorporated. I met with Dr. Phil Rea to discuss this discrepancy, and while we agreed that the boating use mix was not preserved in their original methodology, we also found that the new carrying capacity equations provided by ERM were incomplete. Application of the procedure outlined by ERM did not result in the estimates that were provided in the accompanying tables. At the present time, then, there is no ideal method for estimating optimum carrying capacity for various watercraft types.

Previous Lake Use Rate Data

From historical data collected by MDNR, it was found that "the boats counted on the lake represented about 3.6 to 7.4 percent of the total boats counted along the shoreline, at docks, and on the lake" (ERM, p. 23). This estimated range of lake use rate is notably smaller than any other lake use rate figure I have come across, and demonstrates that the carrying capacity estimation process is dependent upon the use patterns of the study area.

Physical Carrying Capacity Assessment

Overall physical carrying capacity was determined by combining the capacity estimates from each zone. Percent capacities were reported for peak weekend (94%) and peak holiday weekend (133%); these were also broken down by zone.

Social Carrying Capacity: Waterfront Residents vs. Visitors

The study found that "waterfront residents are more concerned [than visitors who completed a contact survey] about the number of watercraft on the lake" (ERM, p. 35). They "attribute this heightened sensitivity regarding crowding to several factors:

- Some waterfront residents are year-round residents and are more accustomed to a rural setting than many of the visitors who come from…metropolitan areas and are more accustomed to crowding.
- Waterfront residents spend more time at the lake than visitors and have greater exposure to crowding issues over the duration of the summer.
- Many waterfront residents have lived at Deep Creek Lake for several years and may be concerned by their perception of increased crowding" (ERM, p. 35).

The first bullet point on crowding tolerance relates to the Water Recreation Opportunity Spectrum (WROS), which will be addressed below.

Social Carrying Capacity Assessment; Perceived Crowding

The contact survey, which was administered on the boat ramp and on the lake itself, measured lake users' perceptions of crowding on the day they were visiting. This method is advantageous because it reduces response bias. Perceptions were measured using a 5-point scale ranging from 1 (not crowded) to 5 (very crowded). Respondents were also asked to describe the number of people at the lake on the day of their visit, and were given the response options of too many, just right, or too few.

In the mail-back survey of waterfront residents, the same scale was used to measure perceptions of crowding, but the question was reframed so that responses reflect an *overall impression*, rather than a reaction to a particular day.

Respondents to both the contact survey and the mail-back survey viewed a series of digitally enhanced photographs depicting five different levels of crowding: 25%, 65%, 81%, 106%, and 155% of estimated carrying capacity. Then three questions were asked:

- What is your preferred boating use level?
- In which photo is the boating level so high that you would not boat on Deep Creek Lake?
- Which photo depicts a boating level at which some type of management action should be taken?

Regarding respondent reactions to the photographs, ERM writes, "Although there is no exact standard for determining social carrying capacity, once 33% of respondents indicate that use levels are sufficiently high to discourage them from boating, we would consider the social carrying capacity to be reached" (p. 64).

Comparison of Physical and Social Carrying Capacity

ERM notes that changes in the boating mix can affect carrying capacity. "Increases in the number of motorboats, which typically need greater surface acreage for safe operation conditions, can reduce the overall carrying capacity of the lake" (ERM, p. 66). They comment, however, that this reduction in carrying capacity is only the case when the powerboats are active. During peak times, when carrying capacity is most likely to have been met or exceeded, "more power boaters are anchored for fishing, picnicking, or swimming; or are using the 100-foot buffer for these activities…Lake managers, however, should not rely on boaters using the 100-foot buffer, and should not encourage use of this buffer for safety and environmental reasons" (ERM, p. 66).

Regarding social carrying capacity during peak periods, ERM writes: "Recreational users, especially visitors, may be willing to tolerate crowded conditions for a short period on a high use weekend without it adversely affecting their overall recreational experience. If this high use level was to occur more consistently, however, it could begin to adversely affect the experience of recreational boaters" (pp. 66-67).

