Overnight Visitor Use and Computer Simulation Modeling of the Yosemite Wilderness

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Introduction

Yosemite National Park uses a trailhead quota system to manage wilderness visitors. Park scientists set zone capacities and subsequent trailhead quotas using travel patterns with the aid of a computer simulation model in the 1970s. Data were collected over four years to associate zone use with trailhead of origin, and trailhead quotas were set in 1977 (van Wagtendonk and Coho 1986) using the Wilderness Simulation Model first developed by Smith and Krutilla (1976).

Limiting how many visitors start daily at a trailhead maintains overnight zone use within capacity, if trip characteristics (party size, trip duration, spatiotemporal itinerary adherence) remain similar to the 1970s. Evidence suggests that travel patterns have changed since this system's inception. Data on which the original trailhead quotas were based, and the data on itinerary adherence, are nearly forty years old, and the supposition is that visitor use consists of a larger number of shorter-duration trips. Consequently, travel zone capacities are being exceeded in some zones on many high-use nights. An accurate account of wilderness use and itinerary deviation to develop a contemporary model may inform quota recalibration to enhance resource management.

Wilderness trips from May 1 through September 30, 2010, into the Yosemite wilderness were evaluated in regard to party size, trip duration, and spatiotemporal itinerary adherence (the degree to which groups adhered to their stated trip route and duration). Using a simulation model, we analyzed visitor use scenarios, and resultant zone use patterns to inform resource managers.

Methods

To evaluate itinerary adherence, we compiled all intended trip itineraries from the park's wilder-

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ness permit database. A sample of actual routes and campsite locations was collected via map diary surveys distributed to visitors on randomly sampled dates, selected in proportion to visitation at these sites, as determined by the 2009 visitor use data. Respondents returned surveys before leaving the park, or by mail. Multiple e-mail follow-ups were sent to late respondents to facilitate a greater response. After passage of a certain amount of time without response, we considered outstanding surveys as non-responses. Subsequent communication with non-respondents, when possible, consisted of asking only for their actual trip duration, for the purposes of assessing non-response bias.

Travel data for trips that originated from outside the park were also collected. Nine Forest Service permit stations, and three in Sequoia and Kings Canyon National Parks distributed the surveys to all parties that intended to enter the Yosemite wilderness from May 1 through September 30, 2010. Those surveys were returned to the permit issuing station, to Yosemite, or by mail.

Data analysis

There were 2,755 permits issued on sample dates, and 1,134 useable returned surveys. Assuming that all permitted parties received a survey, this represents a 41.2% response rate. Table 1 shows that comparison of trip attributes between the 1970s and 2010 indicates that current trips are shorter in duration, and that parties are now smaller.

The proportion of the non-respondent sample that deviated temporally from their stated agenda was 35/75 = 0.4667, and the proportion of the respondent sample that deviated temporally was 417/1123 = 0.3722. A two-sample proportion test indicated this difference was not significant ($z = 1.36$, $p = .111$). A Kolmogorov-Smirnov test showed the distribution of temporal deviations was not significantly different between respondents and non-respondents ($D = 0.0825$, $p = .7425$). A Mann-Whitney test showed there was no significant difference in median deviation between respondents and non-respondents ($W = 41042$, $p = .6701$). Therefore, there is no evidence that non-respondents behaved differently with respect to temporal deviations than survey respondents.

Assessment of the degree to which parties deviated from intended itineraries enables application of an adjustment to the intended itineraries in the park's permit database to produce a more accurate estimate of visitor use based on actual trip durations. Of all sampled parties, 67% deviated spatially and/or temporally, and a small portion (3.6%) reporting not even taking their trips. Linear regression showed that actual trip duration depended significantly on party size ($p < .001$) and intended trip duration ($p < .001$). The regression equation was *actual duration* = $0.270 + 0.0433p + 0.695X$; where p = party size and X = intended trip duration ($R^2 = 0.622$, residual standard error = 0.927, df = 1120).

An estimated 870 surveys were distributed at external distribution sites to parties intending to enter the park. Of those, 147 returned surveys were received, a 16.9% response rate. The only difference found between trips originated outside rather than inside the park was that the mean group size was greater, by 0.4 people, for trips originating from outside the park.

Wilderness visitor use modeling

A travel simulation model of Yosemite wilderness visitor use was created using the Extend software platform, developed by Imagine That, Inc. (Diamond et al. 2007). The model is based on the Yosemite permit database (adjusted for deviation), survey data from non-Yosemite originated parties, and National Park Service-informed estimates of Pacific Crest Trail visitor flows.

