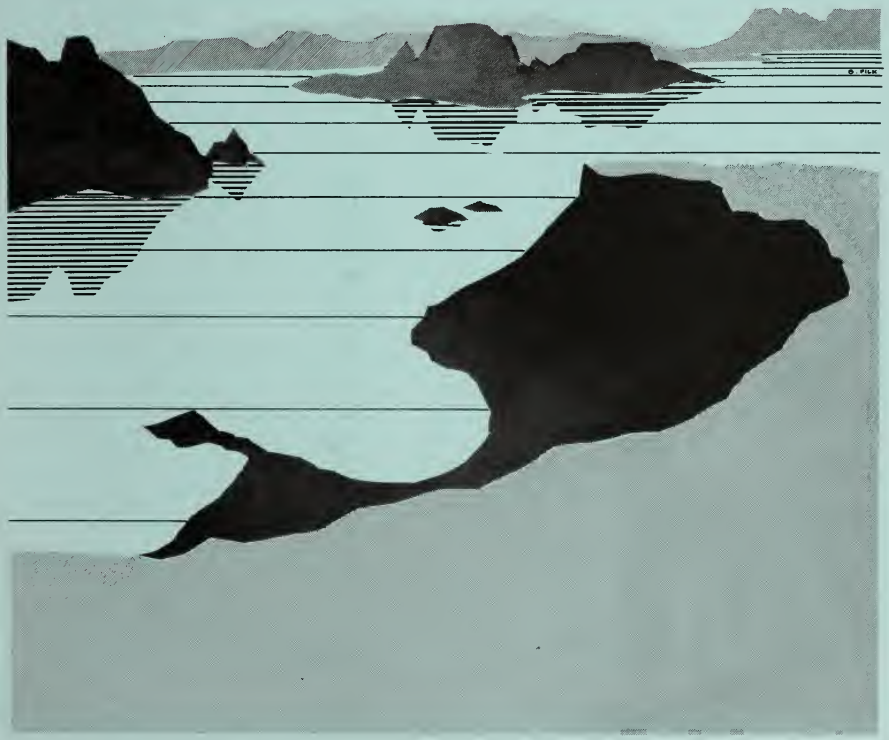
THE CARRYING CAPACITY OF LAKE POWELL

A MANAGEMENT ANALYSIS OF CAPACITY FOR BOATER RECREATION

GLEN CANYON NATIONAL RECREATION AREA
ARIZONA/UTAH

NOVEMBER 1987



ROCKY MOUNTAIN REGION - NATIONAL PARK SERVICE

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GLEN CANYON NATIONAL RECREATION AREA ARIZONA/UTAH

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SUMMARY OF FINDINGS

Glen Canyon National Recreation Area is a developing unit of the National Park System in Utah and Arizona whose major recreational resource is Lake Powell. The lake supports five permanent developed marinas on its 1,900-mile shoreline (a temporary marina on the San Juan arm recently began operation). Plans are proposed for two new marinas and the expansion of several existing facilities has recently been approved.

It is difficult to gauge the cumulative effect on park resources of several expansions and new developments going on concurrently. An assessment of the lake's capacity to absorb increased boater use is therefore needed in order to adjust development sizes to levels consistent with the preservation of park resources and recreation quality. A study completed by the Denver Service Center in 1982 identified important physical and operational factors affecting boat distribution and carrying capacity on Lake Powell. In 1985, it was decided to quantify the limits to boater use through a field study and to include important resource and recreational quality factors. A survey of boaters was conducted at the park in 1985 to obtain additional information on boater activities, to understand current distribution on the lake, and to provide data for defining "carrying capacity" in management terms. Field monitoring of resource impacts experienced on the lake as a result of boater use were completed in 1985 and 1986.

This document is a management analysis of the foregoing information and incorporates physical, safety, resource, and social factors to arrive at use limits expressed as "boats-at-one-time" allowable in zones of the lake. Although many carrying capacity studies have been done for land and river recreation, few are available for flatwater recreation areas which consider the physical, resource, and social limiting factors important in park management and fewer still offer a means of quantifying capacity. The method used in the present analysis is a way of organizing information to document a management problem, and could be applied to other areas of the National Park System concerned with carrying capacity.

The results include the boats-at-one-time limit computed for each zone and a table of boat distribution on the lake by marina of origin. The study identifies the most limiting factor in each zone and apportions that limit among the several marinas using the boater distribution table. Adding the marina shares for all lake zones yields a composite "maximum" launch rate consistent with the lake's carrying capacity. Because boater access to Lake Powell is significant only at the developed marinas, the above may be used by management to contain maximum marina boat-launching capacities to levels which will maintain recreational quality and resource values. The capacity estimates are directly useful in evaluating development expansion proposals and provide a reasoned, documented basis for determinations of maximum marina sizes.

In the table below these results are expressed as "carrying capacity launch rates", and are compared with "existing and approved marina launch capacities":

Table 15
Comparison of Marina Launch Capacity with Carrying Capacity Launch Rate (launches/day)

marina	marina launch capacity		carrying capacity launch rate	
	existing	approved*	existing	additional mgmt.**
Wahweap/ Lone Rock	644	870	↑ 685 ↓	↑ 1,358 ↓
Antelope Point	0	240		
Bullfrog Basin	220	420	↑ 440 ↓	↑ 800 ↓
Halls Crossing	145	206		
Hite	114	* (114)	50	414
total	1,123	1,850	1,175	2,572

* Launch rates from proposed facilities in current plans.

** Additional management – applying management actions to a particular limiting factor to increase BAOT capacity.

The study also provides the management conditions under which the lake's capacity for additional boater use may be increased: Mitigation of the most limiting factor at a given lake zone permits the number of allowable boats-at-one-time in the zone to increase to the level indicated by the next-most-limiting factor. This increase can be traced back to an increase in maximum allowable marina launch rates using methods outlined in the study. In this way, guidance may be obtained on which alternative management actions would be most useful for mitigating capacity constraints and where on the lake they would be most effectively applied.

Management recommendations are made concerning the expansion and construction of approved marina facilities. Construction of such facilities should be consistent with actions to mitigate impacts to the lake environment. Recommendations to improve information gathering and to monitor visitor-use patterns are also made. Usefulness of this study in future planning efforts is documented under "Future Applications".

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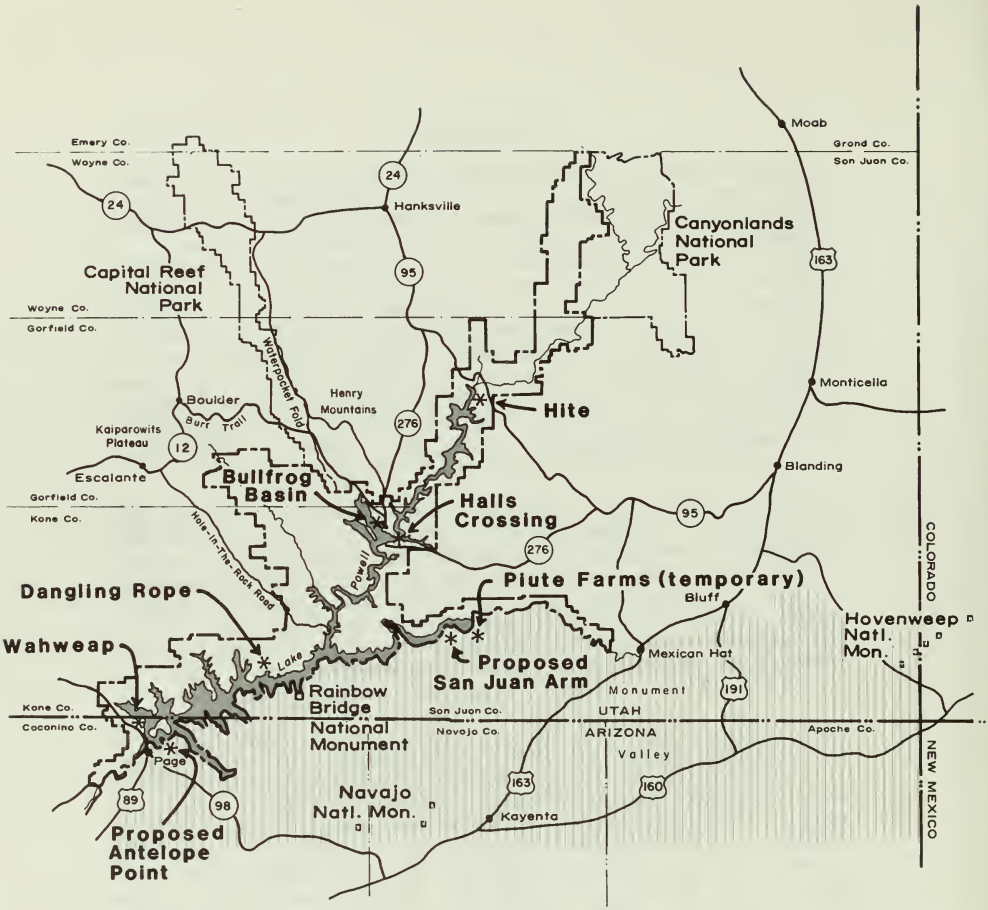
INTRODUCTION

Managers of units in the National Park System are faced with the challenging task of providing for public enjoyment of the parks, while preserving park resources unimpaired for the enjoyment of future generations. To achieve this objective in an era of continually increasing visitor use of the parks, the manager requires a clear picture of the potential resource impacts of additional public use and of the factors which constitute "enjoyment" of the park by its visitors. The park manager, in many cases, must have sufficient information to evaluate the highest rates of use which can be permitted before resources and recreation are adversely affected. This is the concept of carrying capacity as used in the present study.

Implicit in this concept is the fact that the management framework of the park unit usually influences strongly the effect of potentially mutable "limits" to use, such as recreational quality perceived by the visitor, and the presence of resource impacts which could be mitigated. An evaluation of how management options affect carrying capacity is therefore needed by park managers as well as quantification of capacity under current conditions.

Glen Canyon National Recreation Area, a scenic unit of 1.2 million acres in Utah and Arizona, was established for recreation and conservation purposes in 1972. Its major recreational resource is Lake Powell, a reservoir on the Colorado River, located in a remote area of deep canyons and sandstone plateaus. When the area was authorized in the 1950's, it was believed that visitation would reach 500,000 persons annually by the year 2000; by 1986, however, visitation had exceeded 2.3 million persons and is still growing. This level of use has created a high demand for facilities and services on the lake, requiring numerous planning projects and management decisions regarding future development.

The recreation area currently has five permanent developed marinas (figure 1). Four of them are the subjects of expansion proposals. Plans have been proposed for two new marinas, one on the San Juan arm



LEGEND

— — — Glen Canyon N.R.A.

Navajo Indian Reservation

N

0 10 20 miles

0 15 30 kilometers

Figure 1

VICINITY MAP

GLEN CANYON NATIONAL RECREATION AREA

utah-arizona

UNITED STATES DEPARTMENT OF THE INTERIOR
NATIONAL PARK SERVICE

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where a temporary marina recently opened (Piute Farms) and the other at Antelope Point near Page, Arizona. An assessment of the lake's capacity to absorb increased boater use is therefore needed to adjust development to levels consistent with preservation of park resources and recreation quality. The purpose of this analysis is to assess the capacity of Lake Powell for boater recreation and to identify both the management conditions and "fixed" limits on which this capacity might depend.

ANALYSIS OBJECTIVES

*To determine a range of factors which potentially limit the carrying capacity of Lake Powell and to identify specific areas of the lake where capacity may be most limited.

*To develop a method to assess maximum boater-use levels on Lake Powell consistent with high quality recreation experiences, conservation of park resources, and safety.

*To determine the maximum desirable sizes of developed facilities, which would keep boater-use levels within lake capacity.