If a capacity determination is made for an entire body of water, as was the case with Deep Creek Lake, it is still important to take a closer look at the various sections of that body of water, since use is typically unevenly distributed. In this assessment, ERM draws specific attention to areas that could pose safety concerns when crowded, such as narrow passages and areas where sailboats congregate during a regatta.

Effects of Future Growth on Carrying Capacity

Trends such as the increase in year-round waterfront residences and the rise in popularity of water-based recreation indicate that boating use is likely to continue to increase. At Deep Creek Lake, however, waterfront residents will comprise the majority of this increase in users, "because the MDNR has no plans to expand parking facilities at Deep Creek Lake State Park, and commercial rental operations on the lake have maximized the available rental fleet to the extent permitted under the existing dock use regulations" (ERM, p. 67). Equitable resource access is an important management consideration and can be monitored through occasional studies of user composition (i.e., the distribution of residents and visitors).

Summary of Findings and Recommendations

ERM determined a recommended numeric carrying capacity of 450 boats at one time. Exceeding capacity may "result in a less desirable recreational experience" (ERM, p. 74) except in cases where large numbers of boats on the lake are inactive (e.g., peak use periods when boats are anchored for swimming, picnicking, etc.).

ERM recommended that MDNR "continue to monitor recreational use and if use levels begin to exceed the recommended carrying capacity (450 boats), especially on non-holiday weekends, management actions should be considered" (ERM, p. 74). Some proposed management options were to:

a. Limit access at the boat launch (but this has a disproportionate effect on visitors)

b. Increase law enforcement; set restrictions on speed and horsepower (but this would not affect the *number* of boats, only the safety of boaters)

c. Concentrate safety efforts on more crowded areas of the lake

4. Visitor Carrying Capacity Guidelines
Authors: Florida Department of Environmental Protection, Division of Recreation and Parks

Boat Density Guidelines

Attached to this brief report (which does not include a discussion on methods used to estimate carrying capacity) is a table entitled, "Optimum Carrying Capacity for Outdoor Recreation Activities: Water-Based Activities." The relevant portion on fishing and boating area requirements (i.e., boating density) is reproduced in Table 2 below.

Table 2
Optimum Carrying Capacity for Fishing and Boating Activities

Recreation Activity	Required Water/Land Base	Area Requirements	People/Unit of Facility	Turnover Rate
Fishing				
Shoreline	min. 1/4 mile of shoreline for a fishing area, and 1/8 acre of land/fisherman	1 fisherman/20-100 linear feet	n/a	2/day
Jetty Pier	min. 1/8 acre of land/fisherman	1 fisherman/10-40 linear feet	n/a	2/day
Boating				
Limited Power (10 HP or less)	min. 200 acres of water, and 1/4 acre of land/boat	1 boat/5-10 acres of water	2/boat	2/day
Unlimited Power	min. 600 acres of water and 1/4 acre of land/boat	1 boat/10-20 acres of water	4/boat	1/day
Water-skiing	min. 600 acres of water and 1/4 acre of land/boat	1 boat/20-50 acres of water	4/boat	1/day
Sailing	min. 200 acres of water, and 1/4 acre of land/boat	1 boat/5-10 acres of water	2/boat	2/day
No Power, Still Water	min. 50 acres of water and 1/4 acre of land/boat	1 boat/5-10 acres of water	2/boat	2/day

Note. From "Visitor Carrying Capacity Guidelines," by Florida Department of Environmental Protection.

5. Ririe Reservoir Recreation Carrying Capacity Study
Authors: EDAW (2004b)

Four Recreational Carrying Capacity Types

This document cites four types of recreational carrying capacity, which were originally outlined by Shelby and Heberlein (1986) in their seminal work, *Carrying Capacity in Recreation Settings*. The following passage was extracted from the EDAW (2004b) report on the Ririe Reservoir: "These four [recreational carrying] capacity types and examples include:

- Ecological Capacity – Concerned with impacts on the ecosystem, such as the loss of ground cover, impacts to wetlands and riparian communities, observed soil compaction and soil erosion, and observed trash accumulation and sanitary problems. Also concerned with impacts to cultural resources at developed and dispersed recreation areas in the study area.

