YOSEMITE WILDERNESS VISITOR TRAVEL PATTERNS:

IMPLICATIONS FOR TRAILHEAD PERMIT QUOTAS

by

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ABSTRACT

Yosemite Wilderness Visitor Travel Patterns: Implications for Trailhead Permit Quotas

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Yosemite National Park uses a trailhead quota system to manage wilderness visitors. Park scientists set user carrying capacities in the 1970s for backcountry zones and trailhead quotas from prevalent travel patterns and a computer simulation model. 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. To accurately assess wilderness use and itinerary deviation to develop a contemporary travel simulation model, wilderness trips from 1 May through 30 September 2010 were evaluated in regard to mean party size, trip duration; and spatial and temporal itinerary adherence. Strong evidence of visitor spatiotemporal itinerary deviation was found. Travel patterns suggest more concentrated use of frontcountry adjacent areas, and increased visitor attraction to iconic peaks and service facilities. Multiple visitor use scenarios were simulated and resultant use presented to inform resource managers.

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INTRODUCTION

The public lands of the United States contain a multitude of natural resources, offering ample recreation opportunity while also serving as a bank for precious extractable resources, scientific study, education, cultural heritage, scenery, and other ecosystem services. Among the lands managed by the United States departments of Agriculture and Interior there are many designated Wilderness areas. With the Wilderness Act of 1964 (P.L. 88-577), Congress established the National Wilderness Preservation System, protecting vast roadless areas with significant ecological, geological, scientific, educational, scenic or historical value. This legislation represented a milestone for countless crusaders hoping to preserve in perpetuity nature primeval in its most pristine form to benefit generations of citizens. Although the Wilderness Act served to establish the system, it did not establish a methodology for protecting the resources from overuse by the visitors for whom it was, in part, created. It guided agencies, such as the National Park Service (NPS), to "be responsible for preserving the wilderness character of the area" and "administer such area for such other purposes for which it may have been established as also to preserve its wilderness character" (P.L. 88-577). Yosemite National Park's iconic status among public lands, along with its over 280,000 hectares of designated Wilderness, make it perennially popular for recreational visitors; thus, its use levels have steadily increased (NPS 2010). The park has measured, monitored, and managed wilderness user capacities since the establishment of a formal wilderness management division in 1973. The increasing visitation to public lands and Yosemite's designated Wilderness in particular, along with the accompanying impacts to resources, have led to an increased focus by managers on the concept of carrying capacity and the development of management strategies incorporating structured frameworks and implementation of analytical tools designed to balance visitor interests and ecological integrity (NPS 1997).

Focused investigation in the Sierra Nevada has provided the basis for wilderness management programs, and from observational inference to modern computer simulation, the applications of results have helped address challenges "from overgrazing to overused campsites" (van Wagtendonk and Parsons 1996). John Muir was the first to report resource damage in the Sierra Nevada in 1894 by describing impacts to mountain meadows by grazing sheep. Early 1900s Sierra Club trip logs also gave assessments of wilderness conditions (van Wagtendonk and Parsons 1996). In his special report for the park service on High Sierra wildlife in 1936, regional wildlife technician Lowell Sumner wondered "how large a crowd can be turned loose in a wilderness without destroying its essential qualities" (Sumner 1936). He realized that to sustain the wild character of these wilderness areas within parks, managers "cannot hope to accommodate unlimited numbers of people" (Sumner 1936). Sumner would later elaborate on the topic in recommending that wilderness be kept "within the carrying capacity or 'recreational saturation point'" (Sumner 1942). He definitively explained the term carrying capacity as "the maximum degree of the highest type of recreational use which a wilderness can receive, consistent with its long-term preservation" (Sumner 1936).

Recreational Carrying Capacity

Wagar (1964) contributed one of the first substantive studies on carrying capacity, with his key distinction that recreational areas had not only an ecological or biological capacity, but a social capacity as well. This idea incorporates the satisfaction levels of the visitors. "Because the objective of recreation is to provide benefit and enjoyment for people, managers of recreation areas must consider how management procedures will affect satisfaction of the needs that motivate recreation" (p.6). The needs and wants of people are important in determining appropriate uses of natural resources. User perceptions and opinions of what types and level of use are appropriate are an essential element of carrying capacity decisions. This challenges land managers because they must make objective determinations "about what ought to be done in our parks and protected areas—what recreational opportunities should be provided, what conditions should be maintained and how recreation use should be managed" to satisfy stakeholders' subjective interests (Cole 2003).

The application of normative theory is relevant to the issue of crowding and carrying capacity. Normative theory was developed in the disciplines of sociology and social psychology to deal with the inability to factually support subjective perceptions. This adds a significant challenge for recreation managers dealing with the myriad of opinions regarding how much use of a resource is considered too much. Crowding as a concept is subjective and has a social-psychological element. Therefore, for individuals, the point at which visitor use is perceived to interfere with a desired experience may vary widely.

People seeking divergent goals and potentially conflicting experiences make the task of managing lands for maximum satisfaction levels a challenge. Wagar (1964) concluded that carrying capacity is a complex matter requiring managers to make value judgments. These judgments are made based on "experience, research data, basic inventory information, public input, careful analysis, and common sense" (Hendee and Dawson 2002 p. 259).

When viewed strictly through the lens of biology, carrying capacity can be defined as the maximum amount of use sustainable by an area as determined by natural environmental factors such as food, shelter, or water. Any major increases in species population could not be supported within the specified range (Odum 1959). In the realm of recreation, carrying capacity refers to "the types and levels of visitor use that can be accommodated while sustaining the desired resource and social conditions…" (NPS 1997 p. 96). The translation of the term from the biological sciences to recreational resource management is understandable, considering that most managers were trained in the biological sciences and therefore were familiar with the concept as it had been applied to management of wildlife and livestock (Stankey and Manning 1987).

When discussing recreational visitor carrying capacity, it helps to understand it by clarifying what it is not. It is not *only* a numerical value or a function of density. It does not merely rely on space allocation as its determining factor. If it were dependent on space standards then it would simply refer to the maximum number of people that could physically occupy or use the available recreational space at any one time. This would not account for the level of use the physical environment would tolerate before resulting in serious damage. It would also fail to take into account social criteria for recreational visitors in regard to acceptable levels of crowding (Lime and Stankey 1971). Visitor carrying capacities are not necessarily intrinsically linked to locus and therefore are not determined solely by resource characteristics. Because capacity is the level of use compatible with the full management prescription, it may vary if value judgments, allocations, or other determinations in the management prescription change (Whittaker et al. 2010). Capacity may well be more a subject matter or methodology rather than mere metric (Lime 1976).

Recreation managers seeking to identify the amount of use a resource could sustain adopted carrying capacity to assist in making decisions. They aimed to establish the maximum number of people that could use a given recreational setting before unacceptable impact occurred. Greater use levels may induce changes to ground cover within and near campsites, trigger trail erosion, create social trails, or disturb wildlife (Hammitt and Cole 1998). Environmental specifics such as climate, soil type, and vegetative cover, along with other physical and biological characteristics, influence the degree of change in the environment resulting from recreational use (Manning 1986). However, research has shown that most environmental impact occurs during the first uses and additional use does not produce proportionally more impact (Cole and Frissell 1982). Cole's study in the Eagle Cap Wilderness of Oregon revealed that even camp sites used no more than a few nights per year were severely altered through tree damage, loss of seedlings, vegetation loss, and soil compaction. In another experiment, Cole (1995) found that one night of camping on a previously unused, pristine site caused significant vegetation loss. Four nights of use caused less than twice the impact, suggesting that the majority of the impacts occur during the first use. Therefore if greater use amounts do not produce significantly greater detrimental effects on the resource, then attention should be shifted from the quantity of use to the type of use, and the determining factor in this dynamic becomes the visitor and not the resource, for it is the experience sought that will vary more than the ecological integrity of the setting. Yet even given a visitor population well versed in low impact land use techniques, visitor use demand is so great in certain high-profile backcountry destinations during peak use periods that the visitor use must be limited, lest visitor experiences become compromised.

Visitor Use Limits

Restrictions on the number of recreational visitors permitted entrance to a wilderness area have been formally implemented for over forty years. "A use limit policy is a formalized regulation that restricts the number of visitors that may enter an area over a given time period—day, week, month, or season," and managers have applied such limits or quotas due to "insatiable demand for high quality recreational opportunities occurring in magnificent natural environments" (McCool 2000). Use limit policies may employ one or a combination of rationing mechanisms: reservations, fees, queuing, lottery, or merit (Stankey and Baden 1977).

Regardless of the mechanism, use limits may be broadly categorized as internal controls such as fixed itineraries or designated campsites, in which the visitor experience is constrained once inside the wilderness, or external controls such as trailhead and zone quotas, which restrict visitors before entering. By concentrating use at designated sites, fixed itinerary systems seem to reduce biophysical recreational impacts. However, this also means an increased managerial presence in wilderness through campsite hardening by implementing sanitation and food storage facilities. This degree of managerial influence may also fundamentally alter the visitor experience through a loss of visitor autonomy. Trailhead quotas, applied externally prior to the visitor entering the wilderness, preserve a visitor's autonomy once they are in the wilderness; trailhead quotas also tend to redistribute visitors' use and their associated impacts to mitigate congestion and intense damage at the most popular destinations (Hennessy 1991).

Use limit policies should be assessed for their practical utility and evaluated using the criteria of efficiency and effectiveness suggested by Checkland and Scholes (1990). Efficiency may be measured in terms of inputs of staffing and funding compared to impact reduction. Effective use limit policies mitigate impacts and accomplish set goals at present and in long term planning (McCool 2000).

The guidelines established by Stankey and Baden (1977) continue to inform management decisions in the realm of use limits. Managers should be as informed as possible in terms of the wilderness and its user base. Rationing should occur only when less restrictive measures fail. Rationing techniques should be combined to minimize and equalize management and user costs. Visitors who desire wilderness-dependent experiences should be favored. Also, rationing policies should be regularly monitored and evaluated (Stankey and Baden 1977, Hendee and Dawson 2002).

Yosemite Wilderness Management

Systematic studies of resource conditions and recreational impacts within the Yosemite wilderness have been ongoing since 1972, when Holmes and a team of 31 others formed the Wilderness Research Group. Almost every area of the Yosemite backcountry was surveyed, and detailed descriptions and maps were made of more than 7000 campsites. The study described environmental damages quantitatively, qualitatively, and spatially (Holmes et al. 1972). Impacts were reassessed between 1981 and 1986 using methodologies developed by Parsons and MacLeod (1980) in a form that became known as the Wilderness Inventory Monitoring System. A third inventory conducted by park staff was completed in 1999 targeting a smaller indicative sample of 34 campsites throughout the park while continuing to evaluate recreational impacts. Systematic monitoring indicates conditions that may require further investigation or managerial action to preserve ecological integrity and maintain satisfactory conditions for users (Boyers et al. 2000).