The model consists of rule-based "blocks" performing defined functions (Figure 1). A "generator block," for example, represents the arrival of wilder-

Table 1. Yosemite wilderness trip attributes, 1970s and 2010.

	1970s	2010
Mean Group Size (persons)	3.2	2.9
Mean Intended Duration (nights)	2.9	2.4
Mean Actual Duration (nights)	2.4	2.1

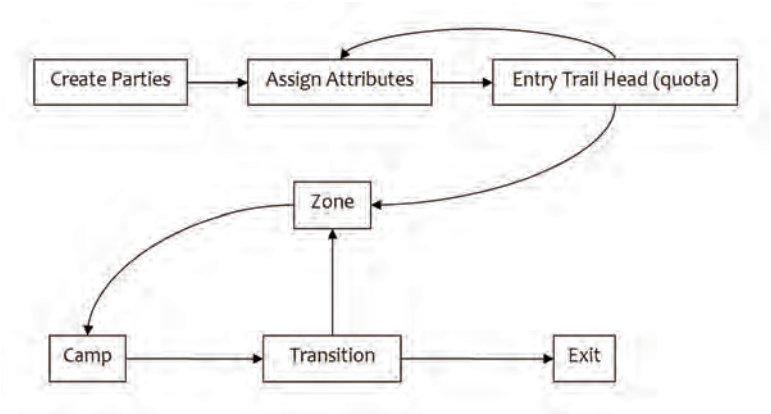


Figure 1. Generalized simulation model block structure.

ness visitors to the park. The "generator block" is linked to a block ("assign attributes") that assigns attributes to the party, such as size and entry trailhead, based on probabilistic distributions. The next block applies trailhead quota rules so that if the daily quota for a particular trailhead has been reached then a new trailhead is stochastically assigned to the party. The model simulates parties moving from trailhead to campsite zone to campsite zone to exit, dependent on the probabilistic determination of nightly zone use, based on the 2010 itinerary database (corrected for spatiotemporal deviation). One may then modify the model under alternative visitor use scenarios, by increasing or decreasing visitor use or trailhead permit quotas, to simulate how different scenarios and the resulting use patterns affect visitor nights in each of the management zones.

For each scenario, 1,000 simulations were run to capture any stochastic nature, and to generate meaningful statistics. All scenarios were run for 153 time-steps representing May 1 through September 30. The main output for each scenario is a table containing the mean and standard deviation across all stochastic simulations of visitor nights spent in each zone on each night across the entire season, and a second table containing how many visitor nights each trailhead contributed to each wilderness zone. Since the mean over a large number of simulations smoothes out the high and low points of the data, output was also produced detailing the frequency with which each zone is over capacity on each night. The frequency is the number of simulations in which each zone is at a given exceedance of capacity on each night. When divided by the total number of simulations, this gives the probability of exceeding capacity at a given use level in that zone on that night.

Five simulation scenarios were executed for the high use period. A *validation scenario* ensures the model is running correctly and accurately simulates observed phenomena. It uses data only from the permit itinerary database, with no spatial or temporal adjustment. Outputs include the number of parties that completed a trip and the total number of nights each party spent in the park. Statistical methods were used to compare distributions of party size, trip duration, and entry trailhead between the model and permit data. We also compared model-predicted use to intended use and verified that 1,000 stochastic replicates were sufficient to accurately estimate variances and capacity exceedance probabilities.

The *baseline scenario* reflects the best attempt at simulating actual Yosemite wilderness visitor use patterns, parameterized by trailhead of entry, entry date, party size, trip length, and probabilistically simulated travel throughout the wilderness zones. The baseline scenario also incorporates additional usage from trips originating at trailheads outside the park. Output categories mimic those of the validation scenario. The distribution of spatial deviations predicted by the model was compared to that observed in the sample of survey respondents to validate the spatial deviation algorithm.

The aim of the reduced use scenario is to reduce use in zones that are frequently over capacity by removing parties at trailheads. In this scenario, when a party draws an entry trailhead with full quota, the party is denied entry, and leaves without spending any nights. Based on entry trailhead contribution output from the baseline scenario, quotas were reduced on trailheads that contribute heavily to the overused zones, until satisfactory levels were achieved. In this case, "satisfactory use" is defined as no zone exceeds capacity, on any given day, in more than 30% of the

simulations. Additional output for this model includes the number of parties and persons denied entry.