- Spatial Capacity – Concerned with space-related impacts, such as the number of people occupying specific areas or lengths shorelines [sic], number of parties per site, or the expansion potential of existing sites.

- Facility Capacity – Concerned with facility impacts, such as number of people, groups, or vehicles per boat ramp, parking lot, or campground; percent occupancy for various facilities; waiting times to use facilities such as boat launches; or the number of refusals for campsites.

- Social Capacity – Concerned with social impacts, such as visitors' perceptions of crowding (assessed from survey data), perceived and actual conflict between different visitor groups, the number of encounters with other parties per day, and the number of encounters with personal watercraft (PWC)" (EDAW, 2004b, p. 13).

EDAW (2004b) investigated all four types of carrying capacity for a variety of sites within the study area. Based on the number of impacts observed, one of the following capacity levels was assigned to each of the four capacity types: *below* capacity level, *approaching* capacity level, *at* capacity level, and *exceeding* capacity level. EDAW then identified one or two of the capacity types as primary limiting factor(s) for each recreation site, the surface water area, and the reservoir as a whole. These limiting factors can be used to prioritize management efforts.

Surface Water Boating Capacity

While the discussion of the four capacity types in the study related exclusively to land-based recreational carrying capacity at Ririe Reservoir, the report also included a section on surface area boating capacity. EDAW (2004b) used on-water observations, recording number and type of watercraft, to develop BAOT estimates for various reservoir segments.

Boating Density Standards

A useful table is included in this section on boating surface water carrying capacity, citing five selected standards for number of acres of surface water per boat. The standards mentioned in this table are:

- National Recreation and Park Association (NRPA) – 4 acres/boat
- Bureau of Outdoor Recreation (BOR) – 9 acres/boat
- Arizona Outdoor Recreation Coordination Commission – 10-20 acres/boat
- Wisconsin Comprehensive Plan – 20-40 acres/boat
- Louisiana Parks and Recreation Commission – 20-40 acres/boat

Note that these five standards provide the more general, aggregate boating density figure, rather than a collection of boating densities specific to boating activity type. In addition, they originated from sources published in the 1970s and early 1980s, which may now be outdated.

EDAW (2004b) comments that surface water acres per watercraft is not the only measure of carrying capacity. "[O]verall surface water capacity is also dependent on the types of watercraft used, the natural topography and setting, safety conditions, and on-water crowding perceptions, among other factors" (p. 22).

Water Recreation Opportunity Spectrum (WROS)

A second table of interest provided in the Ririe Reservoir study deals with the Water Recreation Opportunity Spectrum (WROS). The original Recreation Opportunity Spectrum (ROS) was developed by the U.S. Department of Agriculture's Forest Service as a response to increased demand for a variety of outdoor recreation opportunity settings (Clark & Stankey, 1979). Recently, however, the ROS has been translated to water-based recreation activities.

There are six WROS classes: urban, suburban, rural developed, rural natural, semi primitive, and primitive. The Water Recreation Opportunity Spectrum Users' Guidebook offers the following ranges of reasonable boating capacity coefficients (i.e., boating densities) for the six WROS classes:

Table 3
Boating Density Ranges for Six WROS Classes

WROS Class	**Range of Boating Coefficients**	
	Low end of range	High end of range
Urban	1 acre/boat	10 acres/boat
Suburban	10 acres/boat	20 acres/boat
Rural developed	20 acres/boat	50 acres/boat
Rural natural	50 acres/boat	110 acres/boat
Semi primitive	110 acres/boat	480 acres/boat
Primitive	480 acres/boat	3,200 acres/boat

Note. From "Ririe Reservoir Recreation Carrying Capacity Study," by EDAW, 2004b.

The WROS publication (Aukerman et al., 2004) also includes a guide for managers to decide where on the capacity spectrum their resource falls. (See Aukerman et al., p. 95: "A Boating Capacity Range Decision Tool").