*To identify management options which alleviate user impacts and improve data collection, and to provide a system which shows the positive effect management actions may have on carrying capacity.

BACKGROUND

Carrying capacity is the user population that a given resource (e.g. water or pasture) will support without undergoing deterioration. Land managers are often faced with the need to evaluate the carrying capacity of resources for specific uses, since they are usually responsible for maintaining sustained yields and resource quality. For example, Wildlife Biologists may need to determine an area's carrying capacity for a managed species such as elk. Park Managers, on the other hand, must know their unit's capacity for recreational use while maintaining the integrity of the full spectrum of resources the visitors come to see. While the technical requirements and data needs to determine carrying capacity may vary for each resource situation, the conceptual framework remains the same. Simply put, carrying capacity is determined by factors which act to limit populations. The park management challenge is to identify the most limiting factors operating in a given situation and find out whether they are amenable to management action that would be of benefit in response to increasing visitation.

Much has been said and written about recreation carrying capacity. In wildland planning, most efforts have been directed towards the natural resource's ability to accept recreation use. These efforts have generally centered on the given standard that recreation use should not create natural resource impacts that violate law, regulation, policy, or management objectives. Recently, managers have also become more aware of the social aspects of carrying capacity, enabling recreational quality to be added to the list of protected objectives. Research has recently been conducted on a broad range of variables which influence how people perceive quality in a recreation experience, resulting in new analytical tools for carrying capacity such as the Limits of Acceptable Change (LAC) concept (Cole, D.M., et. al., 1985) and the Recreational Opportunity Spectrum (Brown, P.J. et. al., 1979).

The majority of both natural resource and social carrying capacity studies have been for land- or river-based recreation areas. Little previous literature exists for the flatwater recreation use that

is predominant at Lake Powell, and few examples exist of studies integrating a variety of factors potentially limiting capacity to reach the quantified conclusions necessary to address Glen Canyon's management problems.

In 1982, a conceptual carrying capacity study of boater use was completed for Lake Powell by the National Park Service's Denver Service Center. The primary focus of the 1982 study was development of a model of how and why boaters distribute themselves over Lake Powell, incorporating factors such as physical capacity of the lakeshore for camping, safety, distances from fuel services, and the existence of attractions in certain zones. The study also identified several major resource factors potentially limiting to boater use of the lake and its shoreline, but did not incorporate them into the model or otherwise quantify their effect on existing capacity. Although capacity estimates were derived for various possible management scenarios based on the operational constraints to boater distribution, such as distances, the location of fuel, and shoreline capacity, the model compared predicted boat distribution by zone with the physical capacity of the zones. It provided no means of comparing observed boat distributions with resource impacts or recreation quality. A further constraint on using the model for management purposes was a lack of flexibility in generating new scenarios to test the carrying capacity effect of additional management actions or alternative marina sizes.

The current study employs a "limiting factor" concept in combination with observed boater distributions lakewide, to quantify the carrying capacity of Lake Powell for boater recreation. The purpose of this approach is twofold: (1) to use manageable resource and recreation factors as the basis for analysis, and (2) to incorporate field observations of boater impacts into the assessment of limits. The methodology provides a reasoned basis for decisions on facility sizes and concurrent recreation management programs.

The study addresses Glen Canyon's related management problems which include: (1) a need to determine Lake Powell's capacity in relation to marina launch rates to help guide marina development, expansion, and concession contract negotiations; (2) a need to provide

a mix of recreation opportunities to meet the increasing demands of a broad spectrum of the public; (3) a need to maintain quality experiences to help insure continued public use of the area and maintain viable concession operations; and (4) a need to identify resource impacts and mitigation measures necessary to manage resources for enjoyment by future generations.

Much of the information collected and developed for the 1982 study was used in this effort, which builds on and owes much to that previous work. Background information and methodology from the 1982 work were used to quantify safety and physical limitations, determine lake zoning and shoreline-use characteristics, and to identify potential limiting factors.

Currently, there are four marina expansion programs in various stages of planning and implementation at Glen Canyon and two new marina proposals, one of which has already developed into a temporary marina at Piute Farms on the San Juan Arm. Concessions planning on the lake by Del Webb Recreational Properties and the Navajo Tribe include over one hundred million dollars of new concessions development and more than thirty million dollars for the infrastructures. These new developments will increase boater visitation. This study was conducted to determine the limits and sizes of these developments in relation to the carrying capacity of Lake Powell prior to development of detailed designs and concessioner contracts.

MANAGEMENT OBJECTIVES

Management objectives described in the park's 1985 Statement for Management were used to help formulate the basis of this study and to determine the appropriateness of various management scenarios developed or analyzed. At the outset of this effort management objectives were evaluated to determine their applicability to carrying capacity and the identification of potential limiting factors. This identification led to the collection of data through inventories and surveys necessary to quantify boats-at-one-time capacity for each study zone.

Crowding at launch ramp, Bullfrog
1979 file photo, Glen Canyon NRA

Following are the specific management objectives applicable to this study:

-To manage the recreation area so that it provides maximum recreational enjoyment to the American public and its guests.

-To maximize not only the recreational experiences, but the number of opportunities for enjoying the recreation area as well.

-To create varying kinds and uneven intensities of use along the length of the reservoir and throughout other portions of the recreation area.

-To encourage the maintenance of high water quality in all bodies and sources of water and to perpetuate the natural flow of free water.

-To manage the park's ecosystem in ways that interfere with natural processes as little as possible, consistent with permitted recreational and commercial uses.

-To determine the significance of the park's cultural resources and to maintain the integrity of these resources.

-In the Wahweap/Lone Rock and Warm Creek areas, to provide for intensive water recreation use.

-At Escalante, to maintain a relatively primitive experience.

The emphasis of several management objectives to provide a variety of quality recreation opportunities resulted in the identification of "social elements" as a potential limiting factor. Use of the Recreation Opportunity Spectrum as a planning and analysis tool addressed the need to provide varying degrees of use intensities and experience opportunities. When developing various management scenarios, management objectives for the Escalante and Wahweap areas helped determine appropriate social management categories.

The need to maintain high water quality, natural processes, and integrity of cultural resources are well

documented in the park's management objectives. Hence, it was necessary to measure water quality and shoreline impacts as potentially limiting factors. Although cultural resources may play a role in carrying capacity, they could not be used as a limiting factor in this study because of the lack of field data.

DESCRIPTION OF METHODS

OVERVIEW OF PROCESS

The ability to relate carrying capacity to marina launch rates is key to the utility of this study. At Lake Powell, boater access to the lake is mostly limited to the developed marinas. There is thus controlled access to the resource being used. Management control over this access resides in the authority to approve developments and their sizes, making capacity expressed in terms of boat launches per day from specific marinas a prime objective of the data analysis process as outlined in Figure 2.

BOATER SURVEY METHODS

To determine boater distribution on Lake Powell and help identify factors which could act to limit their recreational enjoyment, an exit survey of boaters was devised. The basic purposes of the survey were to obtain the trip itineraries of a sample of boaters immediately after their trip, to evaluate the relative importance of different recreational activities, and to identify the visitor perception of negative factors which might affect them while on the lake. The survey form (Figure 3) and sample design were prepared for the National Recreation Area by the Statistical Unit, National Park Service, Denver Service Center. To obtain distribution data, the survey form incorporates zoning of the lake as developed for the 1982 study. The zones are geographic. They were devised solely to provide study capability for different areas of the lake. The survey form was designed for numeric responses to facilitate analysis of the results by computer. At the time of interview, each boater was shown the zoning map (Figure 4) and asked to indicate the various zones visited during their trip. The survey of returning boaters was completed during the summer of 1985.

Surveys were taken by uniformed rangers and volunteers on July 2, 4, 6, 7, 16, 18, 20, and 28, and on August 1, 4, 20, and 24 at Wahweap, Bullfrog, and Hite Marinas. The assumption was made when designing the survey that the distribution of boaters from Halls

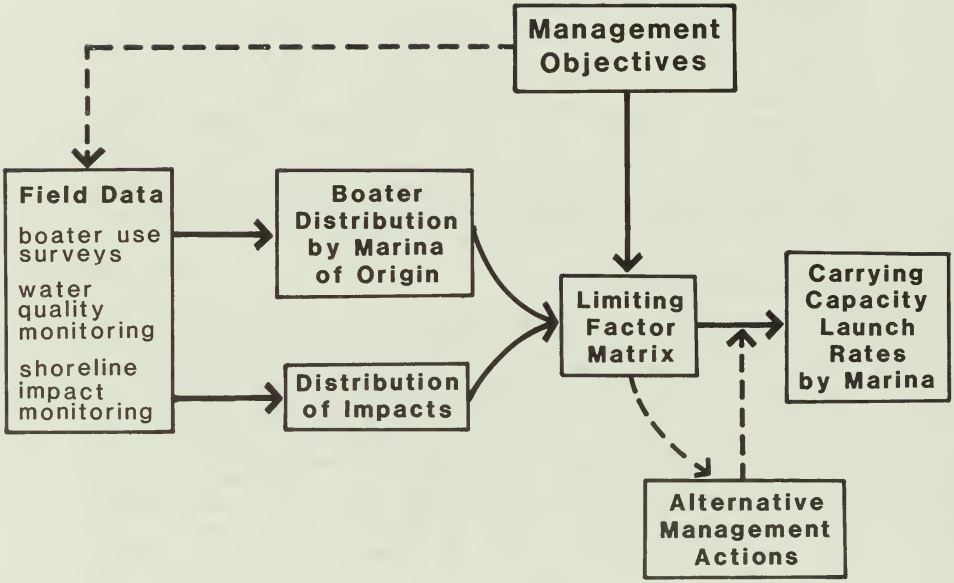

Figure 2

Analytical Process

Figure 3

LAKE POWELL CARRYING CAPACITY STUDY
VISITOR USE SURVEY

1. DATE OF SURVEY: _____(1a) LOCATION: _____(1b)

2. PARTY SIZE: _____(2) persons

3. DATE LAUNCHED: _____(3a), _____(3b) persons a.m. or p.m.

4. MAIN AREAS OF DAY USE: _____(4a), _____(4b), _____(4c), _____(4d), _____(4e),
1st day 2nd day 3rd day 4th day 5th day

_____(4f), _____(4g), _____(4h), _____(4i), _____(4j),
6th day 7th day 8th day 9th day 10th day

(Show visitor map of Lake Powell, put zone number in blanks above and place name, in known.)

5. AREAS OF OVERNIGHT USE: _____(5a), _____(5b), _____(5c), _____(5d), _____(5e),
1st night 2nd night 3rd night 4th night 5th night

_____(5f), _____(5g), _____(5h), _____(5i), _____(5j),
6th night 7th night 8th night 9th night 10 night

(Show visitor map of Lake Powell, put zone number in blanks above and place name, if known.)

6. HOW DID YOU OVERNIGHT: _____(6) where: B = in boat
S = on shore
BT = in boat on shore

7. DAY USE ACTIVITIES:

YOUR ACTIVITY TIME RANKING:		YOUR PREFERENCE LEVEL CONCERNING OTHER USERS IN YOUR ACTIVITY AREA:	YOUR PREFERENCE CONCERNING NPS RANGERS IN THE AREA:
FISHING	(7a)	(7b)	(7c)
TOURING			
CAMPING			
WATER SKIING			
HIKING			
SWIMMING			
JET SKIING			
CLIMBING			
SHORELINE DAY-USE			
(Rank 1-9 where 1 equals most time spent in an activity.)		(Where L = low density only; M = moderate density accepted.)	(Where L = low presence of NPS Rangers; M = moderate presence of NPS Rangers.)