The trailhead reassignment scenario redistributes parties to less-used park zones, instead of denying entry. When a party draws a trailhead with full quota, it is reassigned to a new trailhead from a distribution in which the least popular trailhead has the highest probability of selection and the most common choice has the lowest probability, which forces parties to less-used parts of the park. Additional output includes the numbers of parties and persons redistributed.

The maximum use scenario evaluates maximum visitor use by allocating maximum daily visitor entries at every trailhead, as allowed by the current quotas, for every day of the high use period. Since the same number of visitors enter every day, there is no longer a dynamic component; therefore, this scenario represents a stable equilibrium of wilderness visitation.

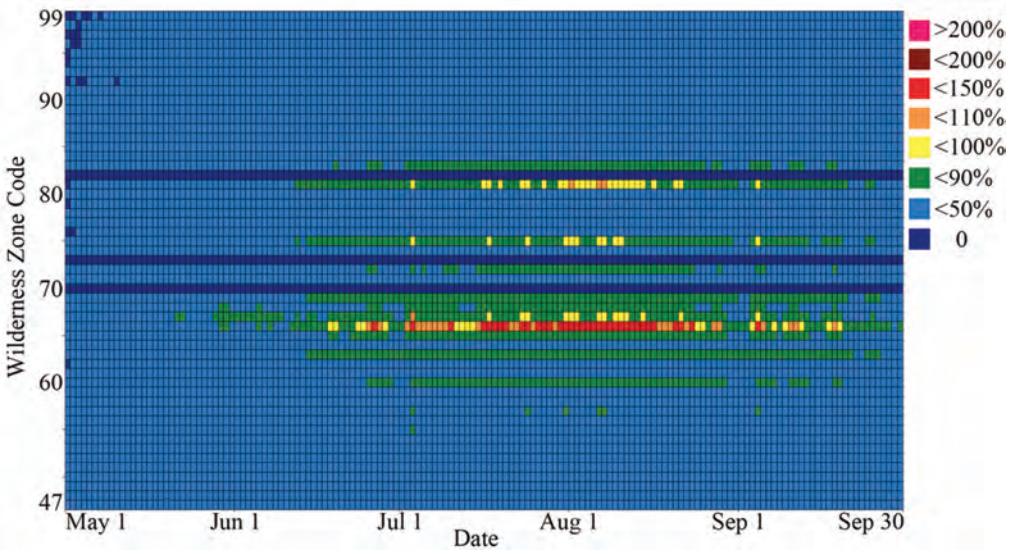
Analysis of simulated visitor use and user capacities

The distribution of party sizes and trip durations resulting from the validation scenario was compared with the permit database. One season-long model simulation was used to generate these parties. Sample size was 15,133 for both the model and the permit database. A Kolmogorov-Smirnov test was run to test for equality of distributions, and Welch's t test was run to compare means. There was no significant difference in either the distribution or the mean between party sizes in the model and the permit database. Relative frequency histograms showed very similar distributions for trailhead usages in both the database and simulation trial.

For season-total use across all zones, the modeled 95% prediction interval was 106,468 ± 4,135, and the observed intended use from the database was 107,677. The observed intended use falls within the prediction interval, indicating that at alpha = 0.05, we do not reject the null hypothesis that observed use belongs to the model-predicted population. For use by zone by night ("zone-night"), we performed the same type of analysis, adjusted for multiple comparisons over all 8,109 zone-nights (53 zones x 153 nights). At 95% confidence for each zone-night, we expect observed zone-night use to fall outside the 95% prediction interval in 5% of the zone-nights. Observed intended use fell outside of the modeled 95% prediction interval in less than 1% of all zone-night combinations, indicating that there is no significant difference in spatiotemporal use distributions between the model and permit database.

The baseline scenario indicates that mean use in three zones exceeds capacity on many nights during the peak season (Figure 2). The same zones are the only ones with nights with a

Figure 2. Percent zone capacity averaged over 1,000 simulations of baseline scenario.



greater than 50% probability of exceeding capacity on given nights (Figure 3). The number of zones with mean use exceeding capacity is greatest July 3 and August 1, 6, and 7 when use in two zones, on average, exceeds capacity.

The model outputs from the reduced use scenario indicate that by reducing the quotas of the trailheads contributing most to zones with nights exceeding capacity, resultant visitor use is such that, on average, no zone exceeds capacity, and overnight use in any zone on any given night exceeds capacity in no more than 20% of all simulations. The frequency with which zones exceed 110 or 150 percent of capacity is no greater than 10% over the 1,000 simulations.