6. Reservoir Boating; Final; R-7; Oroville Facilities Relicensing, FERC Project No. 2100
Study Area: Lake Oroville, CA
Authors: EDAW (2004a)

<u>Study Objectives</u>

This study was conducted by EDAW for the State of California's Department of Water Resources, as part of a FERC relicensing project. One of the study objectives was to "determine if capacity limits for boating are being exceeded on the reservoirs, and if reservoir surface water management changes are needed relative to recreational boating" (EDAW, 2004a, p. RS-2).

Similar to the previous study, EDAW based their analysis on Shelby and Heberlein's (1986) four carrying capacity types: ecological, facility, physical/spatial, and social.

The goal of the reservoir boating capacity analysis was "to determine the maximum amount of use of a particular type an area can sustain without excessive detrimental effects to the natural resource, facilities, or visitors' recreation experience" (EDAW, 2004a, p. 4-11). For each area (e.g., reservoir or lake zone), "conclusions were made regarding which of the four capacity types is or could be a limiting factor(s). Qualitative and quantitative data were used to make these conclusions" (EDAW, 2004a, p. 4-12). As in the previously discussed study (EDAW, 2004b), one of the following conclusions was determined for each capacity type: below, approaching, at, or exceeding capacity.

<u>Use Characteristics</u>

Researchers aboard a survey boat conducted on-water observations through the six delineated zones. These observations typically took place between 2 and 5 p.m. Each watercraft observed in use was indicated on a zone map; both location and boat type were recorded. The six boat type categories were: runabouts/ski boats, jet skis, houseboats, fishing boats, pontoon boats, and sail and other non-motorized boats. The researchers did not count boats moored or docked at the two marinas, nor did they count boats in the process of being launched or retrieved at boat ramps. Boats that were classified as "'in use but inactive'" (EDAW, 2004a, p. 4-3), typically moored houseboats, were also indicated on lake zone maps, but were differentiated from active boats. The study notes that "[t]he distinction is important when analyzing the effect of boat traffic on crowding and reservoir carrying capacity" (EDAW, 2004a, p. 4-3).

On-water boat counts were justified as the most practical method for estimating use; however, the limitations to this method are acknowledged. The researchers state that, "[o]verall, this methodology is estimated to provide an expected error of less than 10 percent" (EDAW, 2004a, p. 4-6).

Aerial photographs were used "to provide data to validate boating levels obtained with the on-water observations" (EDAW, 2004a, p. 4-4). Although the detail of the photographs was not refined enough to determine boat type, the researchers could derive a boat count for the entire lake.

Boating Density Standards

The researchers acknowledge that boating density standards are reservoir-specific and must take into consideration the following factors: "water depth, shoreline configuration, visitors' perceptions, number of accidents involving other boats, boat type and speed, dominant boating activities, and the types of activities that are popular on the water and on the shoreline" (EDAW, 2004a, p. 4-12).

Facility Carrying Capacity

Facility capacity was assessed using information on parking levels at boater facilities, wait times at boat launches, and boaters' perceptions of the adequacy of facilities. "Boat ramp capacity is ultimately limited by the amount of parking available for boaters' vehicles and boat trailers. Capacity at a ramp is clearly exceeded when no parking is available for arriving boaters" (EDAW, 2004a, p. 5-56).

"An important aspect of parking capacity at these sites is the high number of boat/trailer spaces being occupied by single vehicles" (EDAW, 2004a, p. 5-64). Consequently, parking is reduced for those boaters with trailers who need access to boat ramps. The explanation for the disproportionate number of single vehicles is that there are many houseboats moored at marinas adjacent to boat ramps. Marina boaters and their guests often use boat/trailer spaces when the available single-vehicle spaces have been filled.

Long waits to launch also indicate that facility capacity may be exceeded. Observations of boat launching and retrieval were conducted at a major boat ramp one holiday weekend in order to determine the typical rate of launching and retrieval. It was found that a boat was launched at the ramp every 1 to 3 minutes, and the launch and retrieval rate was 40 boats per hour.

