Journal of Leisure Research
2006, Vol. 38, No. 2, pp. 187-207

Benefits and Challenges of Computer Simulation Modeling of Backcountry Recreation Use in the Desolation Lake Area of the John Muir Wilderness

Steven R. Lawson
Virginia Polytechnic Institute and State University
Robert M. Itami
GeoDimensions Pty., Ltd.
H. Randy Gimblett
University of Arizona
Robert E. Manning
University of Vermont

This paper describes the development and application of a computer-based simulation model of recreational use in the John Muir Wilderness Area in the Sierra Nevada Mountains of California, USA. The results of the study demonstrate, conceptually, how simulation modeling can be used as a tool for understanding existing visitor use patterns within the John Muir Wilderness Area, estimating the impact of increasing visitor use levels on management objectives, and evaluating the effects of alternative policy decisions on visitor flows and visitor use conditions. This study also identifies and discusses potential challenges of applying computer simulation to backcountry recreation management and provides recommendations for further research to address these issues.

KEYWORDS: *Visitor flows, monitoring, wilderness management, Limits of Acceptable Change, crowding.*

Introduction

In the United States, legislation dictates that Wilderness areas should be managed to, among other things, provide recreational visitors with "opportunities for solitude or a primitive and unconfined type of recreation" (Hendee & Dawson, 2002). However, the growing popularity of outdoor recreation in backcountry settings threatens the ability of wilderness managers to achieve these objectives. For example, increasing recreational use of wilderness areas can result in perceived crowding and increasing conflict among different types of users (e.g., hikers and packstock; Manning, 1999). These

Address correspondence to: Steve Lawson, Department of Forestry, 307A Cheatham Hall, Virginia Tech, Blacksburg, VA 24061. Phone: (540) 231-8303, Email: *lawsons@vt.edu.*

Author note: The authors would like to thank the following people for their scholarly review and assistance with this study: David Cole, Aldo Leopold Wilderness Research Institute, Gary Oye, USDA Forest Service, Marilyn Hof, Kerri Cahill, and Jan van Wagtendonk, U.S. National Park Service, Mark Vande Kamp, University of Washington, and Aurora Moldovanyi, Virginia Polytechnic Institute and State University.

The research resulting in this publication was funded jointly by the USDA Forest Service, U.S. National Park Service, and the Aldo Leopold Institute.

problems are exacerbated by the fact that backcountry recreation use tends to be concentrated both spatially and temporally (Hendee & Dawson, 2002; Lucas, 1980). For example, most wilderness areas are used most heavily during the summer, and within the summer months, use can be heavier on the weekends than during weekdays. Similarly, recreational use tends to concentrate geographically along established hiking trails/routes, along the periphery rather than within the interior of an area, and close to desirable natural features (e.g., water bodies, scenic views).

Rules and regulations designed to manage recreation-related impacts such as crowding, conflict, and damage to natural resources can diminish visitors' sense of spontaneity and freedom, thus eroding the primitive and unconfined nature of the wilderness experience (Cole, Peterson, & Lucas, 1987). Managers are faced with the challenge of preventing and mitigating recreation-related impacts to wilderness with the most unobtrusive, indirect, light-handed means possible (Hendee & Dawson, 2002). That is, managers are expected to identify the "minimum tool" required to achieve desired conditions within wilderness. Consequently, decisions about how to manage recreational use of wilderness are complex.

Recent research suggests that computer-based simulation modeling is an effective tool for helping to address the challenges associated with managing visitor use in backcountry and wilderness settings (Daniel & Gimblett, 2000; Gimblett, Richards, & Itami, 2000; Lawson & Manning, 2003a, 2003b; Lawson, Manning, Valliere, & Wang, 2003; Lawson, Mayo-Kiely, & Manning, 2003; van Wagtendonk, 2003; Wang & Manning, 1999). For example, simulation modeling can be used to describe and understand existing visitor use conditions that are inherently difficult to observe. That is, given current management practices and existing levels of visitor use, where and when is visitor use occurring? By providing managers with detailed information about how visitors are currently using the area, this baseline information can assist managers in identifying "trouble spots" or "bottlenecks," as well as areas that may be capable of accommodating additional use. Simulation modeling can also be used to monitor the condition of "hard to measure" indicator variables (Lawson, Manning, Valliere, & Wang, 2003; Wang & Manning, 1999). For example, how many encounters do backpacking visitors have with other groups per day while hiking? How many nights do visitors camp within sight of other groups? In addition, simulation modeling can be used to test the potential effectiveness of alternative management practices in a manner that is more comprehensive, less costly, and less politically risky than on-the-ground trial and error (Lawson & Manning, 2003a, 2003b). For example, what effect does a permit quota have on the number of encounters visitors have with other groups while hiking? How would the number of hiking encounters change as a result of redistributing use from heavily used trailheads to less commonly used entry points? These capabilities make computer-based simulation modeling a useful tool for assisting managers in identifying potential recreation-related problems and evaluating the effectiveness and costs to visitors of potential solutions to these problems.

This paper describes the development and application of a computer-based simulation model of recreational use in the John Muir Wilderness Area in the Sierra Nevada Mountains of California, USA. The results of the study demonstrate, conceptually, how simulation modeling can be used as a tool for understanding existing visitor use patterns within the John Muir Wilderness Area and estimating the effects of visitor use policy decisions on the condition of crowding-related indicators of quality. Furthermore, this study illustrates how Geographic Information Systems (GIS) can be used to communicate simulation modeling results regarding the spatial distribution of visitor use of a backcountry recreation area in a manner that may be more useful for managers and easier for interested publics to understand (Landres, Spildie, & Queen, 2001). Lastly, this study identifies and describes several potential challenges associated with applying computer simulation to backcountry recreation management. The lessons learned from this study provide new insight regarding how to efficiently and accurately apply computer simulation modeling to recreational use management and have implications for future research.

Methods

Description of Study Area

In this study, a computer-based simulation model of recreation use was developed for a portion of the Humphrey's Basin area of the John Muir Wilderness Area. The John Muir Wilderness covers 584,000 acres in the Sierra and Inyo National Forests, in the Sierra Nevada Mountains of California. The area is characterized by snow-capped mountains with hundreds of lakes and streams and lush meadows. Lower elevation slopes are covered with stands of Jeffrey pine, incense cedar, white and red fir and lodgepole pine. The higher elevations are barren granite with many glacially carved lakes.