Yosemite National Park was one of the first to deal with over-use problems. The Yosemite wilderness experienced heavy use in the late 1960s and early 1970s with visitor nights peaking in 1975 at 218,890, and averaging 172,310 visitor nights from 1972 to 1979 (van Wagtendonk 1981). Wilderness overnight use dropped in 1983 to less than half the 1975 peak amount and varied around 117,000 in the 1990s (Boyers et al. 2000). More recently, visitor nights in the Yosemite wilderness have increased to 124,817 in 2008 and 142,623 in 2009 (NPS 2010). In the early 1970s it had become overwhelmingly apparent that the Yosemite resource was experiencing overuse, and in 1972 a mandatory permit system was implemented for all overnight visitors.

Wilderness in Yosemite National Park is divided into management zones, which align with watersheds for the most part. For each zone, park research scientist Jan van Wagtendonk determined an overnight user carrying capacity, which is based on zone size, trail length, and ecological fragility. A subsequent trailhead quota system was introduced, derived from permit data and a simulation model that related zone use to trailhead use (van Wagtendonk 1985).

Density guidelines for each management zone were determined based on the number of acres within the zone and the miles of trail in each zone. The National Park Service (1959) had previously determined acceptable visitor density to be one visitor per season for every acre. These figures were later adjusted after accounting for miles of trail within each zone due to the understanding that an increase in trail mileage would increase the ability of a zone to absorb additional visitors. For every mile of trail the capacity increased by two people. Ecological fragility was taken into account dependent on the management zones' rating in the categories of rarity, vulnerability, recuperability, and repairability (van Wagtendonk 1985).

Rarity was determined to be the uniqueness of a particular ecosystem type or ecological community. Vulnerability was based on the susceptibility of the ecological resources within the zones to damage by humans. How well an ecological system could recover without human assistance determined recuperability. After an ecosystem has been impacted, its ability to be restored determined the repairability rating. These four factors, the social density and trail mileage, along with recommendations from rangers familiar with the area produced a calculated total capacity of 4019 people at any one time for all the zones (van Wagtendonk 1985). After presenting the zone capacities to park wilderness managers, some were adjusted based on "experience, ease of administration, and predicted public acceptance" (van Wagtendonk 1985). As an interim measure this was successful, as gauged by a questionnaire administered by the National Park Service (1976). The majority of park visitors indicated approval of the policy in the survey. Data were collected over four years to associate management zone use with trailhead of origin and the trailhead quotas were updated and have been in place since 1977 (van Wagtendonk and Coho 1986). Contemporary guidance (Cole and Carlson 2010) promotes the use of such an explicit framework with user capacity thresholds (Figure 1) and a documented foundation such as van Wagtendonk's set forth precisely and in consideration of public input.

Current trends in management reveal increased use of technology to help managers acquire, review, and evaluate information, including diverse opinions regarding management decisions. Visitor use simulation modeling has emerged as one such effective technological tool. These models can be used to better understand visitor use patterns, test the effectiveness of managerial plans, and improve communication of implications of management decisions to recreational stakeholders (Cole 2005). The spatially and temporally explicit information about visitor use patterns derived from such models help managers identify overused area as well as areas that may accommodate additional use (Lawson 2006). The Wilderness Simulation Model (WSM) first developed by Smith and Krutilla (1976)

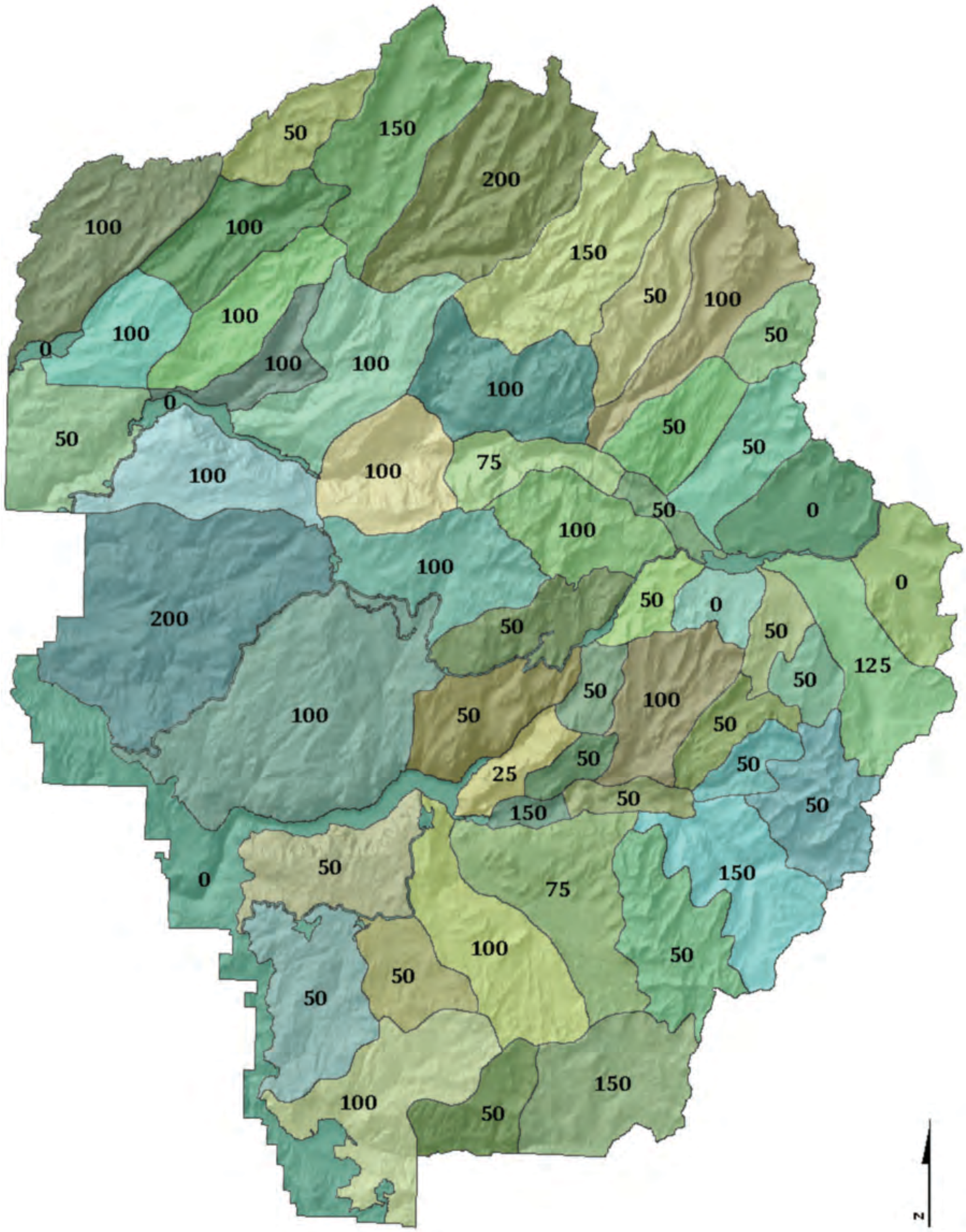

Figure 1. Overnight zone capacities, Yosemite Wilderness.[a]

[a] Overnight wilderness visitor use prohibited in zones labeled 0.

and based on ideas set forth by Stankey (1972) was used to establish trailhead quotas. Simulation modeling of the Yosemite wilderness helped formulate trailhead quotas, which work to ration and redistribute visitor use. Instead of mandating strict itineraries for wilderness visitors, managers allow maximum freedom to visitors consistent with wilderness experience and resource constraints (van Wagtendonk and Coho 1986).

Ultimately land managers, not scientists, the public or computer simulations are charged with establishing user carrying capacities. They must also make choices on how, when, and where to provide the multiple uses, values and benefits of recreation resources. These decisions must be carefully calculated, using established frameworks and technological tools to achieve the preservation of the ideal conditions of shared natural resources for current and future generations (Hendee and Dawson 2002).

This thesis presents findings from investigations of current wilderness visitor travel patterns in Yosemite National Park. It examines the degree to which parties adhered to planned or intended itineraries, and how they deviated, spatially and temporally, from those planned itineraries. Using a travel simulation model, built on primary data collected in 2010, it describes several visitor use simulation scenarios and their implications for Yosemite trailhead permit quotas.

STUDY AREA

The Yosemite Wilderness includes 281,855 ha, nearly 95 percent of the park, which is situated on the western slope of the Sierra Nevada Mountain Range (NPS 2008). Elevations vary from just under 2610 m on the western boundary to just over 3962 m along the Sierra crest. Yosemite National Park experiences a Mediterranean climate with typically long, hot summers and mild winters. Annual precipitation amounts vary from 915 mm at 1200 m elevation to 1200 mm at 2600 m. Between October and April, most of the precipitation falls as snow. From May through September, precipitation is infrequent. Mean daily temperatures range from -4 to 12 degrees Centigrade at Tuolumne Meadows at 2600 m. At the park's south entrance near Wawona (elevation 1887 m) mean daily temperature ranges from 2 to 19 degrees Centigrade. At the lower elevations below 1500 m, temperatures are hotter; the mean daily high temperature at Yosemite Valley (elevation 1209 m) varies from 8 to 32 degrees Centigrade. At elevations above 2500 m, the hot, dry summer temperatures are moderated by frequent summer thunderstorms, along with snow that can persist into July. The combination of dry vegetation, low relative humidity, and thunderstorms results in frequent lightning-caused fires as well (NPS 2004).