8. OVERNIGHT STAYS: Your preference level concerning other users within visible/audible range: _____(8) where: L = lowest possible density preferred, M = moderate density acceptable, H = high density acceptable.

9. MAJOR ENVIRONMENTAL IRRITATIONS:

	ZONE #	DAY or NIGHT (n)	ZONE #	DAY or NIGHT (n)	ZONE #	DAY or NIGHT (n)	ZONE #	DAY or NIGHT (n)	ZONE #	DAY or NIGHT (n)	ZONE #	DAY or NIGHT (n)
NOISE OF OTHER USERS	(9a)	(9b)	(9a)	(9b)	(9a)	(9b)	(9a)	(9b)	(9a)	(9b)	(9a)	(9b)
HUMAN WASTE ON BEACHES												
CAMPGROUND SPACE UNSUITABLE												
OVERNIGHT ANCHORAGE UNSUITABLE												

10. BOAT TYPE: HOUSEBOAT _____ (10)
CABIN CRUISER _____
RUNABOUT _____
NON-MOTORIZED _____

11. REFUELING POINTS: HITE _____(11)
BULLFROG BASIN _____
HALLS CROSSING _____
DANGLING ROPE _____
WAHWEAP _____
OTHER _____ (specify_____)
NONE USED _____

Figure 4

Visitor Use Zones, Lake Powell

Glen Canyon National Recreation Area

U.S. Department of the Interior – National Park Service

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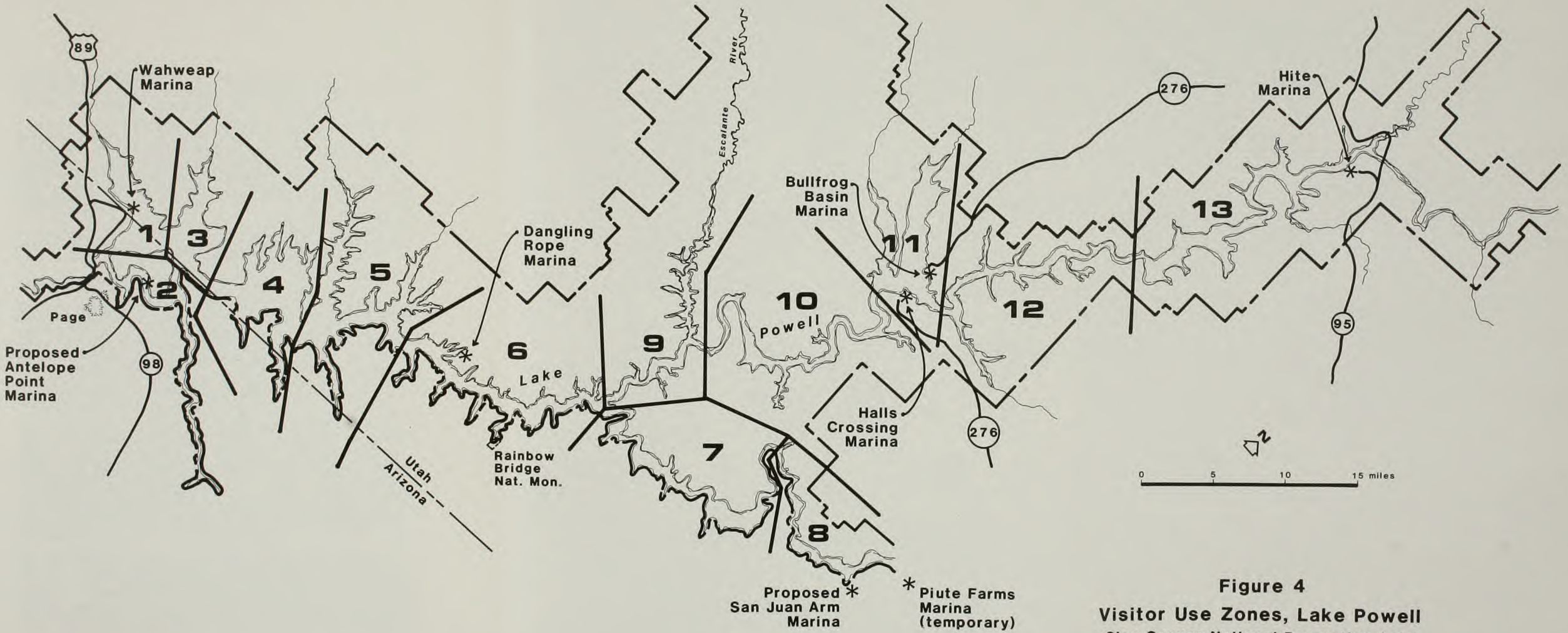

Figure 4

Visitor Use Zones, Lake Powell

Glen Canyon National Recreation Area

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Crossing would be the same as from Bullfrog because the two marinas are in close proximity. The Bullfrog sample is intended to represent both marinas.

Boaters were interviewed during two-hour sampling periods conducted from 6 to 10 a.m. and from 2:30 to 6:00 p.m. The two time periods were used to ensure an adequate cross-section of boaters, since rental houseboats are required to be returned before 10 a.m., while most other boaters end their trips in the afternoon. A total of 299 boating parties were interviewed.

Following the completion of the survey, the data obtained from the interviews were entered and coded onto a LOTUS 1-2-3 "spreadsheet" for analysis.

IDENTIFICATION OF LIMITING FACTORS

Factors selected to describe carrying capacity in a park management context must, to be useful, be quantifiable, lend themselves to monitoring, and be able to illustrate a reasonably direct relationship between levels of visitor use and the quality of the recreational experience or deterioration of natural resources. If an objective standard can be ascribed to a factor representing a threshold of impact, then a capacity for use may be derived.

The 1982 study identified several factors which may be key to evaluating recreation experiences and lakeshore impact as related to user density. The presence of trash and human waste on the shore, noise from other recreationists, water quality, and cultural resource vandalism were mentioned as factors potentially limiting to recreational use. None of these factors were quantified or incorporated into the 1982 model, however, as very little information on them was available.

In the present study, new field data on trash, human waste, noise, and water quality were evaluated for utility as carrying capacity indices, as discussed below. Vandalism to cultural resources (such as petroglyphs and structures left by prehistoric peoples) which are made more accessible by the existence of the lake, may be an excellent index of carrying capacity.

However, not enough information currently exists to relate this effect to use levels, and the factor was not used in the present study.

Physical space for shoreline use, and boating safety were also assessed as limiting factors, since they can be determined for a given set of use conditions and are based on physical characteristics of the lake itself (number of suitable shoreline-use sites and acreage of open water). In considering physical capacity, it is intuitively evident that the space available for overnighting on the shoreline would be much more limiting than acreage of open water. The need for this assumption is borne out by the fact that 95 percent of Lake Powell boaters spend at least one night on shore (1985 survey). Therefore, the "physical" limiting factor in this study focuses on the shoreline space available for overnight use.

Social carrying capacity was incorporated into this study through use of recreational opportunity classes to estimate the maximum densities of boaters which would still permit realization of the quality recreational experience expected by boaters at Lake Powell.

All four classes of factors which limit use (those based on natural resources, recreational opportunities for lake users, safety, and the physical characteristics of the lake) were determined by lake zone.

MEASURING EXISTING BOAT LAUNCHES

For years the recreation area has been keeping visitor-use statistics to evaluate the number of visitors pursuing the major recreational activities at Glen Canyon. Among the data kept are monthly estimates of boater use at each marina. These figures are based on boat trailer counts in parking areas combined with figures for boat-days from rental facilities provided by the concessioner. From this information the mean number of boats "out" daily from each marina was calculated for the periods when monitoring used in this analysis was conducted. For both 1985 and 1986, this period was June, July, and August, the time of peak use on the lake.

The result provides an estimate of boats on the lake during the period in which impacts were being recorded.

QUANTIFYING RESOURCE IMPACTS AS LIMITING FACTORS

Water Quality: Monitoring bacterial indicators of water quality was initiated at shoreline sites lakewide during the summer of 1985 to test the effects of shoreline use on water quality. Surface water samples were taken at 36 sites and transported to a laboratory within 6 hours to be cultured for fecal coliform bacteria using standard techniques (Fitzgerald, et. al., 1985). The monitoring was continued during 1986, concentrating on the contaminated sites found the previous year. For the purposes of the present study, the sample sites were arranged by lake zone (Figure 4) and mean coliform counts for each zone over the two years were calculated.

A management standard is readily available for water quality. The State and Federal criterion for swimming water quality (total immersion) is 200 fecal coliforms per 100 milliliters of water. Setting this criterion as the "limit" for bacterial contamination, the ratio of mean coliform counts in Lake Powell to the standard was calculated for each lake zone using data from both years. Coliform counts from the site having the worst water quality in each zone were used to derive the ratio. This number is termed the "water quality ratio" and represents the proportion of water quality limit consumed under current boater use conditions.

After determining mean launch rates for all marinas (boats per day) during the sample period as described above, and the distribution of boats to each zone from the marinas using the 1985 boater survey (Table 10), an estimate of the mean number of boats-at-one-time present in each zone during the water quality sampling period was calculated. This figure was divided by the water quality ratio to estimate the number of boats-at-one-time in each zone which would result in bacterial levels in shoreline waters equal to the limit set for swimming water quality (at the most popular sites in each zone). These estimates are shown in Table 1.

Lone Rock Beach, 1987

Table 1

Maximum Boats-at-One-Time To Maintain Water Quality

ZONE	BAOT
1 - Wahweap	467
2 - Navajo Canyon	233
3 - Warm Creek Bay	Not Limited
4 - Padre Bay	621
5 - Last Chance	ND
6 - Dangling Rope/Rainbow	1722
7 - Lower San Juan	ND
8 - Upper San Juan	ND
9 - Escalante	253
10 - Main Channel	2015
11 - Bullfrog/Halls	1217
12 - Main Channel	183
13 - Hite/Good Hope	95

ND - no data

Not Limited - Indicates that only Boats-at-one-time far beyond the physical capacity would cause the limit to be reached.

Shoreline Impact: Monitoring of shoreline recreational impact was accomplished lakewide in 1986, quantifying the presence of trash, human waste, and fire rings at a sample of shoreline campsites. Information collected included the number of pieces of trash, human waste deposits, fire rings, and campsite size.

For the purpose of evaluating shoreline effects as a carrying capacity limit, the measured parameters were combined into an index representing current impact for the campsites in each zone. This was done by computing the mean number of fire rings, human waste deposits, and trash pieces per 1,000 square feet of campsite for

each zone and adding them. The result may be termed the "shoreline impact index".

To set a limit, it was necessary to assign a management standard for the index, and this was set at 25, meaning that any numerical combination of litter, human waste, and fire rings per 1,000 square feet exceeding 25 is too much. A standard of 25 was used after comparing the indices for all 13 zones with the percentages of complaints about trash and human waste recorded for each zone during the boater survey. The range of complaints (number of complaints as a percentage of total visits to each zone) was generally 7 to 20 percent, with an inflection to 33 percent occurring at Zone 10. Zone 10 also had the highest shoreline impact index 26.7. By inference, an index of 25 could be used, for the purposes of this analysis, to approximate a maximum tolerable level of impact.

The relationship between shoreline impact and recreational quality is clearly a subject that needs separate study. Such a study should make it possible to develop a more definitive impact standard for use in future capacity analysis.

Campsite having a shoreline impact index of approximately 55 (Mt. Sheep Canyon, 1987)

The ratio of a zone's measured index to the standard 25 is termed the "shoreline impact ratio". It represents the amount of allowable shoreline impact consumed by existing use.