Data Collection

This study evolved from a larger visitor use study conducted in the Inyo National Forest as part of the Environmental Impact Assessment process for the John Muir, Ansel Adams, and Dinkey Lakes Wilderness areas (USFS, 2001). In the study reported in this paper, only trip itinerary data for the Humphrey's Basin area of the Inyo National Forest were used. All data required for the current simulation study, which are described in detail below, were derived from the larger University of Arizona study.

Visitor Characteristics

During the 1999 visitor use season, diary questionnaires were distributed to backcountry visitors in the John Muir Wilderness. Questionnaires were distributed at trailhead self-registration stations and at ranger stations when visitors picked up their agency-issued permit. Randomly selected self-registration stations were periodically attended by data collectors who distributed diaries to visitor groups and collected completed questionnaires from groups as they finished their trips. In addition, questionnaires were distributed by commercial packstock outfitters, following instructions given by the research team.

The diary questionnaire included a series of questions concerning group and trip characteristics and a map of trails and natural features. Respondents were instructed to record their route of travel during their visit, including the trailhead(s) where they started and ended their trip, and their camping location on each night of their trip. Respondents were also asked to report the duration of their visit, the number of people in their party, and their mode of travel. The response rate for the Humphrey's Basin area of the John Muir Wilderness was 32.2%, resulting in a total of 324 completed diaries.

Site Characteristics—Trail Network

Data concerning the trail network within the study area were provided by the USFS Inyo National Forest as a GIS shapefile. The trail network shapefile was created by heads-up digitizing trails and known informal hiking routes from 1994 USGS 7.5 minute quadrangles, 1:24,000 scale. These data were supplemented with information from a campsite inventory completed in the summers of 1999 and 2000. The data included all trail segments and intersections within the study area.

Site Characteristics—Campsite Clusters

"Campsite clusters" were created from the visitor surveys by grouping visitor reported camping locations based on proximity and common access. A single campsite cluster was comprised of all reported camping locations that were within a (subjectively determined) reasonable distance of each other. The campsite clusters were used to determine camping encounters within the travel simulation model. Specifically, groups camping at locations within the same campsite cluster were considered to be within close enough proximity to be within sight and/or sound of each other.

Travel Simulation Model Design and Analysis

The data described in the previous section of this paper were used as inputs in the construction of a dynamic travel simulation model. The travel simulation model was developed using Extend software, and a duplicate model was developed using RBSim2 software (see Lawson, Manning, Valliere, & Wang, 2003 and Itami et al., 2004 for detailed descriptions of Extend and RBSim2, respectively). The scope of this paper is limited to discussing the results of the Extend travel simulation model. Further research is being conducted by the authors of this paper to compare the outputs of the Extend and RBSim2 travel simulation models of the study area.

The Humphrey's Basin travel simulation model is a probabilistic, steady state simulation (Law & Kelton, 2000). Probabilistic simulation models are based on probability theory. In these models, a simple random sample is taken of the population (in this case visitor trip itineraries). The variation of trips is then modeled based on the probability of a visitor selecting a single trip itinerary out of the entire sample, or alternatively, the probability of selecting the next destination based on the probability distribution of all destinations originating from the current destination. Probability models are the standard method for modeling baseline conditions. Probability distributions for either trip itineraries or origin-destination pairs are a convenient way to "ramp up" numbers of visitors in a simulation since the standard assumption is that as the number of visitors increase, the distribution of trip itineraries will remain the same. Steady state simulations are designed to model a system during the period when it reaches its full operating level (e.g., during the peak period of the visitor use season). Consequently, steady state simulations require a "warm up" period to reach the target steady state operating level. Furthermore, steady state simulations require substantial replication (e.g., simulated visitor use days) in order to obtain reliable outputs that are not biased by short-term effects of the probabilistic components within the model or auto-correlation. In the case of steady-state simulation, replications can be obtained by making one single, long run, rather than multiple shorter runs. The advantage of making one single, long run is that it is only necessary to simulate the warm-up period a single time, rather than for each shorter simulation. In all of the simulations conducted in this study, the model was run for a total of 2,000 simulated visitor days. The first 500 days of each simulation were dropped from the study analyses in order to avoid potential start-up effects within the simulation. The outputs from the remaining 1,500 days were used to generate the data reported in this study.

As noted earlier, the response rate to the diary questionnaire was 32.2%, which raises the question of whether the study data constitute a representative sample of trip itineraries in Humphrey's Basin or if they are biased as a result of a relatively high non-response rate. Furthermore, while visitors were randomly sampled at trailheads, there was less control over commercial packstock outfitters' sampling procedures and therefore, less confidence that the sample is completely random. Consequently, the primary purpose of this study was to demonstrate *conceptually* the potential utility of computer simulation modeling as a tool to help managers address the challenges of monitoring and managing recreation use in backcountry and wilderness settings. That is, while the computer simulation model was used to generate quantitative results, these data may be biased due to inadequate sampling of camping trip itineraries and should not be used to inform management decisions in the study area. Therefore, some simplifying assumptions were constructed into the model. First, data concerning packstock trips and day trips were excluded from the simulation. Second, the travel simulation model was designed to simulate backpacking use within a sub-section of the larger Humphrey's Basin study area. Third, the campsite clusters were subjectively defined, based on proximity of campsites. While it would be possible to use GIS to define campsite intervisibility more realistically, subjectively defined campsite clusters were considered sufficient, given the conceptual nature of the study. The section of the study area for which the model was developed is referred to as the Desolation Lake Locale. Figure 1 presents a map of Humphrey's Basin with the Desolation Lake Locale highlighted by a box. Locations of the three access points into the Desolation Lake Locale are labeled on the map by the letters "TH" and a code number, which will be referred to later in the paper.

The majority of visitor use occurs within the Humphrey's Basin area during the summer months, with considerably less recreation use during the earlier and later months of the season. Therefore, the computer simulation model was designed to focus on the "peak" period of the visitor use season by excluding data concerning trips starting before July 1, 1999 and after September 30, 1999. The simplifying assumptions described in the previous paragraph, coupled with the decision to focus on the summer months of the visitor use season, resulted in a total of 190 useable trip itineraries included as inputs into the travel simulation model.

The travel simulation model is designed to allow the user to manipulate several management-related parameters within the model. This feature of the model allows the user to estimate the effect of alternative management practices and visitor use scenarios on visitor use densities and hiking and camping encounters within the study area. For example, the model is designed to allow the user to control the number and timing of trips starting each day from each of the three entry points into the study area. This capability allows the user to design simulations that test the potential effect of increasing total use levels, trailhead quotas, temporal and spatial redistribution of visitor use, and other management practices on crowding-related indicators of quality within the study area.