There are 52 trailheads to access 1112 km of trail and 375 traditionally used established campsites (Figure 2). Wilderness visitors must occupy designated campsites when camping at Little Yosemite Valley or near Glen Aulin, May Lake, Sunrise, Merced Lake, and Vogelsang High Sierra Camps. An additional 46 trailheads feed 669 km and 197 campsites on adjacent Forest Service wilderness lands. The

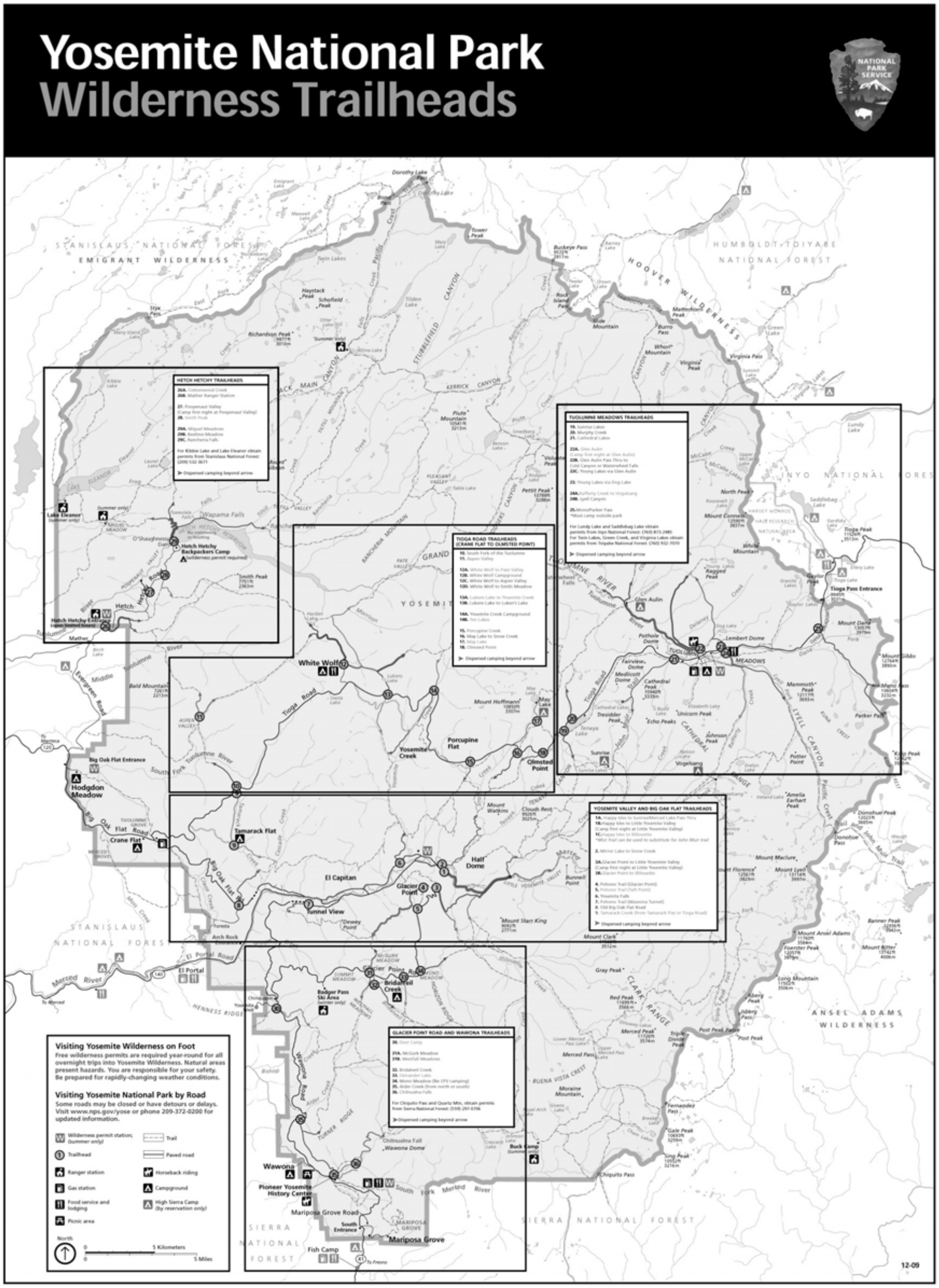

Figure 2. Yosemite National Park wilderness trailheads.[a]

[a]NPS. [updated 3 May 2011]. Trailheads map. http://1.usa.gov/mJskHp.

Emigrant Wilderness borders the Yosemite Wilderness to the north, the Hoover Wilderness to the east, and the Ansel Adams Wilderness to the south. Two popular long distance hiking trails traverse Yosemite's wilderness: the John Muir Trail (JMT) stretches from Yosemite Valley south to Mount Whitney, and 80 km of the Pacific Crest National Scenic Trail are within the park (van Wagtendonk 2004).

Peak use and the demands it places on the limited wilderness resource necessitate use limits from Memorial Day through Labor Day. Permit reservations may be made up to 24 weeks in advance of the date of entry into the wilderness. Sixty percent of each trailhead quota is allocated to reservation, with forty percent left for first-come first-serve access. Unclaimed reservations are made available if not acquired by 10:00 am on the first day of the trip (Hendee and Dawson 2002). The quota system also acts as a mechanism for education by giving park staff the opportunity to convey information about minimum impact regulations and practices to visitors (Boyers et al. 2000).

METHODS

Sampling Procedures

According to the Yosemite wilderness permit database, 12,276 wilderness permits were issued in 2009. With a potential five percent increase in use, it was estimated that 13,000 permits would be issued in 2010. Assuming a 60 percent response rate, a ten percent sample size (n=1300) would require 2167 survey instruments to be distributed. The 2009 permit data and previous studies (van Wagtendonk 1981) show that wilderness use in Yosemite is not distributed uniformly throughout the season / study period (1 May – 30 September, 2010). Weekend and holiday use is much higher than on weekdays, and use increases gradually from the season's beginning and peaks around late July and early August, after which it more rapidly declines to essentially zero use by the end of September (Figure 3). In order to sample according to the temporal distribution of use, the sample frame was defined as all weekends (Friday and Saturday nights for regular weekends; Friday through Sunday nights for the three-day holiday weekends of Memorial, Independence, and Labor Day) and all weekdays in the study period. The sample frame was stratified into two strata: 1) all weekends and 2) the remaining weekdays. Within each stratum, a given unit's probability of being selected for sampling was equal to the proportion of total visitor-nights in that stratum accounted for by trips that began in that unit based on the 2009 permit data. Based on these probabilities, a random number generator resulted in the selection of three weekends and 13 weekdays during the study period. This stratified sampling technique is regarded as more statistically efficient than a census approach and

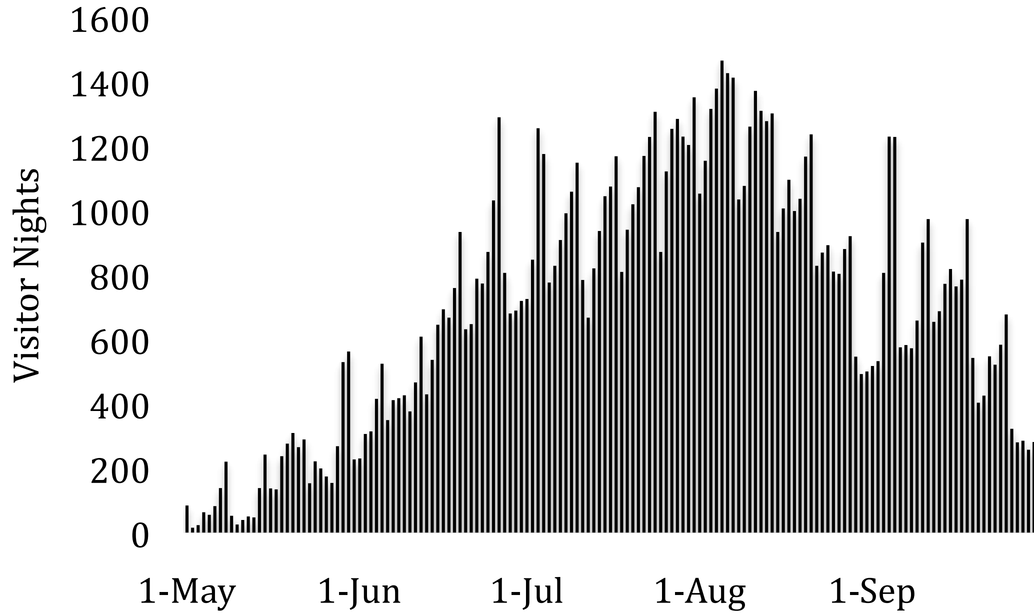

Figure 3. Distribution of overnight Yosemite wilderness use, 1 May – 30 September 2010.[a]

[a]Source: 2010 Yosemite wilderness permit database of intended use.

allowed investigators to minimize the burden of survey distribution on Park Service personnel (Watson et al. 2000). Due to unforeseen circumstances, survey instruments were not distributed on one of the randomly selected dates but were distributed on a day belonging to the same stratum during the following week.

Surveys were administered under permit conditions outlined in HSU Human Subjects in Research approval # 08-82 (expiration 19 April 2011); OMB Expedited Approval for NPS-sponsored public surveys permit # 1024-0224 NPS # 09-014 (expiration 31 December 2010) and NPS scientific research and collecting permit # YOSE 2010 SCI 0048 Study ID 0041 (expiration 31 December 2010).

Survey instruments were distributed at all Yosemite stations that issue wilderness permits (Yosemite Valley Wilderness Center, Tuolumne Meadows Wilderness Center, Hetch Hetchy Entrance Station, Big Oak Flat Information Station, and Wawona Visitor Center at Hill's Studio) to all visitors who obtained a permit on each randomly selected sampling date. Permit identification numbers were recorded on the instrument to later compare actual party routes with planned itineraries. Surveys were also distributed throughout the study period at: White Mountain Ranger Station in Bishop, California; Mono Basin Scenic Area Visitor Center in Lee Vining, California; Mammoth Lakes Visitor Center in Mammoth Lakes, California; Bridgeport Ranger District Office in Bridgeport, California; Eastern Sierra InterAgency Visitor Center in Lone Pine, California; Groveland District Ranger Office in Groveland, California; Mi-Wok District Ranger Office in Mi-Wuk Village, California; Summit District Ranger Office in Pinecrest, California; Bass Lake Ranger District Office in North Fork, California; High Sierra Ranger District Office in Prather, California; Mineral King, Lodgepole, and Cedar Grove Ranger stations in Sequoia & Kings Canyon National Park to all visitors planning to spend at least one night in the Yosemite wilderness (Figure 4). Party size was recorded on surveys distributed outside the park since not all stations permitting Yosemite access maintain detailed permit databases. The research intent was to ascertain the influence on zone use of parties entering from outside the park. The completed surveys were returned either in person directly to Park or Forest Service permit stations, by way of returned rental food canisters, by direct placement in food canister return boxes, in drop boxes at park road exits, on trail at park boundaries at Dorothy Lake, Bond, and Donohue Passes, by mail, or electronically following e-mail reminders to late respondents.