The daily number of boats present in each zone during the sampling period was then computed as explained under"Measuring Existing Boat Launches" (multiplying the mean daily number of boats "out" on the lake from each marina by the distribution factors for each zone obtained from Table 10). This yields an estimate of boats-at-one-time in a zone during the sampling and is thus an estimate of the number of boats which caused the impacts. Dividing this number by the shoreline impact ratio yields the number of boats-at-one-time in a zone which would cause the shoreline impact limit to be reached. Table 2 shows the result for each zone.

Table 2

Maximum Boats-At-One-Time For Shorelines

ZONE	BAOT
1 - Wahweap	Not Limited
2 - Navajo Canyon	444
3 - Warm Creek Bay	1950
4 - Padre Bay	Not Limited
5 - Last Chance	830
6 - Dangling Rope/Rainbow	262
7 - Lower San Juan	560
8 - Upper San Juan	250
9 - Escalante	736
10 - Main Channel	232
11 - Bullfrog/Halls	Not Limited
12 - Main Channel	585
13 - Hite/Good Hope	689

Not Limited - Means low current impact to the extent that estimated boats-at-one-time limit would be far above physical capacity.

SAFETY AS A LIMITING FACTOR

A survey of State Comprehensive Outdoor Recreation Plans (SCORP) was conducted by the Bureau of Outdoor Recreation in 1977 to develop guidelines for various recreational activities, including safe boating on lakes. This survey recommended a range of 9 to 18 acres of surface water per boat as a guideline for safe boating on open water with unlimited power. The guideline is not intended to include accident rates resulting from collisions with docks or other marina improvements. Since an upper "limit" of use is desired for a standard in the present study, the figure "9 acres per boat" was applied here as the density limit for safe boating. This density figure was applied to the surface water acres in each zone at lake elevation 3,700 feet (normal operating pool) to determine maximum number of boats allowed at one time in a zone while still maintaining safe boating conditions (Table 3).

Table 3

Maximum Boats-At-One-Time For Safe Boating Use

ZONE	BAOT
1 - Wahweap	1054
2 - Navajo Canyon	903
3 - Warm Creek Bay	1415
4 - Padre Bay	2094
5 - Last Chance	2950
6 - Dangling Rope/Rainbow	1529
7 - Lower San Juan	1236
8 - Upper San Juan	1002
9 - Escalante	885
10 - Main Channel	1355
11 - Bullfrog/Halls	1997
12 - Main Channel	1085
13 - Hite/Good Hope	2270

Boating in open water at full power,
Wahweap Bay, 1987

PHYSICAL CAPACITY

The physical capacity of Lake Powell to absorb recreational boater use is most clearly limited by the availability of desirable shoreline sites to stop and camp. Much of the lakeshore is cliff, rockslide, or

other unsuitable substrate, and the quantity of good sites varies widely from zone to zone. A good site for shoreline use is one presenting an anchorage and level ground on shore which can be used to set up a camp.

Typical campsite
Lake Powell, 1987

Potter and Pattison (1976 and 1977) mapped Lake Powell's shoreline types as part of a baseline study for the lake. The shorelines were classified as cliff, domed terrace, shelfy terrace, sand beach, alluvium, talus, and rockslide. The mileages of each type by zone are shown in Appendix 1 for lake elevation 3,700 feet above sea level. The 1982 study developed a method of counting the number of campsites per mile for a sample mileage of each shoreline type to arrive at campsite-per-mile factors for each type of shoreline and these were done for lake elevations 3,660 and 3,680 feet above sea level.

Such counts were repeated in 1986, when the lake was at the 3,700-foot elevation operating pool, since this would normally be the elevation during peak visitor use periods. Counts of campsites per mile were performed under the assumption that every site would be filled, with no adjustment made for the negative effects of crowding. For sandy beach, a factor of 52 sites per mile was assigned on the assumption that the physical requirement of a single campsite is approximately 100 feet. The campsite measurement is linear in this study because every boater needs a site with access to shore. Therefore, no "depth" factor entered into the computations.

The factors derived from 1986 field counts were as follows:

Shoreline Type	Campsites/Mile
Cliff	1.0
Alluvium	8.0
Dome and shelfy terrace	4.8
Talus	6.2
Rockslide	1.0
Sand beach	52.0

The number of campsites in each zone was obtained by multiplying these factors by the miles of each shoreline type present in the zone (Appendix 1).

The 1985 visitor survey yielded corrections for day-use-only boaters (4 percent) and for multiple boats per camping party (1.7 boats per party). Applying the corrections to campsite number gives the number of

boats which would be in a zone when every campsite is filled. This is the physical capacity for boats-at-one-time (Table 4).

Table 4

Physical Capacity

ZONE	BAOT
1 - Wahweap	1088
2 - Navajo Canyon	951
3 - Warm Creek Bay	2090
4 - Padre Bay	1431
5 - Last Chance	1770
6 - Dangling Rope/Rainbow	729
7 - Lower San Juan	751
8 - Upper San Juan	1443
9 - Escalante	1341
10 - Main Channel	714
11 - Bullfrog/Halls	1588
12 - Main Channel	327
13 - Hite/Good Hope	2149

LIMITING FACTORS RELATED TO RECREATIONAL QUALITY

The goal of recreationists at Lake Powell is to obtain a satisfying experience. Opportunities to realize various recreation experiences can be provided by managing the natural, social, and managerial settings. The Recreation Opportunity Spectrum (ROS) concept (U.S. Forest Service) arranges these opportunities along a spectrum through recognition of each setting component.

For this study, ROS was refined for application to flatwater recreation (Frye 1986). The flatwater continuum includes five classes: primitive, semiprimitive, rural/natural, urban/natural, and urban. The settings, experiences, and activities for each of these classes are illustrated in Figure 5. At Lake Powell, only the semiprimitive, rural/natural, and urban/natural classes apply.

The social setting is an expression of user encounters, contacts, and visibility of other boaters on the lake. The descriptions in Figure 5 also include a generalized description of the social setting. For this study it was necessary to quantify boating levels as it relates to the previously described factors. The Recreation Opportunity Spectrum Users Guide, U.S. Forest Service, and Special Report No. 1 - A Manual to Determine Recreation Carrying Capacity, National Park Service and University of Arizona (T.M. Moe and A.H. Underhill) evaluated user-density ranges in terms of recreational opportunities for primitive to urban experiences. Capacity coefficients for each experience class of water recreation were given; these were used here to apply user-density ranges to specific study zones of Lake Powell. This was accomplished by comparing actual user-density levels with user preferences identified through the 1985 Lake Powell Boater Survey to derive capacity coefficients for Lake Powell.

The capacity coefficients used may vary according to a factor termed the isolation index. This index measures the physical capability of a lake zone to isolate boating parties. It is based on the premise that meandering shorelines screen the sights and sounds of one boating party from another, thus increasing the opportunities to experience the feeling of isolation. The index is expressed as a ratio of shoreline miles to surface-water acres. For convenience, each zone may be classified as having a high, moderate, or low index, where a low index refers to a relatively low degree of isolation from other boaters in that zone.

1:160 = low index
1:106 to 159 = moderate
1:105 = high index

Figure 5

Description of Opportunity Classes

'NATURAL	URBAN
	
MODIFIED LANDSCAPE TO PROVIDE MAJOR ES IN A SUBSTANTIALLY RONMENT WITH A RING BACKDROP UNTERS WITH OTHER S THE "WEAR" OF TION SIBLE BY MOTORIZED	· COMPLETELY MODIFIED LANDSCAPE WITH FACILITIES TO PROVIDE MAJOR VISITOR SERVICES FOR HIGHLY INTENSIFIED MOTORIZED USE IN A TOTALLY URBANIZED ENVIRONMENT · CONSTANT ENCOUNTERS WITH OTHER WATERCRAFT · SHORELINE IS HEAVILY IMPACTED BY HUMAN OCCUPATION · SHORELINE ACCESSIBLE BY MOTORIZED LAND VEHICLES AND MAY HAVE MASS TRANSIT ACCESSIBILITY
OF MAN ARE DOMINANT NITY TO EXPERIENCE QUILITY, QUIET OR USE OF OUTDOOR DERNESS SKILLS ENCOUNTERS WITH & WATERCRAFT	· SIGHTS & SOUNDS OF MAN ARE DOMINANT · OPPORTUNITY TO EXPERIENCE SOLITUDE, TRANQUILITY, QUIET, IS NONEXISTENT · NO KNOWLEDGE OR USE OF OUTDOOR SURVIVAL & WILDERNESS SKILLS NECESSARY · CONSTANT ENCOUNTERS WITH OTHER HUMANS & WATERCRAFT
D MOTORIZED MPING ATERCRAFT INCLUDING RRY BOATS SAILING M BEACH G ET SKIING	NONMOTORIZED TO MOTORIZED · DESIGNATED CAMPING · ALL TYPES OF WATERCRAFT INCLUDING TOUR BOATS & FERRY BOATS · SAILBOARDING/SAILING · DESIGNATED SWIM BEACH · FISHING · SHORELINE HIKING · WATER-SKIING/JET SKIING