Model Outputs

A series of simulations were conducted to generate a common set of outputs concerning visitor use densities and hiking and camping encounters. The common data generated within this series of simulations included:

(*1*) *Average hiking use per day, by trail segment.* Average hiking use per day is calculated for each trail segment by summing the number of groups that pass through each trail segment during the course of the simulation and dividing by the total number of days simulated.

(*2*) *Average hiking encounters per group per day, by trail segment.* Hiking encounters are calculated for each trail segment on each day that at least one group passes along the trail segment. Two types of hiking encounters were calculated within the simulation model. "Overtaking encounters" are defined as one group passing another group while travelling in the same direction along the trail. "Meeting encounters" are defined as two groups passing each other while travelling along the trail in opposite directions (Schechter & Lucas, 1978). The average number of hiking encounters per group per day is calculated for each trail segment by summing the total number of hiking encounters along the trail segment throughout the sim-

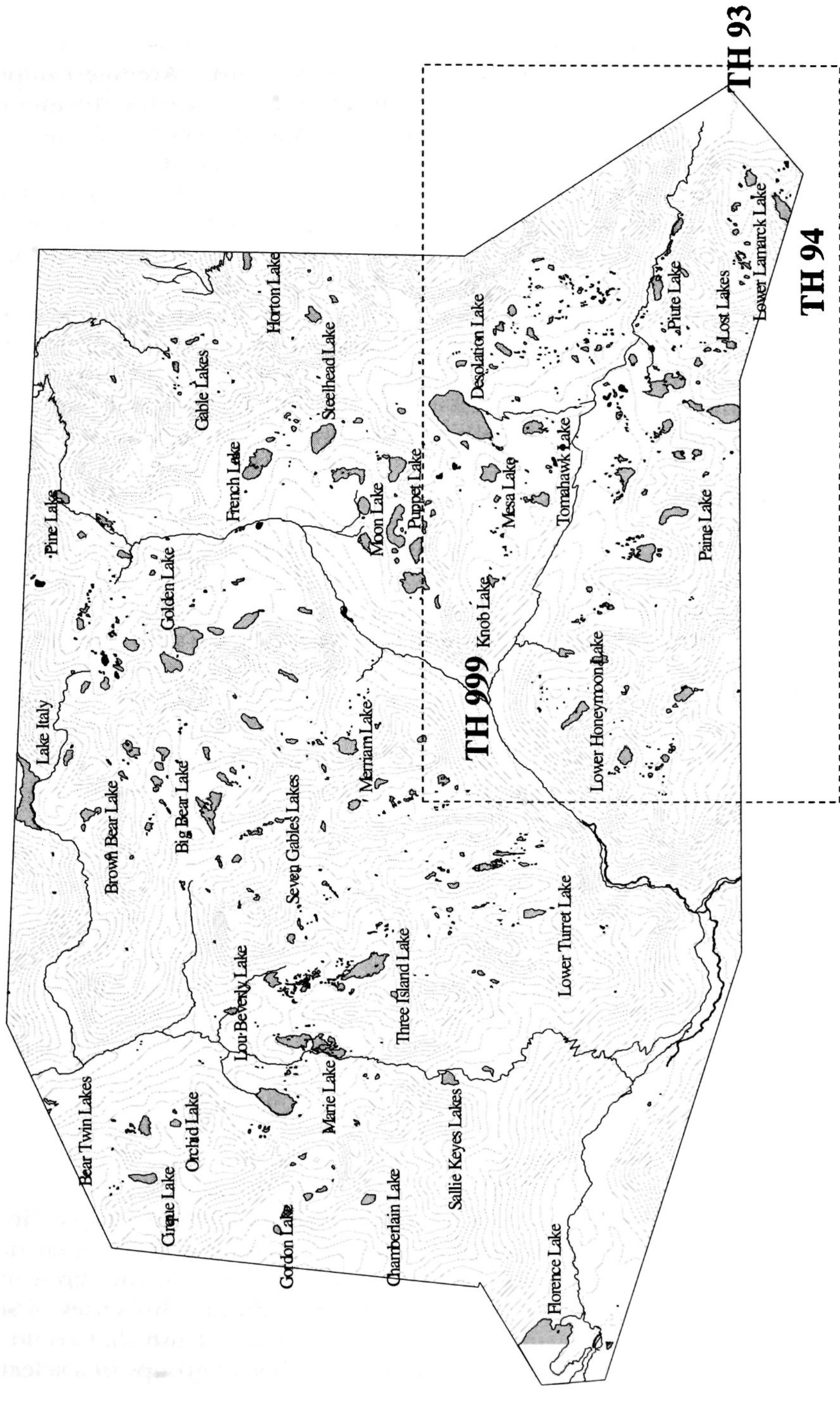

Figure 1. Map of Humphrey's Basin and Desolation Lake Locale

ulation and dividing by the total number of groups that hiked the trail segment during the simulation.

(*3*) *Average camping use per night, by campsite cluster.* Average camping use per night is calculated for each campsite cluster by summing the number of groups that camp at the campsite cluster during the course of the simulation and dividing by the total number of nights simulated.

(*4*) *Average camping encounters per group per night, by campsite cluster.* Camping encounters per group per night are calculated for each night that a campsite cluster is occupied by one or more parties. The number of camping encounters a group has on a given night is equal to the number of other groups camping in the same campsite cluster on the same simulated night. The average number of camping encounters per group per night is calculated for each campsite cluster by summing the total number of campsite encounters throughout the simulation and dividing by the total number of groups that camped at the campsite cluster during the simulation.

Baseline Simulation

The first simulation conducted with the travel simulation model was designed to generate the outputs described above for baseline visitor use levels and existing management practices, where the baseline level of visitor use is assumed to be equal to the number of groups that completed the diary questionnaire during the summer months of the sampling period (July, August and September, 1999). This simulation is referred to as the 1X simulation throughout the remainder of this paper. In addition to generating and reporting tabular results of the 1X simulation, the simulation outputs were imported into a GIS and a map was created to illustrate the baseline spatial pattern of visitor use in the study area.

Increasing Visitor Use Simulation

A second simulation was conducted to estimate the potential effect of increased visitor use of the study area on visitor use densities and encounters along trail segments and within campsite clusters. Within this simulation, the average number of trip starts per day was increased from baseline levels by 400% at each of the three trailheads in the study area. The outputs described above were generated for this scenario. This simulation run is referred to throughout the remainder of this paper as the 4X simulation.