During the study period 15,764 permits were issued, with 2755 issued on the selected sample dates. Of these, 1134 completed surveys with at least some viable information were received, for a response rate of 41.2 percent. Of the 15,764 permits in the database, 14,497 were issued to parties that initiated their trip within the 1 May to 30 September study period and intended to spend at least one night in the Yosemite wilderness. All of these permits contained intended itineraries, from which the number of nights these parties intended to spend in the Yosemite wilderness could be computed. The returned surveys included 1123 for which a complete usable intended trip itinerary was available in the permit database, allowing spatial and/or temporal deviations from intended trip itineraries to be determined, thus lowering the effective response rate to 40.8 percent.

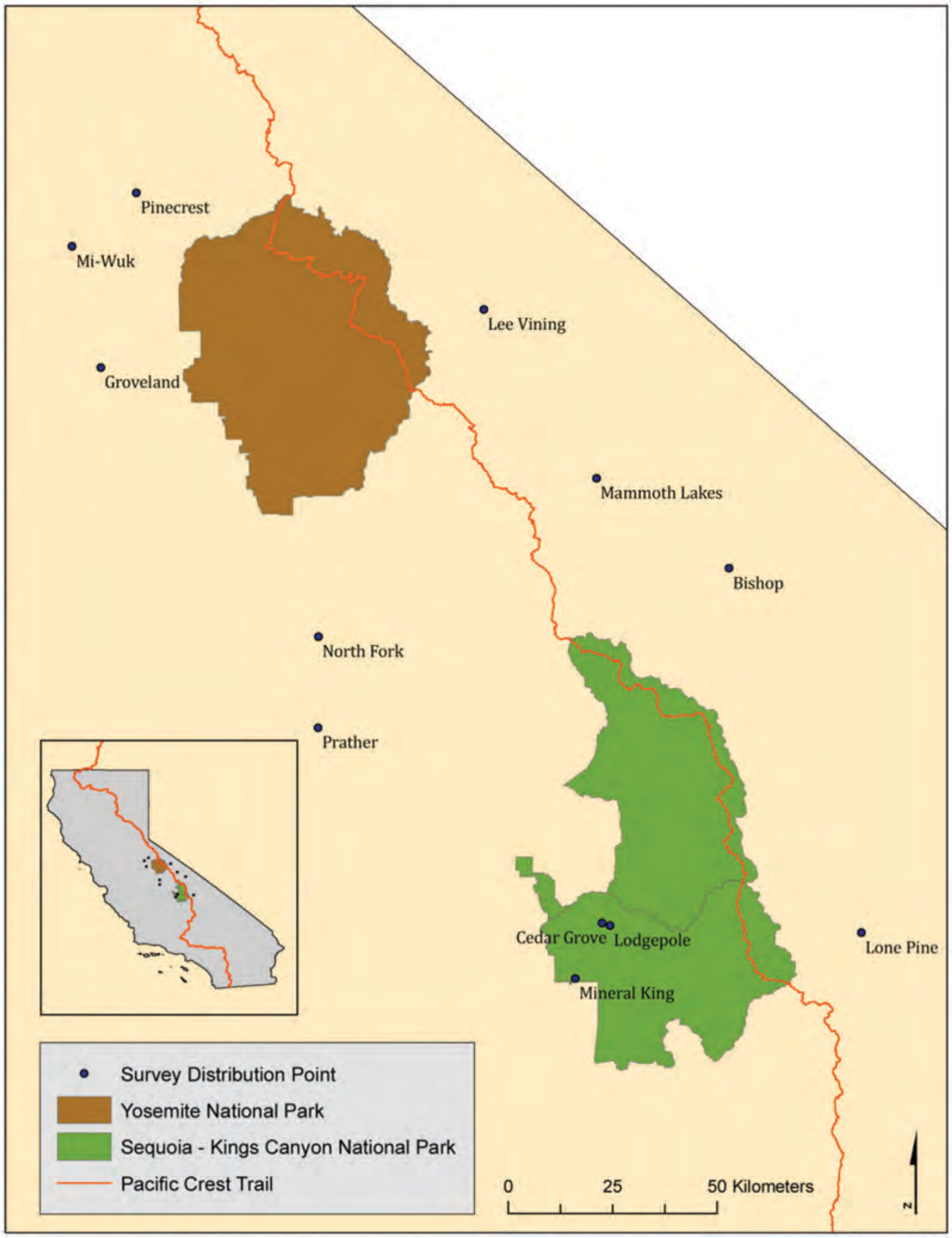

Figure 4. Survey distribution sites outside Yosemite National Park.

Based on information received from participating Forest Service permit stations, it was estimated that 870 surveys were distributed to parties entering the Yosemite wilderness whose trips began outside the park. A total of 147 survey instruments were received from visitors whose trips originated outside Yosemite, equating to a response rate of 16.9 percent. Of those received surveys, 83 contained viable data, thus lowering the effective response rate from this visitor base to 9.79 percent.

In order to conduct a non-response bias check, 75 parties that obtained but did not return a survey were contacted. Each of these parties provided the total number of nights they spent in the Yosemite wilderness. The temporal deviation for these trips was computed by subtracting the number of nights the party intended to spend from the number of nights actually spent in the wilderness. This calculation was repeated for the sample of survey respondents. A two-sample proportion test, Kolmogorov-Smirnov test, and Mann-Whitney test were each performed to compare temporal deviation between respondents and non-respondents.

Survey Instrument

Surveys consisted of map diaries on which respondents marked their trip routes from entry trailhead to campsite to campsite to exit trailhead, indicating each campsite's location with a circled number corresponding to the night of their trip. The park was divided into five sectors, and visitors received survey instruments corresponding geographically to their trailhead of entry and intended route (Figure 5).

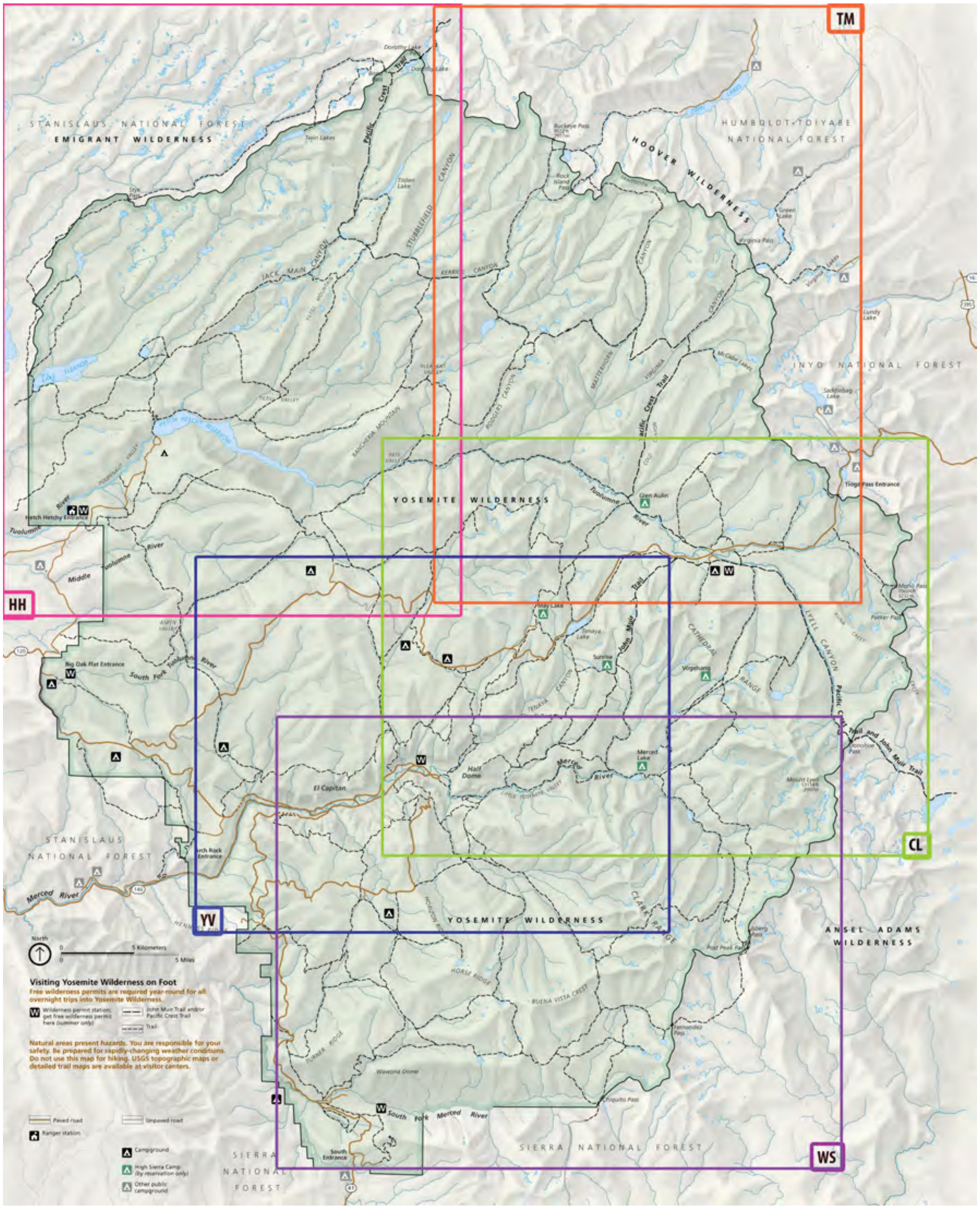

Figure 5. Yosemite National Park survey instrument sectors.[a]

[a] Map base data: NPS [updated March 2008] http://bit.ly/mT1H3s.

Analysis of Survey Instruments and Simulation Model

Returned surveys collected in the park were screened for completeness, and those with discernable route data and sufficient information to link respondents to permit database entries were cross-checked and verified within the database. Surveys were then organized by sample date, duplicated, and transmitted to another project team member to assess spatial and temporal deviation.

The research team created a travel simulation model of Yosemite wilderness visitor use using the Extend software platform, developed by Imagine That, Inc. (Diamond et al. 2007). The Extend model is based on the Yosemite permit database adjusted for deviation, survey data from non-Yosemite originated parties, and park manager informed visitor use estimates for trips originating from external trailheads to the north and northeast of the park, as well as NPS-informed estimates of Pacific Crest Trail visitor flows.