Social Carrying Capacity

Social capacity assessment included survey data on boaters' perceptions of crowding and interactions with other boaters (i.e., user conflict). Crowding was measured using a 9-point scale, as outlined by Shelby and Heberlein (1986). Perceptions of crowding were analyzed for each reservoir/zone by comparing the percentage of low ratings (1-3), moderate ratings (4-6), and high ratings (7-9). Perceptions of crowding were found to be relatively low, even during peak season weekends, where reservoir/zone means ranged from 1.3 to 3.6, and holiday weekends, when reservoir/zone means ranged from 2.3 to 4.6. Social carrying capacity limits were determined to be approaching capacity when mean crowding ratings were approaching 5 and over 40% of boaters reported moderate to high crowding levels. Most respondents reported a low to moderate crowding rating. "The fact that boat traffic and interactions with other boaters were more often seen as problems during the non-peak season highlights that social capacity issues are not solely related to high use levels but are also affected by the types of visitors present and their preferences" (EDAW, 2004a, p. 5-68).

Physical Carrying Capacity

Physical capacity standards were determined based on standards applied to other similar reservoirs in the western United States. Most of these referenced standards used ROS setting types to influence boating standards, which were reported in terms of aggregate acres per boat. Modified WROS density standards were also discussed.

After reviewing the WROS setting types, EDAW (2004a) determined that the reservoirs/zones within the study site did not fit into just one class. They proposed the capacity ranges that appear in Table 4 below.

Table 4
Proposed Boat Traffic Density Ranges for Assessing Project Area Reservoir Boat Traffic Density

Density Classification	Density Range (acres/boat)	Physical Capacity Assessment
Very High Density	≤ 10.0	Exceeding capacity
High Density	10.1-20.0	Approaching capacity
Moderate Density	20.1-50.0	Below capacity
Low Density	> 50	Below capacity

Note. From "Reservoir Boating, Final R-7, Oroville Facilities Relicensing FERC Project No. 2100," by EDAW, 2004a, p. 5-73.

Boat Traffic Density Calculations

Boat traffic density was then calculated by dividing observed boat counts by GIS-produced estimates of surface acreage. "The acreage estimates accounted for changes in the surface area of each Lake Oroville zone resulting from reservoir pool level changes" (EDAW, 2004a, p. 5-73). This technique is innovative; however, the researchers did not describe *how* they accounted for these depth-related effects on surface acreage.

Boating density was calculated in two ways: for all boats observed in a reservoir/zone (including those boats that were inactive but in use), and then again for active boats only. Both density estimates were "reported in order to show the moderating effect of shoreline use on traffic density" (EDAW, 2004a, p. 5-73). Density estimates, in average acres per boat, were then compared to the ranges outlined in Table 4 above to assign a physical capacity assessment to each reservoir/zone. The researchers point out that there are some high-traffic "pockets" within larger areas, even when the larger areas themselves are classified as below capacity. But, "the high level of boat traffic does not in itself indicate a capacity problem" (EDAW, 2004a, p. 5-78). For example, high densities around boat ramps are to be expected. However, a red flag should be raised in situations where there is "high traffic density in areas with unrestricted speed or areas that pose physical restrictions (e.g., narrow arms or coves)" (EDAW, 2004a, p. 5-78).

Deliberate Omission of a Numeric Capacity Limit

Capacity conclusions were made by identifying the limiting factor (or factors) for each zone (e.g., physical/spatial, social, facility, ecological), assessing the capacity level based on the assessment criteria in Table 4, and assigning a level of management priority (e.g., low, moderate, high) to the concern. EDAW's (2004a) rationale for their decision not to include a numeric capacity limit was worded so clearly that it merits repetition here:

> "No attempt was made to develop a numeric capacity limit (i.e., boats at one time) for each zone for each factor…The data collected do not permit a direct relationship to be identified between levels of boating activity and the quality of the recreation experience or deterioration of natural resources, as would be required to derive boats-at-one-time limits. For example, the data indicate that perceptions of crowding on the water are low, but it is not possible to state how many boats would cause an unacceptable number of boaters to feel crowded on each zone. Similarly, few serious or widespread ecological impacts were found, and it is not possible to state how many boats would cause ecological impacts to reach an unacceptable level. It is possible to use existing data to estimate the daily launching capacity of each boat ramp, but it is difficult to associate that limit with specific reservoir zones" (p. 5-80).