Maximum Allowable Use Simulation

A series of simulations were conducted to demonstrate the capability of travel simulation modeling to assist managers in estimating the total daily use that can be accommodated within an area without violating crowding-related standards of quality (Manning, 1999). Specifically, this series of simulations was designed to estimate the maximum level of use that could be accommodated in the study area without the number of groups in a selected campsite exceeding five for more than 5% of nights (an arbitrarily selected potential standard of quality for camping use density). This was done by incrementally increasing or decreasing the simulated use levels evenly across the three entry points until the result "converged" on the desired level of campsite cluster use (Lawson, Manning, Valliere, & Wang, 2003). This analysis illustrates how simulation modeling can be used to establish trailhead quotas to achieve desired social conditions within a wilderness area, and is referred to as the maximum allowable use simulation throughout the remainder of the paper.

Model Verification and Validation

Before using a computer simulation model to support decision-making (e.g., establishing trailhead quotas, redistributing recreation use within a backcountry area, etc.), it is necessary to examine whether the model and its outputs are "correct." The process for doing so involves model verification and validation (Sargent, 1998). Model verification is concerned with assuring that the computer model has been implemented correctly and has been described as dealing with building the model right (Banks, Carson, Nelson, & Nicol, 2001). Model validation tests whether model results accurately represent the "real-world" system the model is intended to replicate and has been described as dealing with building the right model.

Several model verification techniques described in Law and Kelton (2000) were conducted to verify that the simulation model of the Desolation Lake Locale was implemented correctly. First, individual components of the simulation model were developed and debugged to ensure that they functioned properly before integrating them into the full model. For example, modules for the campsite clusters, trail segments, trail junctions, and trailheads were developed and tested individually before being combined in the full model. Second, the authors conducted a structured "walk-through" of the simulation model to review the logic and operation of the simulation model. Third, Extend's built-in debugging functions were used to detect and correct data coding errors in the full model that resulted in incorrect routing of simulated trips. Fourth, Extend's animation function was used to visually verify that the model did not contain errors. Fifth, the trip itinerary data reported by respondents to the diary questionnaire were used as the basis for a quantitative verification technique. Specifically, the proportion of camping use for each campsite cluster was calculated for the diary trip itinerary data and compared to the proportion of camping use for each campsite cluster, based on the results of the 1X simulation. This technique provided a method for comparing the output of the model with known analytical results (Schecter & Lucas, 1978).

In general, the most powerful techniques for validating computer simulation models are those that compare model output data to data from the actual system the model is designed to replicate (Law & Kelton, 2000). Due to a lack of data from the actual system (e.g., hiking encounters per group and hiking use per trailhead in the Humphrey's Basin area), it is not feasible to conduct quantitative techniques such as results validation to assess the validity of the computer simulation model. However, non-statistical techniques were used to assess the content and face validity of the simulation model by examining the reasonableness of the inputs and outputs of the simulation model. Furthermore, sensitivity analyses were conducted to test whether the model outputs change in the expected direction in response to changes in selected input parameters (e.g., total use).

Results

Simulated Use Levels: 1X and 4X Simulations

Table 1 reports the mean number of simulated trip starts per day by trailhead for the 1X and 4X simulations. The trailheads are differentiated with a code number that was assigned to them during the data collection process. As the data in Table 1 suggest, the baseline level of visitor use in the study area is relatively low, with an average of less than two trip starts per day from the most heavily used of the three trailheads (Trailhead 93). Even with a 400% increase in visitor use, two of the three trailheads would have less than one trip start per day into the Desolation Lake Locale.

Camping Use and Encounters, by Campsite Cluster: 1X and 4X Simulations

Table 2 reports average camping use per night and average camping encounters per group per night, by campsite cluster for the 1X and 4X simulations. Results of the 1X simulation suggest that under existing conditions, camping densities are low throughout the entire study area. In all of the campsite clusters within the study area, there is an average of less than one camping group per night. Similarly, the data suggest that under existing conditions, very few visitors encounter other groups while camping.

The 4X simulation results suggest that if use were to increase by 400% at each of the three trailheads in the study area, visitors who camp within campsite clusters 7 and 37 would encounter an average of three other groups per night. Furthermore, visitor use densities and camping encounters would be moderately high in several other campsite clusters, including clusters 42, 44, 46, and 47. However, throughout the remainder of the study area, camping densities and encounters would remain relatively low.

TABLE 1
Simulated Mean Number of Backpacking Trip Starts per Day, by Trailhead

	TH 93	TH 94	TH 999
1X Simulation	1.89	0.01	0.14
4X Simulation	7.61	0.04	0.56

TABLE 2
Average Camping Use and Encounters, by Campsite Cluster—1X and 4X Simulations

Cluster ID	Mean Use[a] 1X Simulation	Mean Encounters[b] 1X Simulation	Mean Use[a] 4X Simulation	Mean Encounters[b] 4X Simulation
7	0.86	0.90	3.43	3.40
36	0.12	0.14	0.47	0.44
37	0.74	0.75	3.04	3.01
38	0.05	0.06	0.22	0.28
39	0.15	0.12	0.52	0.51
40	0.05	0.03	0.21	0.19
41	0.26	0.22	0.95	0.90
42	0.32	0.33	1.44	1.41
44	0.44	0.43	1.84	1.93
45	0.13	0.12	0.66	0.65
46	0.48	0.51	1.90	1.89
47	0.31	0.25	1.21	1.12
48	0.14	0.14	0.56	0.59
49	0.04	0.00	0.13	0.14
50	0.12	0.15	0.46	0.47
51	0.07	0.04	0.25	0.26
52	0.02	0.00	0.08	0.10
53	0.04	0.10	0.18	0.14
56	0.10	0.09	0.33	0.39
57	0.14	0.13	0.60	0.61
80	0.11	0.09	0.42	0.46
81	0.07	0.02	0.25	0.23

[a]Mean number of camping groups per night.
[b]Mean number of camping encounters per group per use night.

The map in Figure 2 portrays the spatial distribution of camping use within the study area for the 1X simulation. While the data in Table 2 suggest that use throughout the study area is low, the map shows the *relative* density of camping use. Specifically, larger circles on the map correspond to higher use camping locations, while smaller circles correspond to lower use locations.

Hiking Use and Encounters, by Trail Segment: 1X and 4X Simulations

Table 3 reports average hiking use per day and average hiking encounters per group per day, by trail segment for the 1X and 4X simulations. Results of the 1X simulation suggest that, under existing conditions, hiking densities are low throughout most of the study area, with moderate levels of visitor use along several trail segments (e.g., trail segments 2, 4, 5, 9, 10, 11). In addition, there are very few hiking encounters among groups under existing conditions.