The model consists of rule-based "blocks" that perform a defined function (Figure 6). A "generator block," for example, represents the arrival of wilderness visitors to the park. The "generator block" is then linked to a block that assigns attributes to the party such as party size and entry trailhead based on probability 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 randomly 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 as determined from the 2010 itinerary database corrected for spatial and temporal deviation. One may then modify the model by

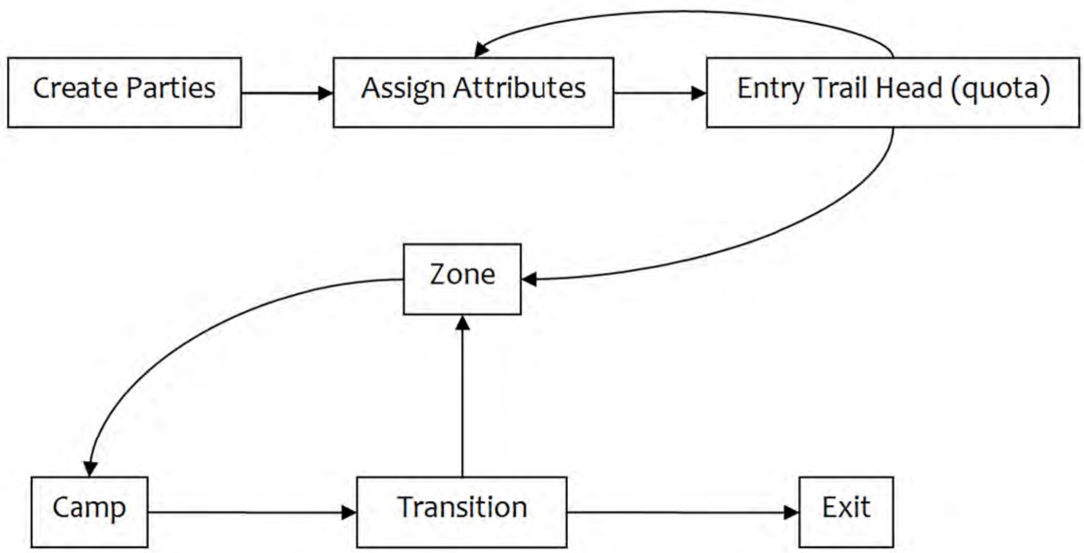

Figure 6. Generalized Extend simulation model blocks.

increasing or decreasing permit quotas at trailheads and to learn how different permit quotas and the resulting use patterns affect visitor-nights in each of the wilderness management zones. Since this project was focused on the application of the simulation model, discussing in further detail its development and validation is beyond the scope of this paper. See Ross (2011) for more model details.

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. Model-predicted visitor use was compared to intended use and verified that 1000 stochastic replicates was 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. It incorporates the additional visitor use from trips originating at trailheads outside the park as well. 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 to be no zone exceeding capacity on any given day in more than 30 percent 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.

RESULTS

Sample Characteristics and Analysis of Non-Response Bias

The 14,497 wilderness trips taken during the 1 May to 30 September time window accounted for 105,715 intended visitor-nights in the Yosemite wilderness. Mean party size was 2.92 (standard deviation = 2.30), with a median of 2 and a maximum of 15. Mean intended trip duration in the Yosemite wilderness was 2.49 nights (standard deviation 1.98), with a median of 2 and a maximum of 54. Usable surveys were received from 1123 out of 14,497 or 7.75 percent of all parties that began their trip in the 1 May to 30 September window, and these surveys accounted for 9511 intended visitor-nights or 9.00 percent of the 105,715 intended visitor-nights in the Yosemite wilderness during the study period.

The proportion of the non-respondent sample that deviated temporally was 35 out of 75 = 0.4667, and the proportion of the respondent sample that deviated temporally was 417 out of 1123 = 0.3722. A two-sample proportion test indicated that this difference was not significant ($z = 1.36$, $P = 0.111$). A Kolmogorov-Smirnov test showed that the distribution of temporal deviations was not significantly different between respondents and non-respondents ($D = 0.0825$, $P = 0.7425$). A Mann-Whitney test showed that there was no significant difference in median deviation between respondents and non-respondents ($W = 41042$, $P = 0.6701$). Therefore, there is no evidence that non-respondents behaved differently with respect to temporal deviations than survey respondents. It is possible that non-respondents could have displayed different patterns in spatial deviation than respondent, but this is unknowable without completed surveys. The lack of difference in temporal deviations and the high correlation between temporal and spatial deviation suggests that the probability of difference in spatial deviation is low. The sample has little if any non-response bias in respect to deviations from intended itinerary.

<u>Spatial and Temporal Deviations</u>

Temporal deviations are defined as the difference between actual and intended number of nights spent in the Yosemite Wilderness. Deviations between actual and intended number of nights spent outside of the park or of total trip duration, including nights on the same trip spent both within and outside of the park were not analyzed. Henceforth, the term "trip duration" refers to the number of nights the party spent or intended to spend on their Yosemite wilderness trip, regardless of whether their trip included nights spent elsewhere. A spatial deviation refers to any difference between the actual wilderness travel zone in which a party camped and the zones in which the party intended to, including difference in temporal order. Deviations, both temporal and spatial were determined and evaluated by comparison of map diary surveys to permit records of sampled respondents (Table 1).

Including only respondents that took their wilderness trip (n = 1083), mean intended trip duration in the park was 2.71 days (standard deviation = 1.69), whereas actual trip duration was 2.35 days (standard deviation 1.45). Of these respondents, 385 (35.5 percent) deviated temporally. Trips were shortened by as much as 11 days and lengthened by as much as 9 days. The mean deviation was -1.02 days (standard deviation = 1.72, (Figure 7)). Linear regression showed that

Table 1. Summary of deviations reported by survey respondents.

Deviation type	Frequency	Percent
Spatial only	328	29.2%
Temporal only	102	9.0%
Spatial and temporal	283	25.2%
No wilderness entry	40	3.6%
No deviation	370	32.9%
Total	1123	99.9%

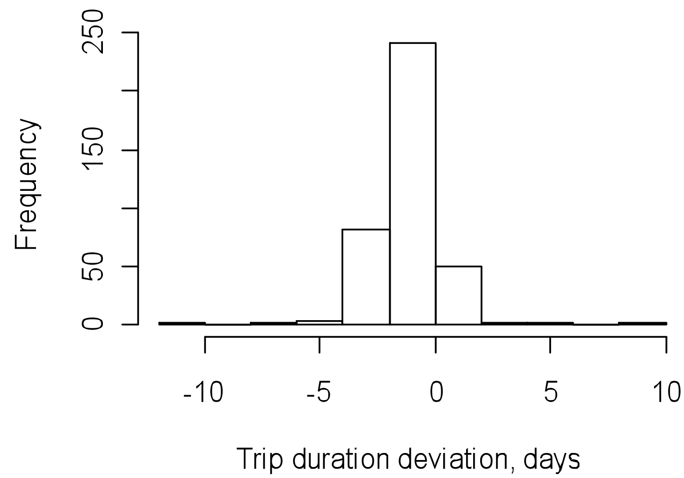

Figure 7. Histogram of trip duration deviations.[a]

[a]Negative values represent trips that were shorter than intended.

temporal deviation did not depend on the start date of the trip ($P = 0.833$) or on party size ($P = 0.492$) but that it did depend significantly on intended duration ($P < 0.001$). Regression of temporal deviation against intended trip duration alone yielded a regression equation of

$$Y = 0.513 – 0.423X,$$

where Y = deviation (days, negative = shorter trip) and X = intended trip duration ($R^2 = 0.303$, residual standard error = 1.218).

Additional analyses of spatial and temporal deviations among overnight wilderness visitors were performed. Spatial and temporal deviations were not independent of one another ($\chi^2 = 70.949$, df = 1, $P < 0.001$). Parties had a very strong tendency to either deviate both spatially and temporally or to not deviate at all. The odds of deviating spatially were 3.1 times greater if the party deviated temporally than if it did not deviate temporally. Logistic regression was used to analyze the probability that a party would make any type of deviation, again using only the 1083 sampled parties that actually entered the park. Logistic regression showed that the probability of deviating spatially or temporally depended significantly on party size ($P = 0.00171$), and intended trip duration ($P < 0.001$). The odds that a party would deviate from its intended itinerary decreased by a factor of 0.889 for every additional party member and increased by a factor of 2.42 per additional day of intended trip duration. The logistic regression model was

$$\text{Probability of deviation} = 1 / [1 + \exp (1.08 + 0.171p – 0.884X)]$$

where p = party size and X = intended trip duration (nights). Model residual deviance was 1162.0 (df = 1082), compared to a null deviance of 1390.8 (df = 1082).

Intended Trip Duration Adjustment

The primary reason to assess deviation from intended itineraries was to apply an adjustment to the intended itineraries in the Yosemite wilderness permit database. The adjustment allowed for a more accurate estimate of visitor use, based not on intended trip duration but on actual duration. Because the linear regression model presented above applies only to trips that deviated temporally, it explains only 30 percent of the variability in trip duration and does not include parties that obtained a permit but did not even enter the park. Linear regression of actual trip duration as a function of trip start date, party size, and intended trip duration was performed using all 1123 surveys. Actual trip duration did not depend significantly on trip start date ($P = 0.786$), so this predictor was eliminated from the model. Actual trip duration depended significantly on party size ($P = 0.000276$) and intended trip duration ($P < 0.001$). The regression equation was

$$\text{Actual duration} = 0.270 + 0.0433p + 0.695X$$

where p = party size and X = intended trip duration ($R^2 = 0.622$, residual standard error = 0.927, df = 1120).

This equation was applied to the 14,497 parties that started trips in the study period to compute the expected number of nights each party spent in the wilderness as a function of party size and intended trip duration. The calculated expected trip duration was then multiplied by the party size to estimate total visitor use and summed over these 14,497 parties to obtain an estimate of total visitor use attributable to these parties. This estimate was 93,795 visitor-nights, 10.8 percent lower than intended use. The 95 percent confidence interval around this estimate was 93,975 ± 818 = 93,975 ± 0.87 percent. This estimate includes a few visitor-nights spent after 30 September by parties that started trips late in September.

Analysis of Simulated Visitor Use and User Capacities

The model produces detailed visitor use tables in a form very similar to the park maintained wilderness permit database that can be queried and analyzed by NPS resource managers with database management or spreadsheet software programs. For the purposes of this paper, I present graphic displays to facilitate interpretation of the findings. For all scenarios there are five possible output matrices that summarize the results of 1000 simulations: an average zone percent capacity matrix, an average percent of trailhead zonal contribution matrix, and matrices of the frequencies zone use exceeds 100, 110, or 150 percent of capacity for each zone on every night.

Validation Scenario

The distribution of party sizes and trip durations resulting from the *Validation Scenario* were compared with the permit database. One season-long model simulation was used to generate these parties. Sample size was 14,497 parties for both the model and permit database. A Kolmogorov-Smirnov test was used to test for equality of distributions, and a Welch t test was used to compare means. For party size, there was no significant difference in either the distribution or the mean between the model and permit database. Relative frequency histograms showed very similar distributions for trailhead use in both the database and simulation trial.