7. Recreational Boating on Delaware's Inland Bays: Implications for Social and Environmental Carrying Capacity
Authors: Falk, Graefe, Drogin, Confer, & Chandler (1992)

Lake Use Rate

Lake use rate was determined using three data collection methods:

- On-water observation
- On-site surveys
- Parking lot counts
- Mail-back surveys

On-water observation was conducted six times. All boats were counted, and their boating types noted. Researchers patrolled the bays in a systematic fashion, following the same route each time. The Delaware Department of Natural Resources and Environmental Control provided water surface acreage estimates using GIS.

On-site surveys were administered to boaters at boat ramps, as they returned from boating on the bays. The questionnaire "was designed to measure boaters' characteristics, activities, and perceptions" (Falk, Graefe, Drogin, Confer, & Chandler, 1992, p. 11).

Parking lot counts were also conducted to verify the information collected via on-site surveying. To estimate peak use, "a statistical correlation analysis was performed to measure the relationship between the on-water boat and parking lot counts for those days when both counts were made" (Falk et al., p. 13). A strong positive correlation was found between the two types of counts, thus justifying the use of parking lot counts for the days when on-water observation was not conducted.

Mail-back surveys were sent to shoreline property owners in two mailings: once after the first on-site sampling weekend, and once after the second. A modified Dillman (2000) technique was employed to ensure a high response rate. Postcard reminders were sent out one week after the initial mailing. A follow-up replacement questionnaire was sent to those who had not responded within three weeks of the initial mailing. After accounting for insufficient or incomplete addresses (99 out of 600 were returned as undeliverable), the response rate was 58%.

Boating Density

Bay usages were examined by comparing aggregate boating density, in average acreage per boat, among all of the bays. Boating density was also compared among zones on each bay as an indication of highest use areas. Although overall densities were not especially intense, locations where three or more boating activities occurred were noted, and future monitoring was suggested to the management.

GIS was used to "examine the spatial distribution of boating activity in the bays" (Falk et al., p. 18). Clustering of boats in certain areas implied possible crowding, overuse, and/or user group conflicts.

Crowding Metric

Crowding was measured using an index combining perceived crowding and influence of others on enjoyment. Perceived crowding and influence of others on enjoyment were both measured on 9-point scales. Falk et al. found that “crowding was felt to be greater on heavier use days” (Falk et al., p. 37). There was not a significant relationship between boating density and boater satisfaction, which the researchers indicate is the case in many other studies.

Study Recommendations

This study did not answer the question of whether there are too many boats on Delaware’s inland bays. Falk et al. did, however, provide baseline data “for establishing quantitative standards of acceptability for a wide range of potential social and environmental factors” (Falk, et al., p. 73), and management recommendations, such as the monitoring of higher density “hot spots,” were also provided.

CONCLUSION

This document served as a review of a variety of existing literature on boating carrying capacity. From the studies outlined above, the subjective nature of carrying capacity determination can be seen, as no two studies were exactly alike. Standards are often adjusted in order to comply with site-specific characteristics.

References

Ashton, P. G. (1971). Recreational boating capacity: A preliminary study of three heavily used lakes in southeastern Michigan. (Doctoral dissertation, Michigan State University, 1971). *Dissertation Abstracts International, 32*, 03-B (UMI No. AAI7123158).

Aukerman, R., Haas, G., Lovejoy, V., & Welch, D. (2004). *Water Recreation Opportunity Spectrum (WROS) users' guidebook.* Retrieved August 7, 2005 from http://www.usbr.gov/pmts/planning/wros/wros_report.pdf

Bureau of Outdoor Recreation (1977). *Guidelines for understanding and determining optimum recreation carrying capacity.* Washington, DC: Department of the Interior.

Clark, R. N., & Stankey, G. H. (1979). *The recreation opportunity spectrum: A framework for planning, management, and research.* Seattle, WA: Pacific Northwest Forest and Range Experiment Station, U.S. Department of Agriculture, Forest Service.

Dillman, D. A. (2000). *Mail and Internet surveys: The tailored design method* (2nd ed.). New York: John Wiley & Sons, Inc.