Figure 5

Description of Opportunity Classes

SPECTRUM OF OPPORTUNITIES	PRIMITIVE	SEMIPRIMITIVE	RURAL/NATURAL	URBAN/NATURAL	URBAN
					
SETTINGS	· NATURAL APPEARING LANDSCAPE · ENCOUNTERS WITH OTHER WATERCRAFT RARE · NO EVIDENCE OF SHORELINE FACILITIES · NO EVIDENCE OF HUMAN OCCUPATION ON SHORELINE · NO MOTORIZED ACCESS TO THE WATER FROM SHORELINE	· PREDOMINATELY NATURAL APPEARING LANDSCAPE · OCCASIONAL ENCOUNTERS WITH OTHER WATERCRAFT · EVIDENCE OF UNOBTUSIVE SHORELINE SUPPORT FACILITIES FOR BOATING & CAMPING - NO SERVICE FACILITIES · SHORELINE MAY SHOW EVIDENCE OF HUMAN OCCUPATION · NO MOTORIZED ACCESS TO THE WATER FROM SHORELINE	· PREDOMINATELY NATURAL APPEARING LANDSCAPE WITH SMALL SCALE MODIFICATIONS · SHORELINE SERVICE FACILITIES FOR MOTORIZED BOATING · FREQUENT ENCOUNTERS WITH OTHER WATERCRAFT · EVIDENCE OF HUMAN OCCUPATION ON SHORELINE · SHORELINE ACCESSIBLE BY MOTORIZED LAND VEHICLES	· PREDOMINATELY MODIFIED LANDSCAPE WITH FACILITIES TO PROVIDE MAJOR VISITOR SERVICES IN A SUBSTANTIALLY URBANIZED ENVIRONMENT WITH A NATURAL APPEARING BACKDROP · CONSTANT ENCOUNTERS WITH OTHER WATERCRAFT · SHORELINE SHOWS THE "WEAR" OF HUMAN OCCUPATION · SHORELINE ACCESSIBLE BY MOTORIZED LAND VEHICLES	· COMPLETELY MODIFIED LANDSCAPE WITH FACILITIES TO PROVIDE MAJOR VISITOR SERVICES FOR HIGHLY INTENSIFIED MOTORIZED USE IN A TOTALLY URBANIZED ENVIRONMENT · CONSTANT ENCOUNTERS WITH OTHER WATERCRAFT · SHORELINE IS HEAVILY IMPACTED BY HUMAN OCCUPATION · SHORELINE ACCESSIBLE BY MOTORIZED LAND VEHICLES AND MAY HAVE MASS TRANSIT ACCESSIBILITY
EXPERIENCE	· ISOLATION FROM SIGHTS & SOUNDS OF MAN · FEELING OF CLOSENESS WITH NATURE · OPPORTUNITY TO EXPERIENCE SOLITUDE, TRANQUILITY, QUIET · HIGH DEGREE OF CHALLENGE, SELF RELIANCE, RISK · KNOWLEDGE & USE OF OUTDOOR SURVIVAL & WILDERNESS SKILLS · INFREQUENT ENCOUNTERS WITH OTHER HUMANS OR WATERCRAFT	· PREDOMINATELY ISOLATED FROM SIGHTS & SOUNDS OF MAN · OPPORTUNITY TO EXPERIENCE SOLITUDE, TRANQUILITY, QUIET MAY BE OBTAINED · INTERACTION WITH NATURE PREDOMINATES · KNOWLEDGE & USE OF OUTDOOR SURVIVAL & WILDERNESS SKILLS · OCCASIONAL ENCOUNTERS WITH OTHER HUMANS OR WATERCRAFT	· LIMITED OPPORTUNITY TO EXPERIENCE SOLITUDE, TRANQUILITY, QUIET · KNOWLEDGE & USE OF OUTDOOR SURVIVAL & WILDERNESS SKILLS IS NOT ESSENTIAL · FREQUENT ENCOUNTERS WITH OTHER HUMANS OR WATERCRAFT	· SIGHTS & SOUNDS OF MAN ARE DOMINANT · LIMITED OPPORTUNITY TO EXPERIENCE SOLITUDE, TRANQUILITY, QUIET · NO KNOWLEDGE OR USE OF OUTDOOR SURVIVAL & WILDERNESS SKILLS NECESSARY · NEAR CONSTANT ENCOUNTERS WITH OTHER HUMANS & WATERCRAFT	· SIGHTS & SOUNDS OF MAN ARE DOMINANT · OPPORTUNITY TO EXPERIENCE SOLITUDE, TRANQUILITY, QUIET, IS NONEXISTENT · NO KNOWLEDGE OR USE OF OUTDOOR SURVIVAL & WILDERNESS SKILLS NECESSARY · CONSTANT ENCOUNTERS WITH OTHER HUMANS & WATERCRAFT
ACTIVITIES	NONMOTORIZED · PRIMITIVE CAMPING · SMALL WATERCRAFT · SAILBOARDING · SAILING · SWIMMING · SNORKELING/SCUBA DIVING · FISHING · NATURE OBSERVATION · HUNTING · SHORELINE HIKING	NONMOTORIZED TO MOTORIZED · SEMIPRIMITIVE CAMPING · SMALL WATERCRAFT · SAILBOARDING · SAILING · SWIMMING · SNORKELING/SCUBA DIVING · FISHING · NATURE OBSERVATION · HUNTING · SHORELINE HIKING	NONMOTORIZED TO MOTORIZED · SEMIPRIMITIVE CAMPING FROM BOATS & VEHICLES · ALL TYPES OF WATERCRAFT INCLUDING TOUR BOATS & FERRY BOATS · SAILBOARDING/SAILING · SWIMMING · SNORKELING/SCUBA DIVING · FISHING · NATURE OBSERVATION · SHORELINE HIKING · WATER-SKIING/JET-SKIING	NONMOTORIZED TO MOTORIZED · DESIGNATED CAMPING · ALL TYPES OF WATERCRAFT INCLUDING TOUR BOATS & FERRY BOATS · SAILBOARDING/SAILING · DESIGNATED SWIM BEACH · FISHING · SHORELINE HIKING · WATER-SKIING/JET SKIING	NONMOTORIZED TO MOTORIZED · DESIGNATED CAMPING · ALL TYPES OF WATERCRAFT INCLUDING TOUR BOATS & FERRY BOATS · SAILBOARDING/SAILING · DESIGNATED SWIM BEACH · FISHING · SHORELINE HIKING · WATER-SKIING/JET SKIING

Table 5 illustrates capacity coefficient ranges used for this study.

Table 5

Capacity Coefficient Ranges

(Surface Water Acres/Boat)

Isolation Index	Semi-Primitive	Rural/ Natural	Urban/ Natural
High	12	9	9
Moderate	69	12	9
Low	125	18	9

Table 6 illustrates the ratio of shoreline miles to surface-water acres for each study zone of Lake Powell at lake elevation 3,700 feet as well as its corresponding Isolation Index. The index is used to determine which capacity coefficient from Table 5 will be used to compute boater limits for each zone.

Table 6

Ratio Of Shoreline Miles To Surface Water

Zone	Ratio	Isolation Index
1 - Wahweap	1:174	Low
2 - Navajo Canyon	1:80	High
3 - Warm Creek Bay	1:187	Low
4 - Padre Bay	1:164	Low
5 - Last Chance	1:127	Moderate
6 - Dangling Rope/Rainbow	1:75	High
7 - Lower San Juan	1:102	High
8 - Upper San Juan	1:54	High
9 - Escalante	1:50	High
10 - Main Channel	1:99	High
11 - Bullfrog/Halls	1:193	Low
12 - Main Channel	1:105	High
13 - Hite/Good Hope	1:99	High

Low isolation index, Wahweap Bay

High isolation index, Escalante

Marina development affects the physical setting of study zones, Halls Crossing Marina, 1986.

Boats-at-one-time limits for each zone was determined by applying the appropriate capacity coefficient to surface-water acres at lake elevation 3,700 feet. Table 7 illustrates the resulting boats-at-one-time capacity for each ROS class by zone. Where existing conditions, or zone-specific management objectives defined in the General Management Plan or Statement for Management, preclude use of a particular ROS class, the entry N/A (not applicable) was made in Table 7. For example, in a zone dominated by a developed marina, a semi-primitive recreational experience could not be realized, so no figure is given in the table. Conversely, where the management objectives are to maintain rural or primitive experiences, the ROS urban class was not used.

Table 7

Social Boats-At-One-Time Capacity

Zone	Semi-Primitive	Rural/Natural	Urban/Natural	GMP Objectives
1 - Wahweap	N/A	527	1054 [1]	Develop/RRU
2 - Navajo Canyon	N/A	903 [1]	903 [1]	RRU
3 - Warm Creek Bay	102	809	N/A	RRU
4 - Padre Bay	151	1047	N/A	RRU
5 - Last Chance	385	2212	N/A	RRU
6 - Dangling Rope/ Rainbow	1147	1529 [1]	N/A	Natural
7 - Lower San Juan	927	1236 [1]	N/A	Natural
8 - Upper San Juan	725	1002	N/A	RRU
9 - Escalante	664	N/A	N/A	Natural
10 - Main Channel	1016	1355 [1]	N/A	Natural
11 - Bullfrog-Halls	N/A	998	1997 [1]	Develop/RRU
12 - Main Channel	814	1085 [1]	N/A	RRU/Natural
13 - Hite-Good Hope	1702	2270 [1]	N/A	RRU/Natural

[1] Capacity limited by safe boating densities and not densities required for realization of a specific opportunity class.

The applicable management objectives from the GeneralManagement Plan are presented for each study zone in Table 7. Areas designated for "Recreation and Resource Utilization (RRU)" emphasize a diversity of recreational activities and would be considered equivalent to the "rural" opportunity category used in this study. Development areas are where marinas and intensive use sites would be located, and Natural areas are managed to maintain existing natural conditions. The latter type would be considered under the "semi-primitive" opportunity class.

COMPUTING MARINA CAPACITIES TO LAUNCH BOATS

Calculation of the capability of marina facilities to launch boats is, for the purposes of this study, needed to compare the capacities of existing and planned marina facilities with the estimated lake carrying capacity launch rates derived from the current study.

Approved marina facility sizes are described in each marina's Development Concept Plan (DCP). The DCP's present the sizes of concessioner rental boat fleets, number of wet-slips and moorings, and public launch ramp operational capacities. In general, concession boats, once launched, are not available for launch again until the length of stay expires. Concessioner records indicate the average length of stay is about 5 days, yielding a mean daily turnover rate of 20 percent. In other words, any combination of five rental boats, wet-slips or moorings is equal to one daily marina boat launch. The DCP public launch ramp capacities are computed from the number of ramp lanes constructed and the estimated time requirements for a boat launch or retrieval. Over a long period of time, public launch ramp capacity to launch boats is equal to one-half of a launch ramp's operational capacity because half of the ramp activity must always be take-outs. It is assumed that there could be an endless supply of boats to use the public ramps, so the public ramp launch rate is not reduced by length of stay. The following illustrates how marina capacities to launch boats were calculated.

MARINA CAPACITY TO LAUNCH BOATS = ((RENTBOAT + SLIP + MOOR) X DTR) + (RAMP X DL)

RENTBOAT = Size of concessioner boat rental fleet

SLIP = Number of marina wet-slips

MOOR = Number of marina moorings

DTR = Daily turnover rate for concessioner rental boat operations (20 percent or .2 at Lake Powell)

RAMP = Operational capacity of public launch ramp

DL = Daily launch factor of 0.5 because 1/2 of ramp capacity will be used for takeouts.

Table 8 presents the maximum daily rate at which existing and approved marina facilities can launch boats.

Table 8

Marina Launch Capacity
(launches/day)

Marina	Existing	Approved [1]
Wahweap/Lone Rock	644	870
Antelope Point	0	240
Bullfrog Basin	220	420
Halls Crossing	145	206
Hite	114	114
Totals	1,123	1,850

[1] **Launch rates from proposed expanded facilities in current plans**

RESULTS AND DISCUSSION

VISITOR SURVEY

The survey of returning boaters yielded excellent data for analysis. Of the 299 interviews obtained, 140 launched at Wahweap, Stateline, or Lone Rock, 131 launched at Bullfrog, and 28 at Hite. The lower number of interviews obtained at Hite was the result of fewer boaters there during the standard survey periods. Lakewide, 96 percent of respondents spent at least one night on the lake; and approximately half had a houseboat with them. The average length of stay for boaters in the survey was 4.5 days, indicating a relatively high intensity of use by those who launch boats in the recreation area. The length of stay result is considered somewhat surprising, but seems reasonable in view of Lake Powell's remote location. Boaters troubling to travel the distance to Glen Canyon evidently are those with the time for a week's stay. An additional factor is the concessioner's minimum houseboat rental period of three nights. The average group size for boater parties interviewed was 8.2 persons, and average number of boats per group was 1.7.

LENGTH OF STAY

To establish the relationship between boats-at-one-time and marina launch rates, knowledge of length of stay is required. This parameter is summarized from the boater survey in Table 9 below.

Table 9

Length Of Stay

	Zone												
	1	2	3	4	5	6	7	8	9	10	11	12	13
Days	4.3	3.8	4.6	4.7	5.6	5.5	5.9	7.0	5.6	5.1	4.5	5.1	5.0

THE DISTRIBUTION OF BOATERS ON LAKE POWELL

The distribution of visitors on the lake was computed from boater overnights in each zone by marina of origin.

These results are presented in Table 10.

Table 10

Boater Distribution from Lake Powell Marinas
(overnight stays in each zone by boats from a particular marina)

Zone	Wahweap	Bullfrog	Hite
1 - Wahweap	#125	#4	#0
2 - Navajo Canyon	42	0	0
3 - Warm Creek Bay	80	2	0
4 - Padre Bay	84	5	0
5 - Last Chance	80	8	0
6 - Dangling Rope/ Rainbow Bridge	38	47	1
7 - Lower San Juan	8	23	0
8 - Upper San Juan	3	2	0
9 - Escalante	16	85	2
10 - Main Channel	6	127	16
11 - Bullfrog-Halls	9	172	14
12 - Main Channel	4	71	40
13 - Hite-Good Hope	0	3	66
Totals	495	549	139

data source: 1985 boater exit survey

The distribution table shows where boats go when they leave a marina and how much relative time is spent in particular areas. As might be expected, the majority of overnight stays are spent in zones near the point of origin with emphasis on those with most suitable shoreline for establishing campsites. Zones 3, 11, and 13, for example, have high numbers of suitable campsites and are near marinas. They receive much of the overnight use. Zone 2 (Navajo Canyon) receives a low level of use considering its proximity to Wahweap, probably because its isolation from the main axis of the lake would make it a "side-trip" for many recreationists. Zone 2 also has low physical capacity because it is dominated by shorelines with high cliffs.