For season-total use across all zones, the modeled 95 percent prediction interval was 103,941 ± 2245, and the observed intended use from the database was 105,715. 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"), the same type of analysis was performed, adjusted for multiple comparisons over all 8721 zone-nights (57 zones x 153 nights), which includes the frontcountry backpacker camps and an "unspecified" zone code used for permit itineraries in which the intended camping zone for one or more nights was not specified. At 95 percent confidence for each zone-night, observed zone-night use is expected to fall outside the 95 percent prediction interval in fewer than 5 percent of the zone-nights. Observed intended use fell outside of the modeled 95 percent prediction interval in less than one percent of all zone-night combinations, indicating no significant difference in spatiotemporal use distributions between the model and permit database.

Baseline Scenario

Mean use predicted by the *Baseline Scenario* was 89,977 visitor nights per year, with a 95 percent confidence interval of 89,977 ± 55. The 95 percent prediction interval was 89,977 ± 1,743, which did not overlap with the 95 percent confidence interval for deviation-adjusted use produced by applying the temporal deviation regression model to the permit database. However, as mentioned above, the estimate produced by that method included visitor nights spent after 30 September, whereas the model estimate does not include these nights. Subtracting the roughly 200 extra visitor nights included in the estimate produced by adjusting the database figures results in overlap of the two intervals, again providing evidence that the observed use belongs to the model-predicted population.

Trips originating outside of Yosemite accounted for a mean of 10,010 additional visitor-nights during the study period, with a 95 percent confidence interval 10,010 ± 23. The total, model-estimated use during the study period from all sources was 100,007 visitor-nights per year, with a 95 percent confidence interval of 100,007 ± 61. Of that use, an estimated 2272 visitor-nights per year (95 percent confidence interval 2227 ± 17) occurred in the backpacker camps.

The model outputs from the *Baseline Scenario* show visitor use levels by zone by night relative to the capacity of each zone. The average zone percent capacity matrix (Figure 8) shows four zones with at least one night when mean visitor use exceeds 90 percent of capacity (rows with yellow cells) and three zones with at least one night when mean use exceeds capacity (rows with orange cells). Zones 66, 81, and 67 (Figure 9) with 59, 3, and 1 night(s) respectively, are the only zones with nights when mean use exceeds capacity (orange or red cells). The same zones (66, 81, 67) have the most nights when use has a greater than 50 percent probability of exceeding capacity (Figure 10). It is worth noting that while on average a zone may be under capacity, in any given simulation it has a possibility of exceeding capacity (Figure 10), and in some zones on some nights, use may exceed 110 or 150 percent capacity (Figures 11 and 12). The simulation results from 1000 season replications indicate that using the 2010 trailhead quota scheme, and with current visitor flow conditions, there are 28 nights on which the Sunrise Creek zone (66) may receive

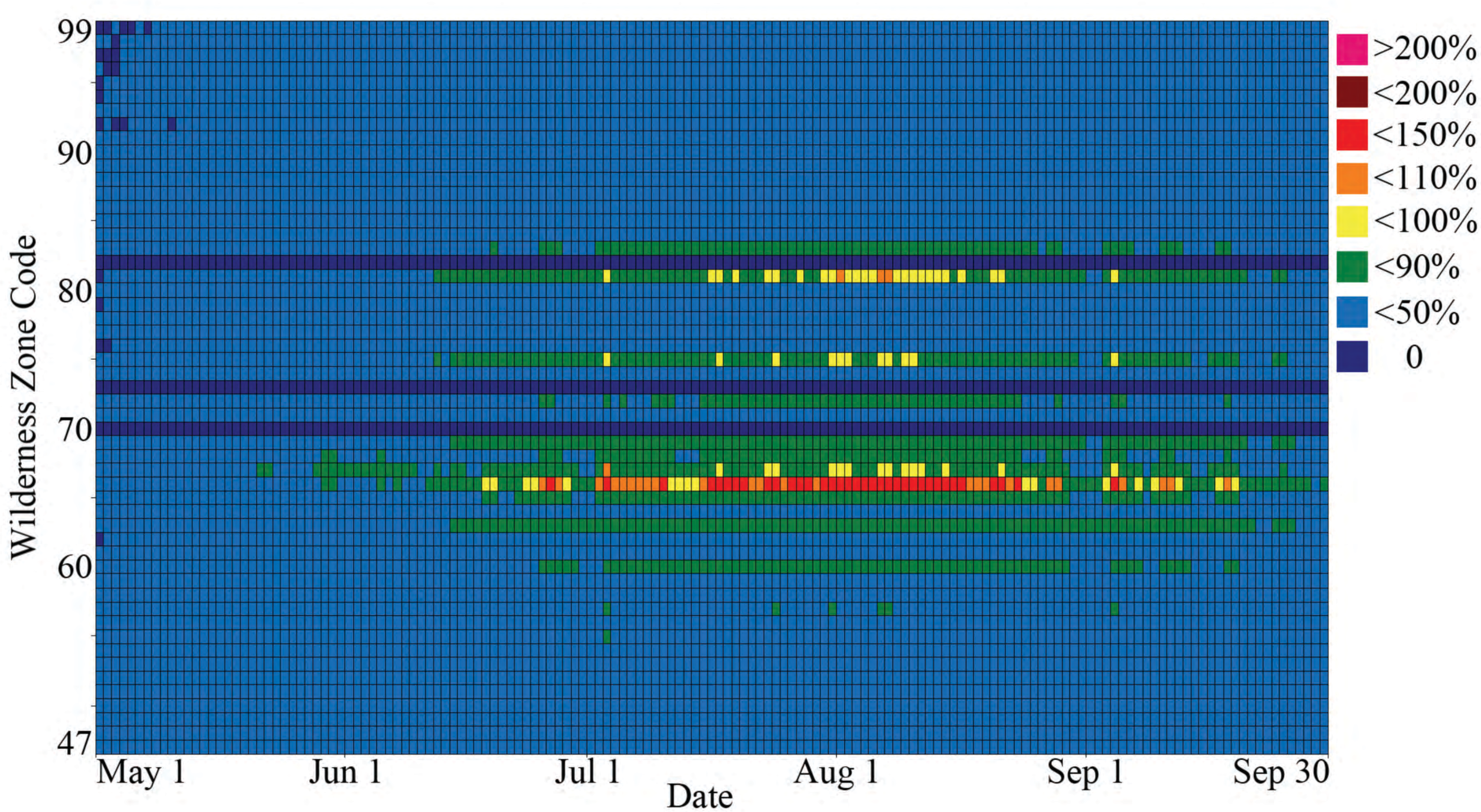

Figure 8. Average zone percent capacity for Baseline Scenario.

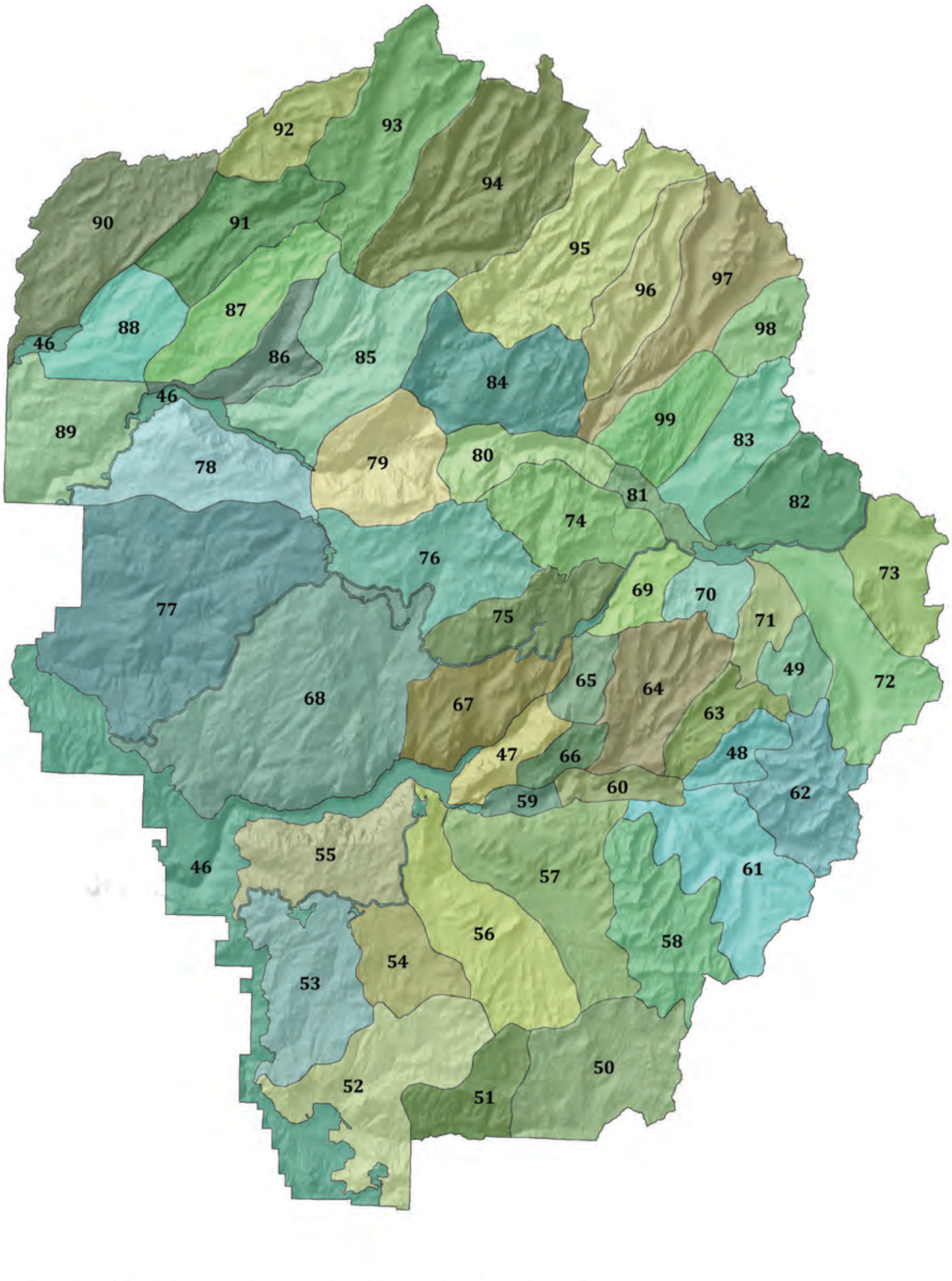

Figure 9. Management zones, Yosemite National Park.