Output from the trailhead reassignment scenario was similar to that of the reduced use scenario. There were no nights on which mean use exceeded capacity. There were a few zone-nights in which it is probable use may exceed capacity but none in more than 50% of simulations. Just three zone-nights were likely to exceed 110% of capacity, and none in more than 30% of simulations. This scenario has no nights in any zone in which use exceeds 150% of capacity in over 10% of the 1,000 simulations.

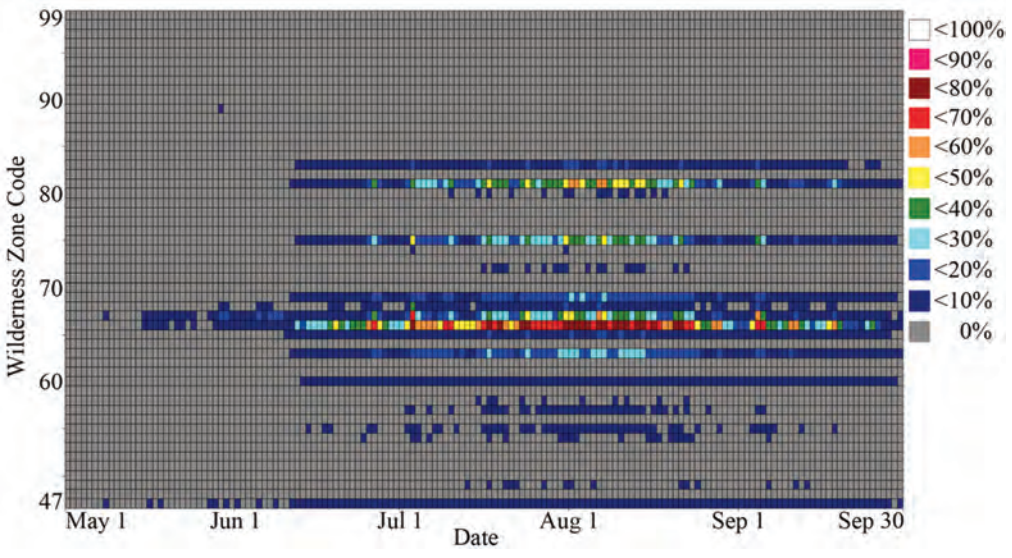
The maximum use scenario indicates three zones in which average use exceeds 150% of capacity nearly every night. The predominant travel patterns are such that, despite maximum use conditions, use in many zones do not, on average, reach 50% of capacity, and many of those same lesser-used zones have no nights on which the model predicts any chance of exceeding capacity. The results indicate a 100% probability that use exceeds 110 and 150% of capacity in two zones on nearly every night. The current quota scheme limits maximum daily wilderness visitation to an average of 2200 visitors in this scenario, whereas the sum total of all zone capacities is 4200, making the maximum allowed use 52.4% of total capacity at full trailhead quotas.

Discussion

The results of this simulation model allow the park to quantitatively understand the existing conditions. With this model, the park will be able to evaluate the effectiveness of alternative management strategies more efficiently and with less risk than trial-and-error methods. They may evaluate potential visitor use demands and develop informed plans to prepare for those potential conditions (Lawson 2006).

The Yosemite trailhead quota system is designed to allow visitors the freedom to roam, and gives visitors the right to alter their plans serendipitously. It provides maximum freedom to visi-

Figure 3. Probability of exceeding 100% capacity over 1,000 simulations of baseline scenario. Percent zone capacity averaged over 1,000 simulations of baseline scenario.



tors, consistent with wilderness experience and resource constraints (van Wagtendonk and Coho 1986). This characteristic may increase the potential of Yosemite wilderness experiences to provide visitors with a sense of inspiration, escape, and autonomy.

This study found strong evidence that visitors are altering their trips in both time and space; thereby demonstrating both the necessity for managers to allow for, and proof of visitors exercising those rights to, logistical freedom. This study also found that that on some nights, a portion of the wilderness management zones likely receive use exceeding their user capacities. This study produced a management tool for Yosemite National Park. It is up to the park to decide how best to implement the modeling tool provided, but it may be worth noting that a previous study using stated-choice modeling found that Yosemite visitors would be willing to accept a lower chance of receiving a permit in order to gain improvements in other conditions, such as having fewer encounters with other visitors during their trips (Newman et al. 2005). Another study in Oregon and Washington found that wilderness visitors are more supportive of use limits if the rationale given for limits is protection of the environment rather than protection of visitor experiences (Cole and Hall 2008). Therefore, if the park implements an alternative quota configuration reducing use then actual visitors are likely to accept it in regard to what they may gain experientially, while the public may be more likely to support it in consideration of resource preservation.

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