There is a "pulse" of boaters from Bullfrog (and presumably Halls Crossing) that spend time in Zone 6, where Dangling Rope and Rainbow Bridge are located. A smaller pulse of boaters from Wahweap reach the Escalante Canyon area, which is scenic and considered an attraction. Two other distribution factors borne out by the data are that very few boaters reach the upper San Juan arm which is a long way from fuel (the survey was conducted prior to opening of the temporary Piute Farms marina) and that boater use originating at Hite is largely contained in the upper zones of Lake Powell.

LIMITING FACTOR MATRIX

The limiting factors calculated for each zone (described in methods) were integrated into a matrix, Table 11, facilitating identification of the factor most constraining the use of each zone.

The matrix should be read in rows to identify each zone's most limiting factor. Reading the matrix by columns is not particularly useful analytically, but does give an idea of capacity differences between zones caused by physical characteristics and distribution patterns.

Physical capacity is not the limiting factor for any zone under existing conditions. It should be noted that by way of corroboration, boaters in the survey were given an opportunity to record any problems they had finding suitable space and anchorages yet very few

(up to 9 percent) mentioned either of these problems in any zone. These results suggest that the method used for estimating physical capacity is effective.

Table 11

Limiting Factor Matrix

(Number of Boats-At-One-Time)

Zone	Physical	Safety	Water Quality	Shore Impacts	Semi-Primitive	Rural/ Natural	Urban/ Natural
1	1088	1054	467	NL	N/A	527	1054
2	951	903	233	444	N/A	903	903
3	2090	1415	NL	1950	102	809	N/A
4	1431	2094	621	NL	151	1047	N/A
5	1770	2950	ND	830	385	2212	N/A
6	729	1529	1722	262	1147	1529	N/A
7	751	1236	ND	560	927	1236	N/A
8	1443	1002	ND	250	725	1002	N/A
9	1341	885	253	736	664	N/A	N/A
10	714	1355	2015	232	1016	1355	N/A
11	1588	1997	1217	NL	N/A	998	1997
12	327	1085	183	585	814	1085	N/A
13	2149	2270	95	689	1702	2270	N/A

N/A = Not Applicable

ND = No Data

NL = Not Limited

The resource parameters, water quality and shoreline impact, are the most limiting factors in 9 out of the 13 zones and would appear to be the dominant constraints under current conditions.

Water quality is an excellent parameter with which to evaluate carrying capacity because there is a regulatory guideline available to use as a standard. The method used here shows that water quality monitoring data can be related quantitatively to visitor use sufficiently well to produce an estimate of use limits.

Shoreline impacts limit capacity in four zones principally due to accumulations of trash and human waste. The problem is especially acute where high levels of use coincide with low physical capacity (Zones 6 and 10) as a comparison of Tables 2 and 4 will show.

Low sample size affects some of the figures in the limiting factor matrix, and these may change somewhat as the data base grows. For example, water quality information for Zone 3 is based on five samples from only one site. Since these samples had very low bacterial counts, and the zone receives a large distribution of boats, the result is an unusally high boats-at-one-time limit for this factor and the conclusion that water quality would not be limiting even at very high use levels. Additional water sampling would probably moderate this result by improving the estimate of mean bacterial counts.

Interpretation of Table 11 for results pertaining to specific zones might include the following considerations:

Zone 1 - Wahweap: Water quality limiting--partly a consequence of the worst-quality site (Lone Rock) having intense use by land-access visitors as well as boaters. The low shore impact is a little surprising, but may reflect effective results of cleanup campaigns such as the National Park Service-sponsored Adopt-A-Canyon program.

Heavy boating use created by presence of Wahweap Marina and the popularity of Lone Rock beach provides the boater with near constant visual contact with other users. Developments at the Wahweap Marina create a modified shoreline appearance. These factors contribute to Zone 1 providing an urban/natural recreation experience. Although this zone could be managed for rural/natural opportunities, that would be

ineffective because of use demands. Should water quality constraints be mitigated, safe boating density would limit use in this zone before physical boating capacities would be exceeded.

Zone 2 - Navajo Canyon: Another zone whose water quality limit is probably influenced by land-access users (Antelope Point). The zone may never be physically constrained because the safety limit is lower. Safety could be a prime consideration when the planned marina at Antelope Point becomes operational.

Presence of the City of Page, Navajo Generating Station, and future Antelope Point Marina creates a physical setting conducive to urban/natural recreation opportunities. Until completion of the Antelope Point Marina, portions of this zone could provide rural/natural opportunities. However, long-range sustained opportunities must be viewed as urban/natural.

Zone 3 - Warm Creek Bay: This zone indicates high physical capacity and has low resource impact under moderate use (refer to Table 10 for an indication of relative use).

Absence of modifications to shorelines creates opportunities for semi-primitive or rural/natural experiences. Social capacity would limit use in both classes and still maintain safe boating densities. Existing management zoning indicates the rural/natural social experience category would apply, making the boats-at-one-time limit applicable to this zone 809 instead of 102. (Refer to Table 7 and narrative for a description of management zones and relation to opportunity classes).

Zone 4 - Padre Bay: The water quality result is affected by certain mid-channel beaches used by cattle as well as visitors. Shoreline impacts are not limiting.

High levels of use in Padre Bay create near constant visual contact with other users in a natural appearing environment. This results in rural/natural opportunities (which is consistent with existing management objectives) and limits the feasibility of managing this zone for semi-primitive recreation.

Openness afforded by this portion of Lake Powell provides a large acreage of water for boating compared with shoreline mileages and therefore maintains boat density well within safe limits.

Zone 5 - Last Chance: This zone is free of human shoreline developments. Along the main channel high boating use presents rural/natural opportunities. In the upper reaches of Last Chance and Rock Creek Bays, meandering shorelines present opportunities providing a sense of isolation and a more semi-primitive experience. Current management objectives would apply the rural/ natural recreation experience to this zone.

Without the shoreline impacts it is experiencing, this zone would be unconstrained within its physical limits.

Zone 6 - Dangling Rope/Rainbow Bridge: This zone has a low physical capacity and use levels similar to zones with twice the capacity. This may be attributed to the presence of Dangling Rope Marina and Rainbow Bridge National Monument, and is probably the explanation for a high level of shoreline impact. Should shoreline impacts be mitigated, physical capacity would limit boater use of this zone.

High levels of boating use generated by the Dangling Rope Marina and Rainbow Bridge National Monument create user encounters more compatible with rural/natural recreation, although the management zoning (Table 7) would indicate a nominal semi-primitive ROS objective for the many isolated side canyons in this zone.

Zone 7 - Lower San Juan: The shoreline impact limitation on use is lower than, but of similar magnitude, to the physical capacity of the zone. This means that removing shoreline impact in this zone would have a comparatively small influence on overall carrying capacity of the lake.

Physical capacity would limit use in this zone below the level permitted by either recreational opportunity class.

Zone 8 - Upper San Juan: The use constraint presented by shoreline impact is probably influenced by debris coming down the San Juan River which gets deposited

along the lakeshore in the upper San Juan Arm. The remote location has made the collection of water quality information infeasible, but monitoring will be needed as the proposed San Juan Marina becomes operational.

Presently, this zone is dominated by semi-primitive opportunities. With development of the San Juan Marina, settings would change to favor rural/natural experiences, in which case safe boating density would limit use if shoreline impact were mitigated.

Zone 9 - Escalante: The water quality result is a significant constraint. It comes from concentrated use at one of the most popular single sites in the area (Davis Gulch).

General Management Plan direction limits this zone to semi-primitive recreation opportunities. Boating densities needed to provide this type of experience are well within safe boating limits.

Zone 10 - Main Channel: A high use distribution (Table 10) combined with low physical capacity has probably led to the heavy shoreline impact here.

Meandering shorelines provide a high isolation index. Along the main channel thoroughfare safe boating densities would limit use and provide rural/natural opportunities. Remaining portions of this zone provide semi-primitive experiences.

Zone 11 - Bullfrog/Halls Crossing: The presence of the Bullfrog Basin and Halls Crossing marinas as well as the cross lake ferry service creates use levels and shoreline modification most conducive to urban/natural recreation opportunities, and this would be the applicable ROS class. Water quality and physical capacity becomes the limiting factors in this zone.

Zone 12 - Main Channel: This zone has growing use and low physical capacity. It experiences concentrated visitor activity at a few sites, resulting in low water quality at Moki Canyon. The level of shoreline impact is also relatively high.

Rural/natural opportunities would prevail under current management objectives; however, physical capacity would

generally limit use below the level for semi-primitive experiences.

Zone 13 - Hite/Good Hope Bay: This zone has the largest capacity of any and a moderate level of use. The water quality constraint is at Farley Canyon, another land-access site. Management action to alleviate water quality concerns would result in a large increase of carrying capacity because the next limiting factor is an order of magnitude higher. Mitigating both resource factors would result in an even greater capacity increase for the zone.

In the upper reaches of this zone, presence of the small Hite Marina creates shoreline modifications and use levels consistent with rural/natural opportunities. Although lower portions of this zone are dominated by semi-primitive experiences, management zoning would call for use of the rural/natural opportunity class as an objective.

CARRYING CAPACITY LAUNCH RATES

Management of boating use within carrying capacity limits can be achieved by constraining the size of Lake Powell's developed marinas so that the physical ability to launch boats is consistent with the lake's carrying capacity for boater use. Remote locations and the cliff/canyon topography prevents any significant number of launches occurring outside of these developed zones. Thus, the number of boats using Lake Powell can effectively be controlled through the location, distribution and size of marinas. Recognition of these factors during advance planning activities can eliminate the need to implement permit systems or other reactive techniques designed to control use after realistic limits have already been exceeded. There would be no point in constructing boat launching facilities which could launch more boats than the lake's recreational environment could absorb.

Using the applicable boats-at-one-time limit for each zone and the distribution of boats from each marina found in the visitor survey, one can compute the launch rate for every marina which would result in boats distributed in accord with the capacity of each zone. These rates are termed carrying capacity launch rates. Table 12 illustrates the calculation of carrying

capacity launch rates for each marina. Beginning with the most limited factor for each zone from Table 11 (in boats-at-one-time), the following formula is used for the calculation.

Carrying Capacity Launch Rate = SUM (BAOT LIMITzi X DISTRIBUTIONzi)/LENGTH OF STAY zi

BAOT LIMITzi = Limiting factor in BAOT for Zone i (1-13) (from Table 11)

DISTRIBUTIONzi = Distribution factor, zone, i for marina origin (from Table 10)

NOTE: The unit of the carrying capacity launch rate figure is boats per day. Length-of-stay enters the equation as the time element. It represents the amount of time each boat is consuming shoreline sites, lake resources, and recreational opportunity.