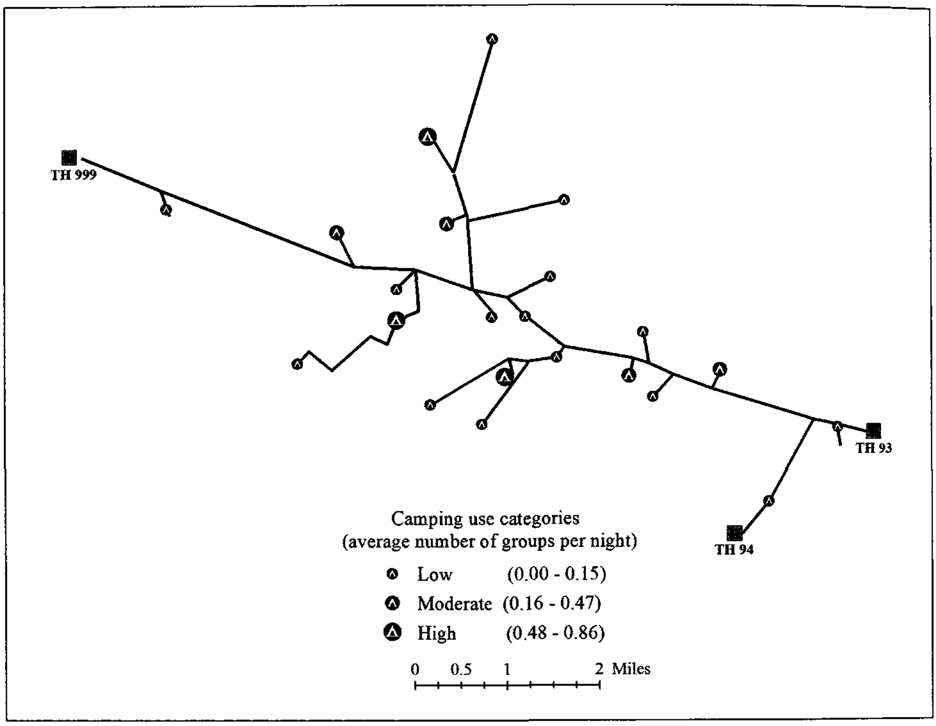

Figure 2. Spatial Distribution of Camping Use—1X Simulation

Results of the 4X simulation suggest that while hiking densities would increase along several trail segments in the study area if use were to increase 4-fold at each of the trailheads, hiking encounters would remain low throughout the trail network. In fact, the model estimates that hikers along only one trail segment (segment 5) would have an average of more than 1 encounter per group per day.

The map in Figure 3 portrays the spatial distribution of hiking use within the study area for the 1X simulation. Again, overall recreational use of the study area is quite low, however, the map illustrates the *relative* density of hiking use throughout the trail network. In particular, thicker lines on the map correspond to higher use trail segments, while thinner lines correspond to lower use segments.

Maximum Allowable Use Simulation

As stated earlier, simulation modeling can be used to help managers estimate the impact of alternative policy decisions related to visitor use and visitor flows within a recreation area. Table 4 reports the results of a series of simulations designed to estimate the maximum amount of use that could

TABLE 3
Average Hiking Use and Encounters, by Trail Segment—1X and 4X Simulations

Trail ID	Mean Use[a] 1X Simulation	Mean Encounters[b] 1X Simulation	Mean Use[a] 4X Simulation	Mean Encounters[b] 4X Simulation
2	3.51	0.20	14.02	0.75
3	0.08	0.00	0.35	0.00
4	3.51	0.11	14.02	0.42
5	3.43	0.34	13.75	1.48
6	0.58	0.03	2.35	0.11
7	0.14	0.03	0.55	0.06
8	0.04	0.00	0.18	0.01
9	3.35	0.11	13.41	0.40
10	3.28	0.10	13.17	0.40
11	3.20	0.05	12.83	0.17
12	0.12	0.00	0.42	0.02
13	0.20	0.01	0.86	0.04
14	0.80	0.04	3.31	0.16
15	2.95	0.20	11.72	0.80
16	1.10	0.02	4.56	0.06
17	2.47	0.11	9.77	0.42
18	2.41	0.05	9.61	0.19
19	0.15	0.01	0.62	0.05
20	0.99	0.01	4.13	0.07
21	0.90	0.03	3.70	0.10
22	0.77	0.06	3.21	0.20
23	0.09	0.00	0.43	0.03
24	0.13	0.01	0.49	0.05
25	2.31	0.07	9.16	0.27
26	0.15	0.02	0.50	0.04
27	1.08	0.06	4.47	0.22
28	0.15	0.01	0.68	0.08
29	0.45	0.02	1.93	0.08
30	1.29	0.01	5.34	0.02
31	0.68	0.03	2.77	0.12
32	0.63	0.05	2.61	0.18
33	0.04	0.00	0.16	0.02
34	1.87	0.09	7.22	0.37
35	0.07	0.00	0.26	0.03
36	1.43	0.08	5.54	0.30
37	0.29	0.02	1.13	0.07
38	0.88	0.06	3.66	0.35
39	1.29	0.21	5.03	0.76
40	0.22	0.01	0.84	0.04
41	1.25	0.07	4.87	0.35
132	0.06	0.00	0.26	0.02

[a]Mean number of hiking groups per day.
[b]Mean number of hiking encounters per group per use day.