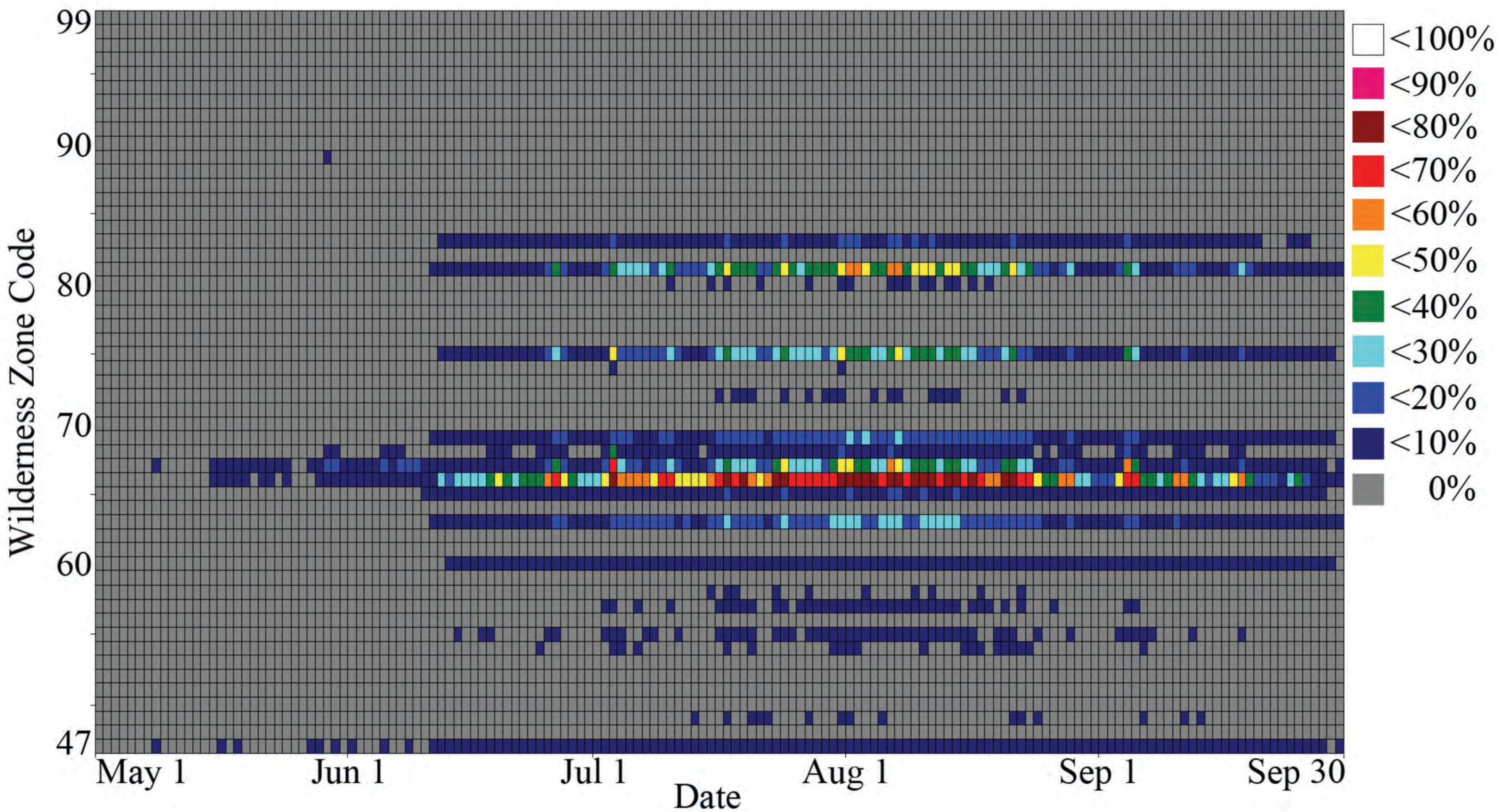

Figure 10. Probability of use exceeding capacity over 1000 simulations of the Baseline Scenario.

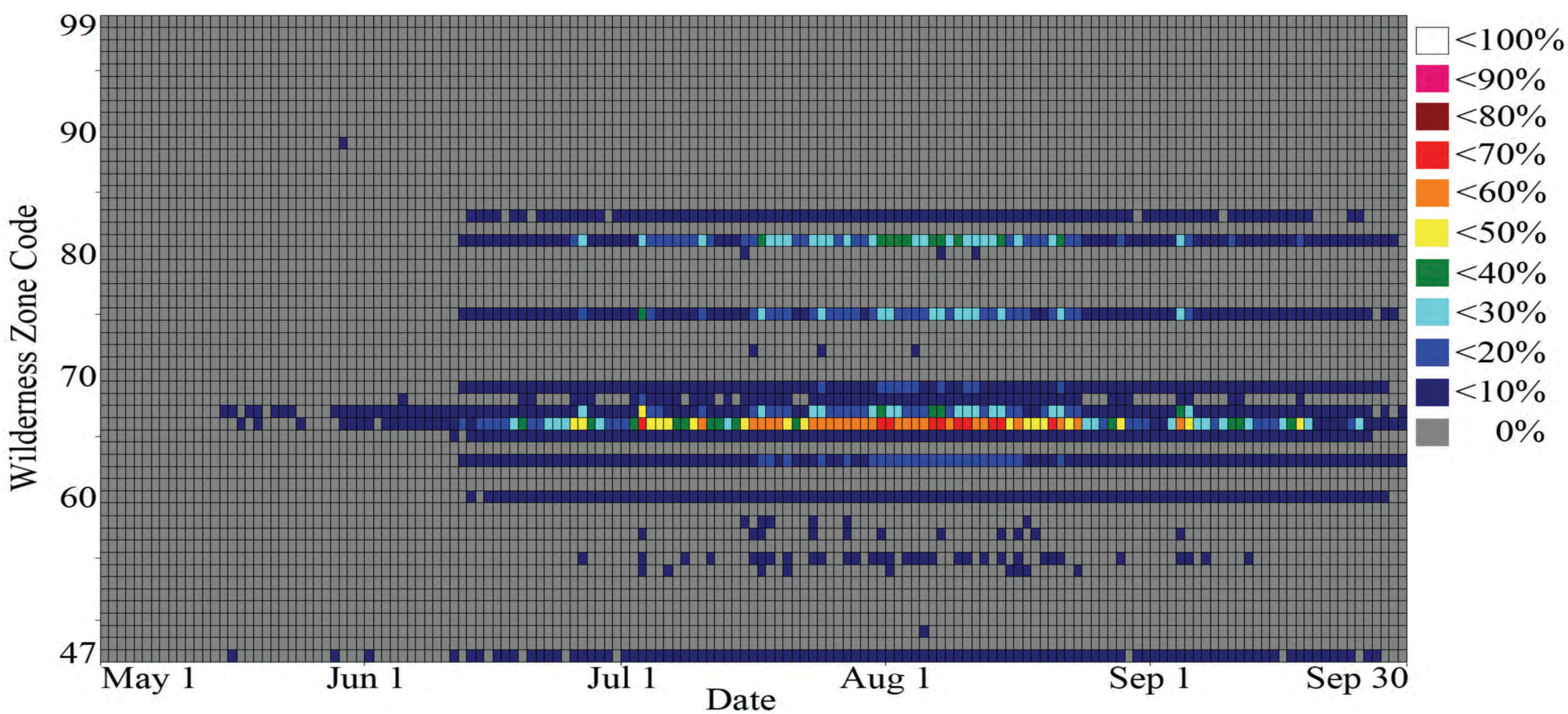

Figure 11. Probability of use exceeding 110% of capacity over 1000 simulations of the Baseline Scenario

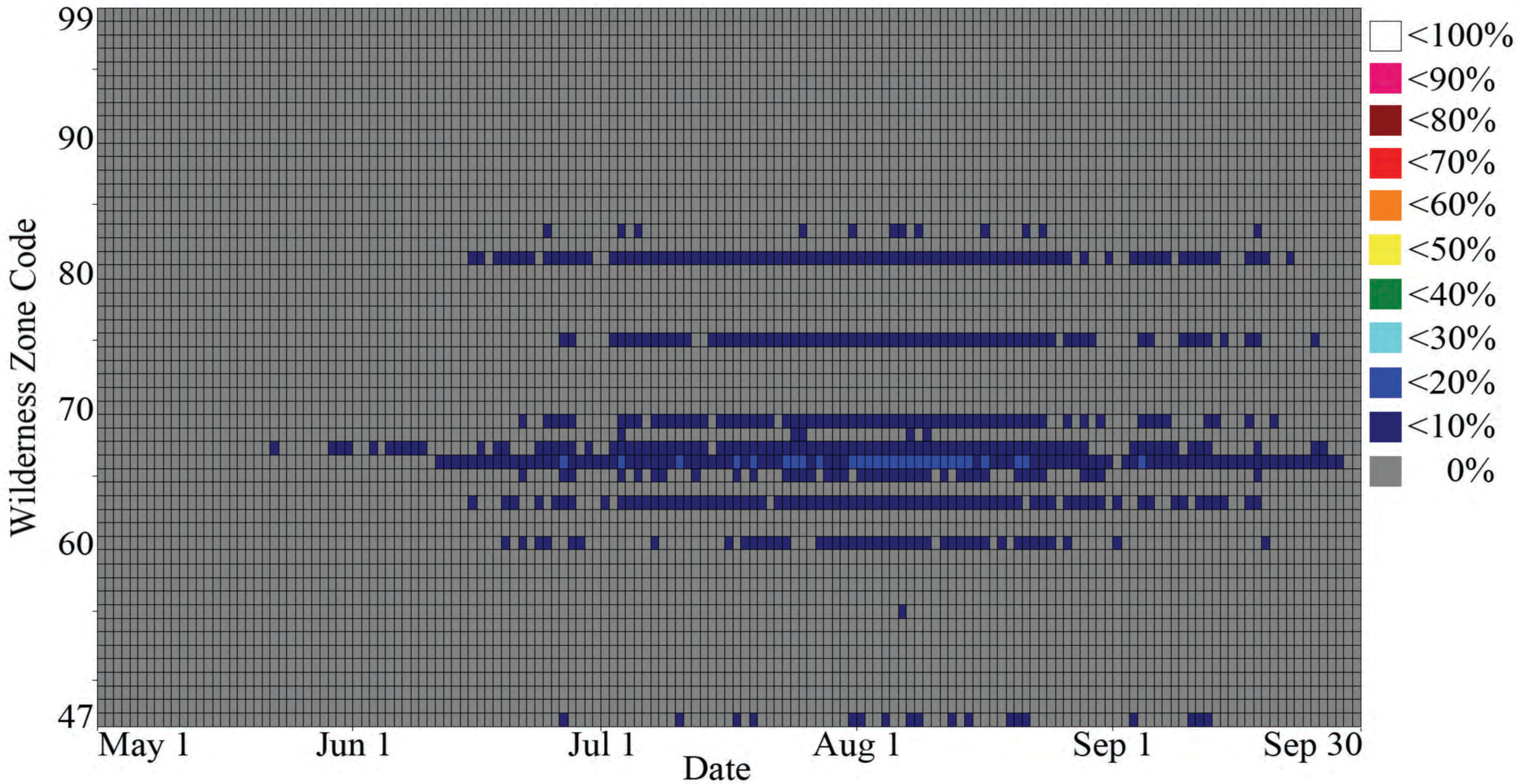

Figure 12. Probability of use exceeding 150% of capacity over 1000 simulations of the Baseline Scenario.

use exceeding 150 percent of capacity in one out of every ten years (Figure 12). Visitor use is greatest in terms of average park-wide zone capacity use on 3, 24, 31 July; 6, 7 August; and 4 September when four zones receive use exceeding 90 percent of their capacities and Zone 66 receives use exceeding 110 percent of capacity. Figure 13 shows the contribution of visitor use to each zone by trailhead of origin.