Table 12

Carrying Capacity Launch Rates - Existing Management Scenario

BAOT (Boats-At-One-Time)
Dist % (Distribution %, see Table 10)
LOS (Length-Of-Stay, see Table 9)
CCLR (Carrying Capacity Launch Rate)

zone	limiting factor BAOT	Wahweap/Lone Rock/ Antelope Pt.			Bullfrog Basin/ Halls Crossing			Hite		
		Dist %	LOS	CCLR	Dist %	LOS	CCLR	Dist %	LOS	CCLR
1	467	97	4.3	105.3	3	4.3	3.3	0	4.3	0
2	233	100	3.8	61.3	0	3.8	0	0	3.8	0
3	809	97	4.6	170.6	3	4.6	5.3	0	4.6	0
4	621	94	4.7	124.2	6	4.7	7.9	0	4.7	0
5	830	91	5.6	134.9	9	5.6	13.3	0	5.6	0
6	262	45	5.5	21.4	55	5.5	26.2	0	5.5	0
7	560	26	5.9	24.7	74	5.9	70.2	0	5.9	0
8	250	60	7.0	21.4	40	7.0	14.3	0	7.0	0
9	253	15	5.6	6.8	83	5.6	37.5	2	5.6	0.9
10	252	4	5.1	2.0	85	5.1	42.0	11	5.1	5.4
11	998	5	4.5	11.1	88	4.5	195.2	7	4.5	15.5
12	183	3	5.1	1.1	62	5.1	22.2	35	5.1	12.6
13	95	0	5.0	0	16	5.0	3.0	84	5.0	16.0
		total CCLR 684.8			total CCLR 440.4			total CCLR 50.4		

total lakewide CCLR 1,175 boats/day

THE EFFECT OF ADDITIONAL MANAGEMENT ACTIONS ON CARRYING CAPACITY LAUNCH RATES

One of the greatest advantages in using the procedure presented in this document for evaluating capacity is that specific zones of the recreation area which are most limited can be identified, as can the parameter(s) exerting the greatest constraint. Management options for alleviating the constraints can thus be focused on zones where they will do the most good. In the present case, for example, water quality appears as the factor most limiting for Zone 13 (Table 11). If it is assumed that management options are available which would effectively reduce water quality impact in Zone 13, then the influence of such actions on carrying capacity may be evaluated by removing the water quality limitation and basing the Zone 13 capacity on the next-most limiting factor in Table 11. In this case that would be the shoreline impact caused by visitor use. Concurrent action to mitigate shoreline impact would raise the capacity of Zone 13 two orders of magnitude, all the way up to its physical capacity. Similar actions in Zone 7 would have relatively little effect because of the zone's lack of sites--a judgement that can readily be made from table 11.

If one wants to determine where management actions should be applied to lift carrying capacity constraints on the current size of Wahweap marina, several tabular comparisons of marina launch rates could be prepared in the same manner as Table 12 using various combinations of higher boats-at-one-time rates (assuming that new actions would mitigate the lowest ones). In this way, the combination of actions could be found having the most beneficial effect in terms of relieving carrying capacity limits to Wahweap's size.

For the sake of illustration in the present exercise, a policy of improving water quality and diminishing shoreline impact in all of the zones may be assumed to determine the effect of additional management actions lakewide on carrying capacity launch rates. It is assumed that the new management program would be completely effective in removing water quality and shoreline impacts as limiting factors. In practice, such an assumption would have to be validated by continued monitoring after the management program was implemented. Table 13 compares the limiting factors

used for all zones under the existing management and additional management scenarios. The resulting increase in allowable boats-at-one-time for the whole lake is very great.

Table 13

Limiting Factor By Scenario

(Boats-At-One-Time)

Zone	Existing Management	Additional Management
1	Water Quality (467)	Safety (1054)
2	Water Quality (233)	Rural/Natural (903)
3	Rural/Natural (809)	Rural/ Natural (809)
4	Water Quality (621)	Rural/ Natural (1047)
5	Shoreline Impacts (830)	Physical (1770)
6	Shoreline Impacts (262)	Physical (729)
7	Shoreline Impacts (560)	Physical (751)
8	Shoreline Impacts (250)	Safety (1002)
9	Water Quality (253)	Semi Primitive (664)
10	Shoreline Impacts (252)	Physical (714)
11	Rural/Natural (998)	Rural/Natural (998)
12	Water Quality (183)	Physical (327)
13	Water Quality (95)	Physical (2149)

Table 14 shows the resulting increase in carrying capacity launch rates - from 1,175 boats per day from all marinas to 2,572 boats per day, a substantial potential benefit from management actions to clean up the shoreline and alleviate water quality.

Table 14

Carrying Capacity Launch Rates - Additional Management Scenario

BAOT (Boats-At-One-Time)
Dist (distribution %, see Table 10)
LOS (Length-Of-Stay, see Table 9)
CCLR (Carrying Capacity Launch Rate)

zone	limiting factor BAOT	Wahweap/Lone Rock/ Antelope Pt.			Bullfrog Basin/ Halls Crossing			Hite		
		Dist %	LOS	CCLR	Dist %	LOS	CCLR	Dist %	LOS	CCLR
1	1,054	97	4.3	237.6	3	4.3	7.4	0	4.3	0
2	903	100	3.8	237.8	0	3.8	0	0	3.8	0
3	809	97	4.6	170.6	3	4.6	5.3	0	4.6	0
4	1,047	94	4.7	209.4	6	4.7	13.4	0	4.7	0
5	1,770	91	5.6	287.6	9	5.6	28.4	0	5.6	0
6	729	45	5.5	59.6	55	5.5	72.9	0	5.5	0
7	751	26	5.9	33.1	74	5.9	94.2	0	5.9	0
8	1,002	60	7.0	85.9	40	7.0	57.3	0	7.0	0
9	664	15	5.6	17.8	83	5.6	98.4	2	5.6	2.4
10	714	4	5.1	5.6	85	5.1	119.0	11	5.1	15.4
11	998	5	4.5	11.1	88	4.5	195.2	7	4.5	15.5
12	327	3	5.1	1.9	62	5.1	39.8	35	5.1	22.4
13	2,149	0	5.0	0	16	5.0	68.8	84	5.0	361.0
		total CCLR 1,358			total CCLR 800.1			total CCLR 414.3		

total lakewide CCLR 2,572 boats/day

Physical and safety limitations do not lend themselves to correction by management action as long as visitor activity patterns remain the same. Table 13 indicates that constraints remaining after implementing a program to resolve resource impacts are largely physical or safety constraints, and these may represent an upper limit to carrying capacity beyond which the visitor experience would suffer greatly.

Throughout this exercise, it is important to keep in mind that the limiting factors evaluated here are partly a function of the information available and the ability to quantify it. Future monitoring may reveal new possibilities for useful factors to assess carrying capacity. Were we able to quantify a relationship

between cultural resource damage and boater numbers, for example, then cultural resource impacts could be incorporated into the matrix. This would very likely yield a lower carrying capacity until management actions were implemented to reduce or eliminate the impacts.

ZONE-BY-ZONE RESULTS OF ADDITIONAL MANAGEMENT

Zone 1 - Wahweap: Eliminating the water quality constraint through management would more than double the capacity of this zone, raising it to the safety limit for boating. Boating would occur in an Urban/Natural environment consistent with existing management objectives for the zone which is dominated by the Wahweap Marina and Stateline developments. Intensive use of the Marina as well as Lone Rock Beach provides near constant visual contact with other watercraft. The water quality constraint in this zone occurs at Lone Rock Beach, where land-access usage is believed a contributing factor to contamination. This is an instance where managing a non-boating use could benefit the carrying capacity for boaters.

Zone 2 - Navajo Canyon: Reducing water quality impacts would raise this zone's capacity to a level consistent with both rural/natural and urban/natural recreation opportunities (Table 11). Presence of the City of Page, Navajo Generating Station, and future development of the Antelope Point Marina would present a modified appearing shoreline. Construction of the proposed Antelope Point Marina would create near constant visual contact with other watercraft through much of the zone. Water contamination in this zone is found at the undeveloped Antelope Point area where land access is again an influence.

Zone 3 - Warm Creek Bay: This zone is not limited by the resource impact factors under current conditions, so under the additional management scenario, its capacity would remain the same.

Zone 4 - Padre Bay: Alleviating water quality limitations would raise the zone's capacity to the rural/natural social limit, which is the management objective for the zone.

Zone 5 - Last Chance: Eliminating shoreline impacts as a constraint would raise the capacity up to its physical limit, which is about the same as the rural/natural opportunity class. This zone would provide a mix of semi-primitive and rural/natural opportunities. Rural/natural would predominate in the main channel from contacts with other users. Semi-primitive opportunities would be available in the upper reaches of Last Chance Bay, where topographic screening will provide some feeling of isolation. Shorelines will appear as natural landscapes. Should this zone be redesignated a semi-primitive management area, its capacity would be reduced approximately 75 percent.

Zone 6 - Dangling Rope/Rainbow: This zone is more complex due to its low physical capacity and the presence of Dangling Rope Marina and Rainbow Bridge National Monument. These factors are the reason shoreline impacts are heavy and make the zone something of a pass-through area where sightseers and boaters needing marina services converge for part of a day. Reducing shoreline impact would raise capacity to the physical limit, which is still well below the natural zone (semi-primitive) management objective. High levels of boating use created by presence of Rainbow Bridge National Monument and Dangling Rope Marina result in a rural/natural recreation setting. Near constant visual contact with other watercraft will predominate during the daylight hours in the main traffic areas. A majority of shorelines will appear as natural landscapes, and semi-primitive recreation opportunities would continue to be feasible in side canyons.

Zone 7 - Lower San Juan: Mitigating shoreline impact would raise the zone quickly to its physical limit, which is also below the semi-primitive recreational opportunity objective. The meandering nature of channels in this zone and predominant high cliffs provide topographic screening for boaters, and thus create opportunities to experience solitude. There will be occasional contacts with other watercraft and the shoreline will present a natural appearing landscape.

Zone 8 - Upper San Juan: Mitigating shoreline impacts

could quadruple the capacity of this zone to its boating safety limit. Following development of the San Juan Marina this zone will shift from semi-primitive to rural/natural recreation opportunities.

Zone 9 - Escalante: Reducing water quality effects would bring this zone's capacity up to the semi-primitive opportunity limit. Pursuant to the park's General Management Plan, this zone will be managed for primitive to semi-primitive opportunities. To maintain the zone at use levels consistent with opportunities to experience quiet, tranquility, and solitude, boater distribution patterns will have to be closely monitored.

Zone 10 - Main Channel: In this zone mitigating shoreline impacts would allow use up to the physical capacity level. Semi-primitive opportunities would continue to predominate in side canyons. Shorelines appear natural with only occasional encounters with other watercraft outside the main channel thoroughfare.

Zone 11 - Bullfrog/Halls Crossing: This zone is not limited by the resource impact factors under current conditions, so under the additional management scenario its capacity would remain the same.

Zone 12 - Main Channel: Water quality improvement would permit use up to the physical capacity. Semi-primitive to rural/natural opportunities would predominate with a natural appearing shoreline and occasional encounters with other watercraft.

Zone 13 - Hite/Good Hope Bay: Water quality and shoreline impact improvement here would raise capacity twenty times. Such action would be essential before any expansion of the uplake marinas. The zone would continue to have rural/natural recreation opportunity objectives.

CARRYING CAPACITY IN PLANNING

Glen Canyon National Recreation Area is still a developing unit of the park system experiencing a steady rise in visitation and demand for recreational facilities. Plans to expand the marinas at Wahweap, Bullfrog, Halls Crossing and Hite have recently been

approved, as have plans to develop new facilities. To use the procedures presented here for evaluating the effects of these and other potential expansions on carrying capacity, it is only necessary to calculate the additional capacity of the marinas to launch boats in the same manner as was done for existing facilities (Table 8), and compare the result with carrying capacity launch rates. This comparison is illustrated on Table 15 between existing facilities and approved expansions at the same marinas.

Antelope Point, an approved Navajo marina development near Page, would be located across the lake from Wahweap and could be expected to tap a similar pool of boating recreationists. The assumption could reasonably be made that boaters launching there would distribute themselves on Lake Powell according to the same pattern as Wahweap boaters. For simplification, Antelope Point is treated on Table 15 as part of one large downlake launch point including Wahweap, Stateline, and Lone Rock.