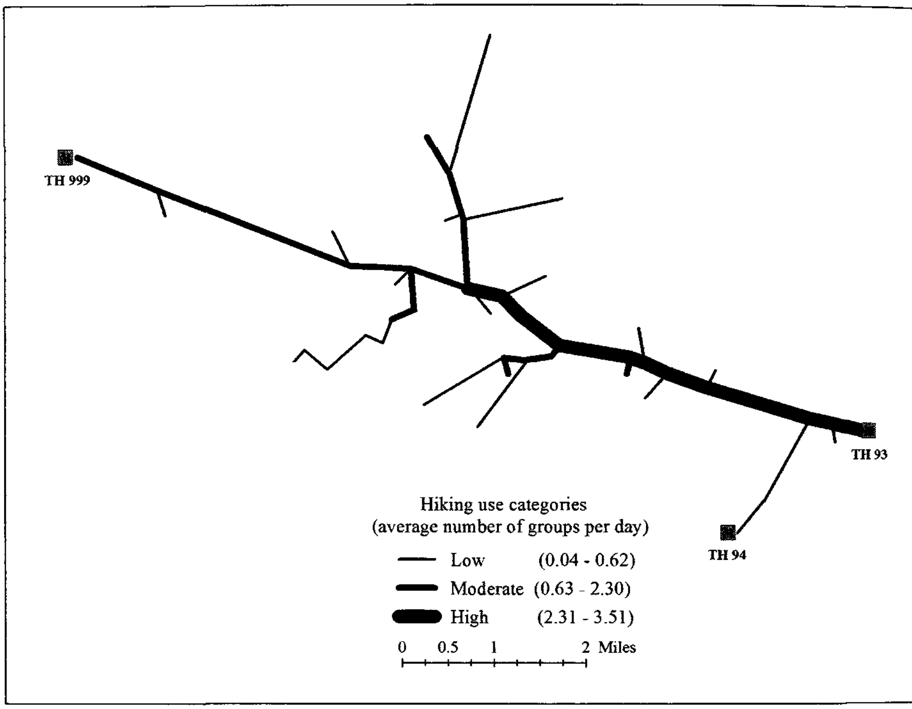

Figure 3. Spatial Distribution of Hiking Use—1X Simulation

be accommodated in the study area without the number of groups camping within a selected campsite cluster exceeding 5 more than 5% of nights. The results of this simulation suggest that use could be dramatically increased from existing levels without exceeding this standard. While the standard and campsite cluster selected for this analysis are hypothetical, the analysis demonstrates the potential capability of computer-based simulation modeling to assist managers in evaluating the implications of policy decisions.

TABLE 4
Maximum Allowable Use, by Trailhead, for Hypothetical Camping Use Density Standard

TH 93	TH 94	TH 999
10.95[a] [10.80, 11.10][b]	0.06[a] [0.05, 0.08][b]	0.78[a] [0.74, 0.82][b]

[a]Simulated mean number of trip starts per day,
[b]95% confidence interval for simulated mean number of trip starts per day,

Model Verification and Validation

The results reported in Table 5 suggest that the computer simulation model has been constructed correctly and that operating errors have been eliminated through the debugging and verification techniques described earlier in this paper. Specifically, as indicated in Table 5, there is no substantive difference between the distribution of campsite cluster use reported in the diary survey and the 1X simulated trips. Furthermore, a paired-t confidence interval for the difference between the diary survey data and the simulation model outputs suggests that there is no statistically significant difference between the survey data and simulation outputs. These verification results suggest that the model has been constructed correctly.

Due to the low response rate to the questionnaire and a lack of data to test for systematic differences among respondents and non-respondents, it is difficult to assess the content validity of the model, which is concerned with the reasonableness of the model inputs. Furthermore, statistical comparisons

TABLE 5
Travel Simulation Model Verification Results

Cluster ID	Survey Data[a]	Model Output[b]	Difference[c]
7	0.18	0.18	0.00
36	0.02	0.02	0.00
37	0.16	0.16	0.00
38	0.01	0.01	0.00
39	0.03	0.03	0.00
40	0.01	0.01	0.00
41	0.05	0.05	0.00
42	0.07	0.08	−0.01
44	0.09	0.10	−0.01
45	0.04	0.03	0.01
46	0.10	0.10	0.00
47	0.06	0.06	0.00
48	0.03	0.03	0.00
49	0.01	0.01	0.00
50	0.03	0.02	0.01
51	0.01	0.01	0.00
52	0.00	0.00	0.00
53	0.01	0.01	0.00
56	0.02	0.02	0.00
57	0.03	0.03	0.00
80	0.02	0.02	0.00
81	0.01	0.01	0.00

[a]Proportion of total camping use based on survey data itineraries.
[b]Proportion of total camping use based on simulation model output.
[c]Survey data proportion minus simulation model proportion.

of model outputs to actual system data are not possible due to a lack of "ground-truthing" data. However, the results of the 1X and 4X simulations support the internal and face validity of the model. That is, as the total simulated use of the Desolation Lake Locale is "ramped up" in the 4X simulation, estimates of camping use and encounters increase for all campsite clusters (Table 2). Furthermore, estimates of hiking use and encounters increased from the 1X to the 4X simulation for all but one trail segment (there was no change in encounters for trail segment #3).

Conclusions

The Benefits of Computer Simulation for Backcountry Recreation Management

The study described in this paper illustrates the potential usefulness of computer-based simulation modeling in monitoring and managing recreational use in backcountry and wilderness landscapes. Dispersed recreation in such areas is inherently difficult to observe directly. However, the study findings suggest that by collecting representative data on recreational use levels and patterns by means of trailhead counts and a diary survey of a sample of visitor groups, it is possible to develop a computer simulation model to estimate detailed levels and patterns of visitor use. The model developed for the Desolation Lake Locale illustrates how computer simulation can inform managers about levels of use and resulting encounters at all trail segments and campsite clusters within a backcountry recreation area, and this information can be used for several purposes, including identifying potential bottlenecks or congested sites, scheduling maintenance and patrol activities, and educating visitors about the conditions they are likely to experience.

This study also demonstrates how computer simulation can be used for monitoring purposes. Monitoring is becoming increasingly important in park and wilderness planning and management and plays a vital role in application of the Limits of Acceptable Change (LAC; Stankey et al., 1985) and Visitor Experience and Resource Protection (VERP; Manning, 2001; National Park Service, 1997) frameworks developed and used by the U.S. Forest Service and U.S. National Park Service, respectively. These frameworks require formulation of indicators and standards of quality for resource and experiential conditions in parks and wilderness. Indicator variables must be monitored to help ensure that standards of quality are maintained. Often times in monitoring, relatively easy to measure variables, such as parking lot counts, will be observed as a means to estimate the condition of harder to measure variables, such as use densities and encounters within a recreation system (Hollenhorst, Whisman, & Ewert, 1992). Similarly, simulation models like the one developed in this study can be used to monitor crowding-related indicator variables such as trail and campsite encounters. Trailhead counts (gathered on a periodic basis by means of automatic trail counters, self-registration stations, or permit data) can be used to run the model and estimate trail and campsite encounters. Moreover, as the "Maximum Allowable Use" simulation conducted in this study demonstrates, computer simulation models can be used in a more "proactive" way by estimating the total daily use that can be accommodated without violating crowding-related standards of quality. In this way, a trailhead quota or permit system could be designed to ensure that crowding-related standards of quality are maintained.