EDAW (2004a). *Reservoir boating, Final R-7, Oroville Facilities Relicensing FERC Project No. 2100*. The State of California, Department of Water Resources.

EDAW (2004b). *Ririe Reservoir recreation carrying capacity study.* Prepared for U.S. Department of the Interior, Bureau of Reclamation, Pacific Northwest Region, Snake River Area Office, Boise, Idaho. Retrieved July 1, 2005 from http://www.parksandrecreation.idaho.gov/Data_Center/PDF/2004_Ririe_RCC_Complete_Final.pdf

ERM, Inc. (June 2004). *Deep Creek Lake boating and commercial use carrying capacity study.* Prepared for Maryland Department of Natural Resources. Proposal No. KOOR2200624. Retrieved June 10, 2005 from dnrweb.dnr.state.md.us/download/dclfinalreport.pdf

Falk, J., Graefe, A., Drogin, E., Confer, J., & Chandler, L. (Dec. 1992). *Recreational boating on Delaware's inland bays: Implications for social and environmental carrying capacity.* Prepared for the Inland Bays Estuary Program, Delaware Department of Natural Resources and Environmental Control, Division of Water Resources.

Florida Department of Environmental Protection, Division of Recreation and Parks (n.d.). *Visitor carrying capacity guidelines.* Retrieved June 30, 2005 from http://www.dep.state.fl.us/parks/planning/forms/CarryingCapacityGuidelines.pdf

Jaakson, R., Buszynski, M. D., & Botting, D. (Nov. 1989). Carrying capacity and lake recreation planning (part I). *The Michigan Riparian*, pp. 11-12, 14. Retrieved July 1, 2005 from http://www.mi-riparian.org/RiparianImages/Riparian-800x600/198911-11.jpg, http://www.mi-riparian.org/RiparianImages/Riparian-800x600/198911-12.jpg, http://www.mi-riparian.org/RiparianImages/Riparian-800x600/198911-14.jpg

Jaakson, R., Buszynski, M. D., & Botting, D. (Feb. 1990). Carrying capacity and lake recreation planning (part II). *The Michigan Riparian*, pp. 7-8. Retrieved July 1, 2005 from: http://www.mi-riparian.org/RiparianImages/Riparian-800x600/199002-07.jpg and http://www.mi-riparian.org/RiparianImages/Riparian-800x600/199002-08.jpg

Kusler, J. A. (1972). Carrying capacity controls for recreation water uses. Upper Great Lakes Regional Commission.

Manning, R. E., Lime, D. W., & Hof, M. (1996). Social carrying capacity of natural areas: Theory and application in the U.S. National Parks. *Natural Areas Journal, 16* (2), pp. 118-127.

Progressive Architecture Engineering (May 2001). *Four Township recreational carrying capacity study: Pine Lake, Upper Crooked Lake, Gull Lake, Sherman Lake.* Retrieved July 1, 2005 from http://www.kbs.msu.edu/ftwrc/publications/carryingcapacity.pdf

Schneberger, E., & Threinen, C. W. (1964). Lake management for recreation uses. *Wisconsin Academic Transactions (53)*, Part A.

Shelby, B., & Heberlein, T. A. (1986). *Carrying capacity in recreation settings*. Corvallis, OR: Oregon State University Press.

Urban Research and Development Corporation (URDC) (Oct. 1988). Recreation carrying capacity study and management guidelines for Deep Creek Lake NRMA, final report. Bethlehem, PA: URDC.

Wagner, K. J. (1991). Assessing impacts of motorized watercraft on lakes: Issues and perceptions. In *Proceedings of a National Conference on Enhancing the States' Lake Management Programs*, 77-93.

Warbach, J. D., Wyckoff, M. A., Fisher, G. E., Johnson, P., & Gruenwald, G. (1994). Regulating keyhole development: Carrying capacity analysis and ordinances providing lake access regulations. Planning and Zoning Center, Inc.

Warren, R., & Rea, P. (1989). *Management of aquatic recreation resources.* Columbus, OH: Publishing Horizons, Inc.