Table 15 shows that currently developed facilities closely match the lake's capacity, although Hite appears to have the capability to launch too many boats. (The worst-case figures used in Table 15 represent the maximum physical ability of the facilities to launch boats, not their actual rate of use.)

Implementing the approved marina expansions while retaining current management conditions would result in the lake's carrying capacity being greatly exceeded. If, on the other hand, effective mitigation of shoreline and water quality impact is assumed, then the expanded marina capacities (1,850 boats per day) would still be within Lake Powell's carrying capacity for boater use (equal to a launch rate of 2,572 boats per day.)

Inherent in the comparisons on Table 15 is the implication that final marina expansion approvals could and should be made contingent on the implementation of management actions to reduce the water quality and shoreline impacts of boater use. It is beyond the scope of this document to determine which management actions would be taken, but actions to alleviate these problems are recommended in the park's Natural Resource Management Plan and Water Resources Management Plan.

Table 15
Comparison of Marina Launch Capacity with Carrying Capacity Launch Rate (launches/day)

marina	marina launch capacity		carrying capacity launch rate	
	existing	approved*	existing	additional mgmt.**
Wahweap/ Lone Rock	644	870	↑ 685 ↓	↑ 1,358 ↓
Antelope Point	0	240		
Bullfrog Basin	220	420	↑ 440 ↓	↑ 800 ↓
Halls Crossing	145	206		
Hite	114	* (114)	50	414
total	1,123	1,850	1,175	2,572

* Launch rates from proposed facilities in current plans.

** Additional management - applying management actions to a particular limiting factor to increase BAOT capacity.

Boater distribution on the lake would eventually change in response to future developments in recreational equipment, the popularity of certain activities, or a host of other reasons. Visitor use surveys should therefore be repeated every 5-7 years to monitor recreational use patterns and retain a current assessment of desirable user rates at facilities.

The prediction of carrying capacity effects from marinas not yet constructed in new locations would require a model, since the present methodology depends on an observed distribution of boaters and consequent impacts. Such a model is currently needed to evaluate the desirable size range of a permanent marina on San Juan Arm. The 1982 Lake Powell Carrying Capacity Study

model cannot be used to evaluate this in its present form, although it may be adaptable to the purpose.

Alternatively, it may be feasible to make the assumption that boat distribution from a San Juan Arm marina would resemble that of Hite, since each marina would serve a relatively self-contained area of the lake. In any case, this is an area of endeavor which needs more work.

One planning-related influence on the present study is the existence of boat launching from miscellaneous undeveloped access points. Most of these points are reached over rough roads, so it is believed that the total launch rate from these sources is relatively minor. To the extent that it does occur however, miscellaneous access launching consumes some of the lake's capacity. Such issues are now being evaluated in detail in a Management/Development Concept Plan for Lake Powell's Accessible Shorelines.

A final consequence of this study may be realized by comparing Table 13 with 15. The carrying capacity launch rate allowable under additional management (2,572 boats per day) is based on a scenario where 8 of 13 zones are limited by physical or safety constraints (Table 13). These constraints are not easily relieved by management action. The consequences of exceeding such limits could be an overall reduction of recreational quality on the lake; for example, some boaters might be reduced to shoreline sites that are not level should physical capacity be exceeded. These considerations mean that adding boat-launching capacity beyond the already approved facility expansions and planned Navajo marinas would not be recommended on the basis of current information.

MONITORING

PHYSICAL

The physical characters of Lake Powell's Shoreline will not change over time. However, the way in which recreationists fit themselves into this space may change in response to activity preferences, equipment available on the mass market, or any number of unforeseeable factors. Currently, the calculated physical limits for each zone are based on minimum space requirements and an enumeration of "good" usable shoreline sites (sites with sand or silt and level ground for anchorage and camping). This is based on the assumption that the strongest preference on the part of overnight recreationists is currently for a campsite on shore, even if they are in a houseboat. Quite possibly, events would occur causing additional kinds of shoreline sites to be used more frequently, thereby increasing the physical capacity of a zone. An increase in the proportion of day-use boat launches would also raise the carrying capacity launch rate since the increase would not affect competition for shoreline space. An increase in length-of-stay, on the other hand, or a trend toward larger group sizes might increase competition for shoreline space and lower effective physical capacity (keeping in mind that the most efficient management control is over the number of boats launched). Physical capacity factors will thus be reevaluated following the next boater distribution survey. Should the survey indicate that more or fewer shoreline sites are being used than currently assumed, new counts of sites-per-mile of shoreline type would have to be made to update the physical limits and apply them to the type of sites actually being used.

WATER RESOURCES

Monitoring shoreline water quality for comparison with the criteria for bacterial contamination should continue in concert with repeat boater distribution studies about every 5 years. While continuous monitoring is planned at specific sites for water resource management purposes, assessment of water quality as a limiting factor in carrying capacity depends on a monitoring survey covering all zones at the same time a boater distribution study is done, so that a legitimate inference of cause-and-effect may be obtained.

Each zone should be sampled several times over the course of a season, and every sample replicated at least twice to provide an adequate statistical basis for results.

SHORELINE IMPACT

Monitoring shoreline impact should be included in an organized program to measure the major impact parameters over the course of the same season boater distribution is surveyed.

A random sample of shoreline sites in each zone should be monitored. The most effective parameters to measure at present are the presence of human waste, number of litter items, and number of fire rings. These parameters are measured at the immediate shoreline campsite, and are not an indicator of impacts which may be spreading back from shore. A promising monitoring parameter for this would be quantification of trailing. Methods will be explored in the park to measure the level of trailing which spreads back from campsites.

SOCIAL

Monitoring is necessary to measure changes in visitor uses and patterns to provide current information to update the marina launch rate model. A boater survey should be conducted every five years to determine changing conditions. The boater survey should be for the summer season when visitor use is highest. No boater surveys are necessary during shoulder use seasons or the winter; lower use levels during these periods should not affect carrying capacity as it relates to use distribution, activities mixes, length-of-stay, and other factors considered important to the social limiting factor.

Boater surveys should consider the following:

Boat Distribution - Measure how boats are being distributed from each marina to various lake study zones.

Length-of-Stay - Determine how long each boating party stays on the lake during each visit.

Party Size - Determine average party size per boat and correlate to zones of primary use for reference in determining changes in opportunity spectrum classes.

Activity Composition - By study zone, determine activity mixes that are occurring. Analyze data to determine if user activities are changing and what effects these changes may have on carrying capacity. For example, a significant increase in jet skiing may pose potential safety hazards.

User Perception and Preference Levels - Sample visitors to determine perceptions of overcrowding and preferences regarding number of other boats on the lake. Correlate data to managed opportunity class by zone to determine potential changes in social capacity coefficients.

Adverse Natural Resource Conditions - Used to determine success of management actions designed to mitigate the amount of human waste and debris on beaches. Gather data by study zone to help determine where management actions should be concentrated.

SAFETY

This study used predetermined standards for safe motorized boating densities (Bureau of Outdoor Recreation, 1977). These densities were developed for high speed boats in open water, such as Wahweap Bay. At Lake Powell, use also occurs by slow moving houseboats in meandering channels.

Annually, open water accident rates by study zone should be compiled for each month of use during the heavy visitor-use season. Marina launch rates could be recorded concurrently. Accident rates might then be correlated to boat density to help determine if the safe boating density figures used for this study are appropriate. If it is determined that accidents are occurring from overcrowding, then the carrying capacity model should be adjusted or management actions implemented to mitigate overcrowding accidents.

CULTURAL RESOURCES

To aid in developing information for managing visitor

use effects on cultural resources, the next cycle of boater surveying should include questions on visitation of lakeshore cultural sites and perception of their condition.

FUTURE APPLICATIONS

Concepts used in this study are applicable to many National Park System areas, whether it be for river, land, or flatwater based recreation. Potential limiting factors may change and analyses or data collection techniques may differ, but the concept of combining limiting factors with user distribution in an analysis would remain viable for virtually any situation where a relationship between use and impact can be measured.

The limiting factor concept is flexible and can be used to produce a quantified result as in this study or a qualitative discussion addressing impact problems, their causes, and potential management strategies to reduce impacts. Use of this concept in qualitative or quantified analysis will save monitoring costs if a basis exists for screening limiting factors to find those most constraining to use. This is because only the most important limiting factors need to be monitored. In other words, if analysis indicates water quality and vegetative trampling are the best limiting factors, then monitoring would concentrate on water and vegetation. There should be no need to monitor wildlife, soil erosion, or other elements affected by visitor use because the monitored effects on water quality and vegetation would indicate a restriction of visitor use in an area before unacceptable impacts occur to other resources.

In National Park System areas where a quantified result is necessary to balance resource preservation with visitor use development, this study's concept is very appropriate. It can be applied to all types of land- and water-based recreation wherever a management control over visitor use exists and resource-based constraints on use can be quantified. Most importantly, concepts in this study may not require extensive research because it will often be found that information already in existence may be used by simply reorganizing it into a carrying capacity analysis. In the present case, for example, water quality data and boat launching statistics were already being gathered and simply had to be adopted for use in this study. Continuing monitoring programs afford the opportunity to test and refine any assumptions made for the study.

When the most direct management control over the use being evaluated is facility development, as in the present case, a limiting factor analysis and capacity study can be accomplished in advance of construction or expansion stages, thereby gaining insight into desirable facility sizes. These will be especially effective when goal-oriented standards such as the recreational opportunity classes are used.

RECOMMENDATIONS

1. The expansion of existing marinas and construction of the Navajo Marinas should be contingent on the implementation of management actions to mitigate water quality and shoreline impacts by lake users.

The specific actions needed would be those recommended in Glen Canyon's Natural Resource Management Plan and and Water Resources Management Plan.

2. Improvement of the "problem" sites in key zones should be incorporated into development planning documents such as the Lone Rock Development Concept Plan and the Development Concept Plan for Lake Powell's Accessible Shorelines, as appropriate.

3. An evaluation of carrying capacity effects should be incorporated into the planning process for a permanent marina on the San Juan Arm.

4. Recreational opportunity class designations should be reviewed for the next Statement for Management update. After implementing impact-reducing management there may remain sufficient carrying capacity to manage additional zones for semi-primitive recreation.

5. Design and conduct management studies to quantify a relationship between cultural resource damage and boater use.

6. Survey Lake Powell boaters every 5-7 years to monitor distribution patterns and activities. Conduct concurrent monitoring of water quality and shoreline impact, obtaining coverage of all zones.

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Appendix 1

Shorelines and Surface Water Acres at Lake Elevation 3700'

Zone	Miles of Shoreline Types						Total△ Miles	Total△ Acres
	Cliff	Alluvium	Dome & S.T.	Talus	Rock slide	Sand Beach		
1	23.95	—	17.50	—	.04	8.08	49.57	9483
2	68.75	--	19.84	.37	—	5.79	94.75	8125
3	4.55	9.29	33.37	—	—	14.61	61.82	12731
4	49.24	—	52.45	5.58	—	7.31	114.58	18847
5	134.35	.33	21.36	31.92	1.32	7.65	196.93	26549
6	139.24	—	28.84	4.62	—	.15	172.82	13765
7	50.85	—	5.44	48.03	.72	—	105.04	11128
8	63.64	—	30.54	54.72	.04	3.32	152.26	9021
9	110.48	—	16.51	15.59	.66	7.37	150.61	7964
10	67.75	3.14	18.31	21.69	5.66	.66	117.21	12196
11	18.05	—	48.07	15.08	—	8.43	89.63	17974
12	68.54	1.39	7.89	4.73	2.71	.26	85.52	9768
13	49.82	—	21.88	108.32	3.72	4.69	188.43	20432

△Total Miles means total shoreline miles

Total Acres means total surface water acres

Dome & S.T. means dome and shelfy terrace

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