Travel simulation modeling can be used to test the potential effectiveness of management practices, such as those designed to reduce trail and campsite encounters. For example, travel simulation modeling provides managers with a tool to estimate the potential effect of redistributing use among entry points to a wilderness area, or altering the temporal distribution of use on visitor flows and visitor use-related conditions. While the level of visitor use in the Desolation Lake Locale is too low to demonstrate this capability of travel simulation modeling, several other studies have illustrated this (Manning & Potter, 1984; McCool, Lime, & Anderson, 1977; Potter & Manning, 1984; Smith & Krutilla, 1976; Underhill, Xaba, & Borkan, 1986; Van Wagtendonk & Coho, 1986; Wang & Manning, 1999). For example, in a study at Isle Royale National Park, a travel simulation model was developed to test the effectiveness of a range of management practices designed to reduce crowding within the Park's backcountry campgrounds (Lawson & Manning, 2003a, 2003b). Travel simulation results from the study suggested that implementing a permit quota, a fixed itinerary system, and/or campsite development would reduce crowding in backcountry campgrounds, while redistributing use among the entry points to the Park's backcountry would not be an effective strategy. These findings assisted managers in identifying management practices that would potentially reduce campground crowding, while avoiding the costs associated with instituting potentially ineffective management policies. Findings from a travel simulation model of visitor use along the Appalachian Trail suggested that the number of hiking encounters along the Trail could be reduced by altering the number and timing of arrivals at various trailheads (Manning & Potter, 1984; Potter & Manning, 1984). In fact, spatial and temporal redistributions of use along a section of the trail were found to be more effective at reducing the number of hiking and camping encounters than across-the-board use limits. In such cases, simulation modeling may be a useful tool for optimizing the design of trailhead quota systems and/or information and education programs that redistribute use across starting locations and starting times.

Finally, the results of this study demonstrate that computer simulation provides outputs that integrate well with other resource data and assessments. For example, by exporting computer simulation results to a GIS database, it is possible to conduct overlay analyses with resource data to examine relationships between natural resource characteristics (e.g., resource fragility, resource impacts, etc.) and existing visitor use patterns. Furthermore, the integration of GIS and computer simulation technologies provides managers with a tool to illustrate with maps the potential effects of alternative visitor use policy decisions and management practices on visitor use patterns and natural resources within a dispersed, backcountry setting.

The Challenges of Computer Simulation for Backcountry Recreation Management

In addition to demonstrating the potential value of computer simulation for backcountry recreation management, this study has identified several analytical issues that need to be addressed through further research. The first challenge that emerged in this study has to do with collecting reliable, representative data with which to construct computer simulation models. Backcountry recreation areas, by definition, are dispersed in nature, often having many remote entry points. Consequently, it is often difficult to capture travel itineraries and other data needed to construct a computer simulation model using on-site survey techniques. The response rate to the diary questionnaire in this study (32.2%) bears evidence to this challenge and calls into question the representativeness of the camping itinerary data used to construct the simulation model of the Desolation Lake Locale. Other studies, however, have been more successful in collecting data for computer simulation models. For example, in the study at Isle Royale discussed earlier in this paper, the computer simulation model was constructed from a census of all permits issued during the 2001 visitor use season. In addition, computer simulations of visitor use on the Carriage Roads and the loop road on Schoodic Peninsula of Acadia National Park were constructed from data collected through visitor surveys that had response rates of 83.3% and 95.4%, respectively. Further research and coordination with land managers is needed to identify methods for collecting trip and visitor characteristics data in a reliable and consistent manner. For example, alternative data collection methods, including global positioning system, automatic timing systems (i.e., race technology), mechanical counters, and related technologies should be compared with on-site survey methods (and each other) to assess their effectiveness for collecting travel itinerary data. The relative strengths and weaknesses of alternative methods for collecting travel itinerary data should be documented and published. Furthermore, in areas where permits are issued, researchers should work with managers to develop standardized permit applications with questions designed to collect the information needed to construct valid computer simulation models.

Secondly, in this study, validation of the simulation model was limited to techniques that rely on intuitive judgments. For example, sensitivity analyses conducted with the simulation model suggest that when total simulated use was increased, estimates of hiking and camping use and encounters increased. While this analysis supports the internal and face validity of the simulation model, it is less useful for making conclusions concerning how well the simulation model outputs represent corresponding data for the actual Desolation Lake Locale trail and campsite system. Due to a lack of sufficient data concerning actual hiking and camping use and encounters, quantitative validation techniques were not used in this study. Furthermore, existing applications of computer simulation to recreation management and planning, including the example presented in this paper, have generally lacked or been limited in the use of quantitative validation techniques. This underscores again the need for further research designed to improve researchers' and managers' ability to collect data that can be used not only as inputs to a computer simulation model, but as the basis for quantitative, results validation of simulation models. Furthermore, while there is a relatively extensive body of literature describing validation techniques for simulation models of manufacturing systems, there is a lack of recent research concerning the appropriateness of alternative statistical techniques for validation of computer simulation models of parks, wilderness and related outdoor recreation systems. Consequently, existing applications of computer simulation, including the example presented in this study, may overstate the utility of computer simulation. More research is warranted to develop standardized methods and procedures to assess the validity of computer simulation models designed for outdoor recreation management.

Third, as noted earlier in this paper, the computer simulation model of the Desolation Lake Locale is a steady state simulation model. One of the most difficult challenges of steady state simulation is determining the appropriate runtime length needed to generate statistically valid model outputs (i.e., outputs that are not biased by start-up effects or autocorrelation; Centeno & Reyes, 1998). Through previous research on simulation, techniques have been developed to establish steady state runtime lengths needed to achieve specified levels of accuracy for model outputs (Centeno & Reyes, 1998). However, like the quantitative validation methods referred to in the previous paragraph, these methods were designed primarily for manufacturing applications and were of limited utility in this study. Consequently, the runtime length for the Desolation Lake Locale simulations was selected arbitrarily. While intuitively one would expect the 2,000 day runtime length used in this study to be adequate, the methods developed in the simulation literature could not be used to test our intuition. Before the full potential of computer simulation can be realized for outdoor recreation management, more research is needed to develop and standardize methods to establish steady state simulation runtime lengths.

Fourth, an underlying assumption of the 4X and the Maximum Allowable Use Simulations is that the relative frequency of the hiking and camping itineraries that visitors follow will remain the same, even as use levels rise. Since people's choice of hiking and camping itineraries are often driven by the amount of time they have and the location of key attractions (e.g., water bodies, vistas, mountain tops, etc.), this assumption seems reasonable. However, this assumption may become more problematic for dramatic increases in overall use levels in which case use densities may override the attractiveness of specific landscape features and, to a lesser extent, time constraints in determining people's hiking and camping routes. In cases where the scenarios to be simulated deviate dramatically from existing conditions, it may be more appropriate to use an agent-based simulation approach (Daniel & Gimblett, 2000). With this approach, simulated visitor behavior is driven by a set of rules that take into account such factors as the number of other visitors in selected locations, time constraints, and the attractiveness of landscape features. A primary challenge of agent based simulation lies in defining rules that accurately represent human behavior. If rules of human behavior are not specified correctly, results of agent based simulations will not be valid. Consequently, the choice of simulation approach must be based on the objectives of the simulation project and more research is needed to develop guidelines to assist computer simulation users in making the best choice among simulation options.

In conclusion, this study demonstrates that computer simulation is a tool with great potential for assisting managers as they attempt to address the complexities of managing recreational use in dispersed, backcountry settings. In addition, this paper provides new insights about the limitations and challenges of computer simulation for backcountry recreation management. To help ensure that managers can confidently use simulation as a standard tool in recreation planning and management, future research should focus on addressing the challenges and limitations described in this paper.

References

Banks, J., Carson, J., Nelson, B., & Nicol, D. (2001). *Discrete-event system simulation.* Upper Saddle River, NJ: Prentice Hall.

Centeno, M. & Reyes, M. (1998). So you have your model: What to do next? A tutorial on simulation output analysis. *Proceedings of the 1998 Winter Simulation Conference,* pp. 23-29.

Cole, D., Peterson, M., & Lucas, R. 1987. *Managing wilderness recreation use: common problems and potential solutions* (Research Paper INT-230): USDA Forest Service, Intermountain Research Station.

Daniel, T., & Gimblett, R. 2000. Autonomous agents in the park: An introduction to the Grand Canyon river trip simulation model. *International Journal of Wilderness, 6*(3), 39-43.

Gimblett, R., Richards, M., & Itami, R. 2000. RBSim: Geographic simulation of wilderness recreation behavior. *Journal of Forestry, 99*(4), 36-42.

Hendee, J. & Dawson, C. 2002. *Wilderness management: Stewardship and protection of resources and values* (3rd ed.). Golden, CO: Fulcrum Publishing.

Hollenhorst, S., Whisman, S., & Ewert, A. (1992). *Monitoring visitor use in backcountry and wilderness: A review of methods* (General Technical Report PSW-GTR-134): USDA Forest Service, Pacific Southwest Research Station.

Itami, R., Raulings, R., MacLaren, G., Hirst, K., Gimblett, R., Zanon, D., & Chladek, P. (2004). RBSim 2: Simulating the complex interactions between human movement and the outdoor recreation environment. *Journal of Nature Conservation, 11*(4), 278-286.

Landres, P., Spildie, D., & Queen, L. (2001). *GIS applications to wilderness management: Potential uses and limitations* (General Technical Report RMRS-GTR-80): USDA Forest Service, Rocky Mountain Research Station.

Law, A. M.. & Kelton, W. D. (2000). *Modeling simulation and analysis* (3rd ed.). Boston: McGraw Hill.

Lawson, S. & Manning, R. (2003a). Research to inform management of wilderness camping at Isle Royale National Park: Part I—descriptive research. *Journal of Park and Recreation Administration, 21*(3), 22-42.

Lawson, S. & Manning, R. (2003b). Research to inform management of wilderness camping at Isle Royale National Park: Part II—prescriptive research. *Journal of Park and Recreation Administration, 21*(3), 43-56.

Lawson, S., Manning, R., Valliere, W., & Wang, B. (2003). Proactive monitoring and adaptive management of social carrying capacity in Arches National Park: An application of computer simulation modeling. *Journal of Environmental Management, 68*, 305-313.

Lawson, S., Mayo Kiely, A., & Manning, R. (2003). Integrating social science into park and wilderness management at Isle Royale National Park. *George Wright Forum, 20*(3), 72-82.

Lucas, R. (1980). *Use patterns and visitor characteristics, attitudes, and preferences in nine wilderness and other roadless areas* (General Technical Report INT-253): USDA Forest Service, Intermountain Research Station.

Manning, R. (2001). Visitor experience and resource protection: A framework for managing the carrying capacity of national parks. *Journal of Park and Recreation Administration, 19*(1), 93-108.

Manning, R. (1999). *Studies in outdoor recreation: Search and research for satisfaction.* Corvallis, OR: Oregon State University Press.

Manning, R., & Potter, F. (1984). Computer simulation as a tool in teaching park and wilderness management. *Journal of Environmental Education, 15*, 3-9.

McCool, S., Lime, D., & Anderson, D. (1977). Simulation modeling as a tool for managing river recreation. *River recreation management and research symposium proceedings* (General Technical Report NC-28), USDA Forest Service, North Central Research Station.

National Park Service (1997). *VERP: The visitor experience and resource protection (VERP) framework: A handbook for planners and managers.* USDI National Park Service Technical Report.

Potter, F., & Manning, R. (1984). Application of the wilderness travel simulation model to the Appalachian Trail in Vermont. *Environmental Management, 8*, 543-550.

Sargent, R. (1998). Verification and validation of simulation models. *Proceedings of the 1998 Winter Simulation Conference*, 121-130.

Shechter, M. & Lucas, R. (1978). *Simulation of recreational use for park and wilderness management.* Washington, D.C.: Resources for the Future.

Smith, K., & Krutilla, J. (1976). *Structure and properties of a wilderness travel simulator.* Baltimore, MD: Johns Hopkins University Press.

Stankey, G., Cole, D., Lucas, R., Peterson, G., Frissell, S. & Washburne, R. (1985). *The limits of acceptable change (LAC) system for wilderness planning* (General Technical Report INT-176): USDA Forest Service, Intermountain Research Station.

Underhill, A., Xaba, A., & Borkan, R. (1986). The wilderness use simulation model applied to Colorado River boating in Grand Canyon National Park, USA. *Environmental Management, 10*, 367-374.

United States Forest Service. (2001). Wilderness recreation study: Appendix I and Appendix N. *John Muir/Ansel Adams & Dinkey Lakes Wilderness Management Plan Final Environment Impact Statement.*

Van Wagtendonk, J. (2003). The wilderness simulation model: A historical perspective. *International Journal of Wilderness, 9*(2), 9-13.

Van Wagtendonk, J. & Coho, P. (1986). Trailhead quotas: Rationing use to keep wilderness wild. *Journal of Forestry, 84*, 22-24.

Wang, B., & Manning, R. (1999). Computer simulation modeling for recreation management: A study on carriage road use in Acadia National Park, Maine, USA. *Environmental Management, 23*, 193-203.