Reduced Use Scenario

The model outputs from the *Reduced Use Scenario* indicate that by reducing the quotas of trailheads contributing most to zones with nights exceeding capacity (Figure 13 and Table 2), resultant visitor use is such that on average no zone exceeds capacity (Figure 14), and overnight use in any zone on any given night exceeds capacity in no more than 30 percent of all simulations (Figure 15). The frequency with which zones exceed 110 or 150 percent of capacity is no greater than 10 percent over the 1000 simulations (Figures 16 and 17).

Trailhead Reassignment Scenario

With trailhead quotas set at *Reduced Use Scenario* levels and total visitor use maintained at Baseline Scenario levels parties distributed to trailheads with full quotas were reassigned to the least used trailheads. Resultant visitor use in this scenario was similar to that of the *Reduced Use Scenario*. There were no nights in any zone on which the mean use exceeded capacity (Figure 18). There were a few zone-nights in which it is probable use may exceed capacity but none in more than 50 percent of simulations (Figure 19). In addition, a few zone-nights may receive

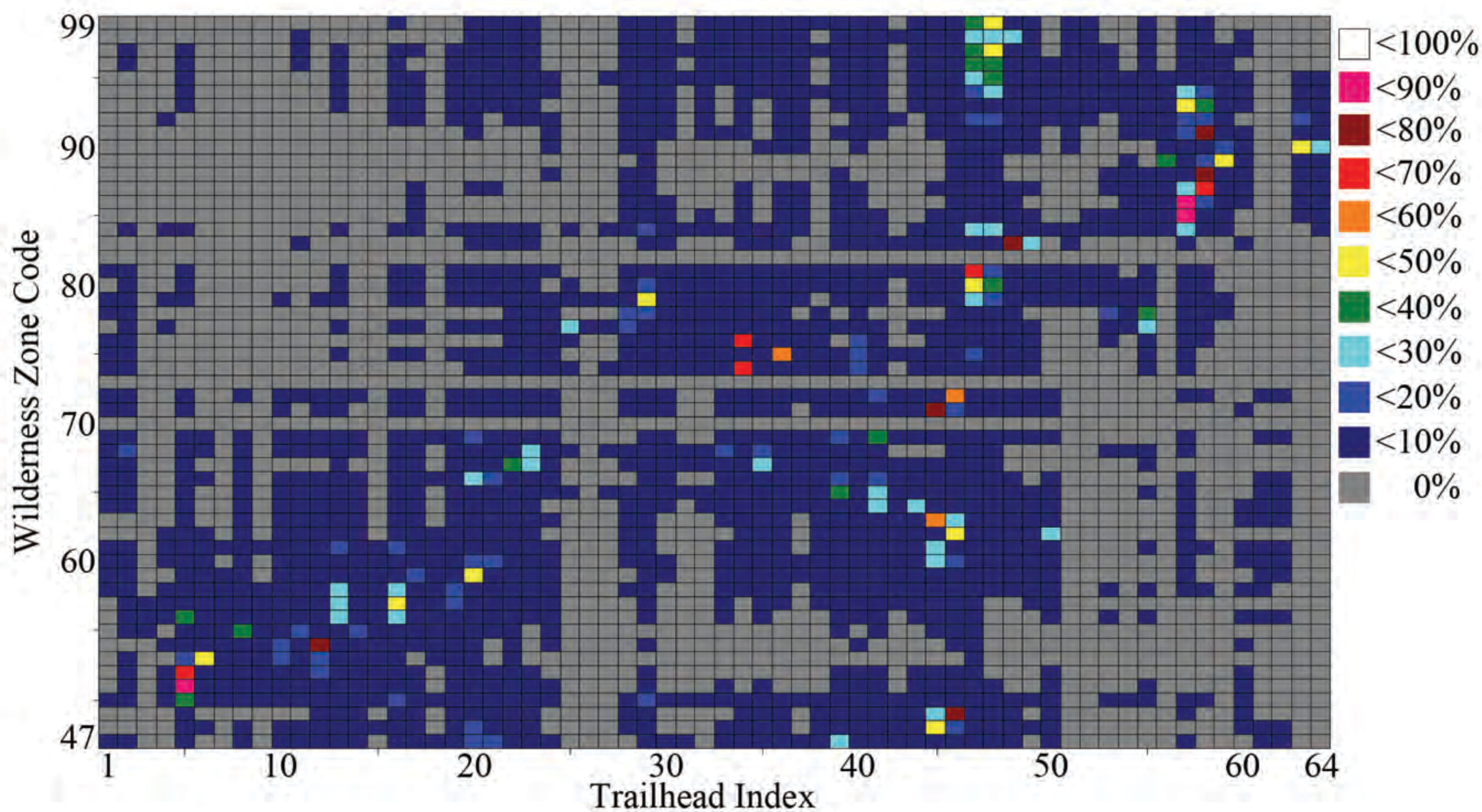

Figure 13. Trailhead contribution to zone use for Baseline Scenario.

Table 2. Trailhead quota adjustments for the Reduced Use Scenario.

Trailhead	Baseline Quota	Adjusted Quota
Happy Isles to Little Yosemite Valley	30	10
Happy Isles to Sunrise (Pass-Through)	10	5
Mirror Lake to Snow Creek	25	18
Yosemite Falls	25	18
Porcupine Creek	25	18
Sunrise Lakes	20	8
Cathedral Lakes	25	10
Lyell Canyon	40	30
Glen Aulin	35	22

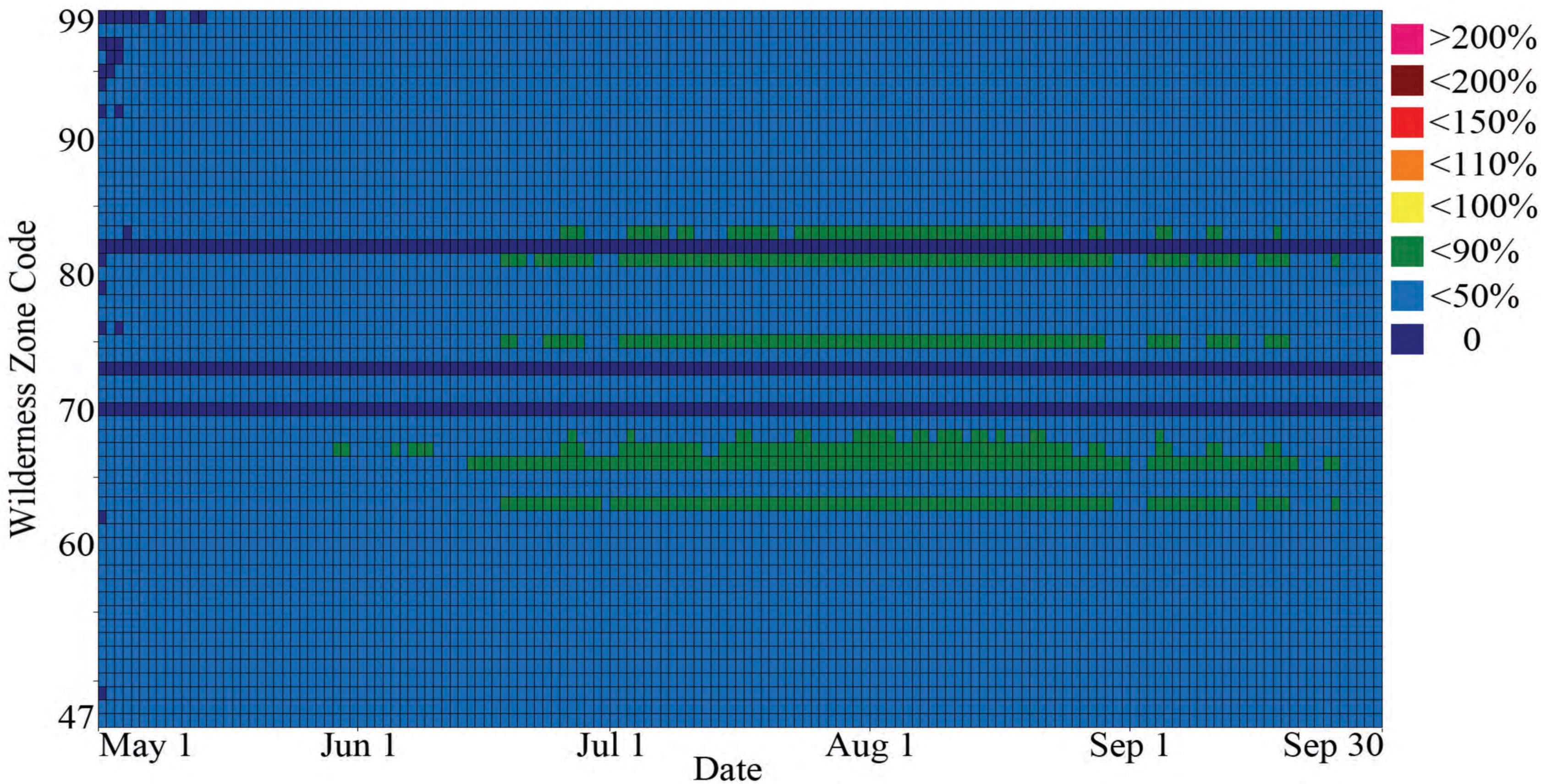

Figure 14. Average zone percent capacity for the Reduced Use Scenario.

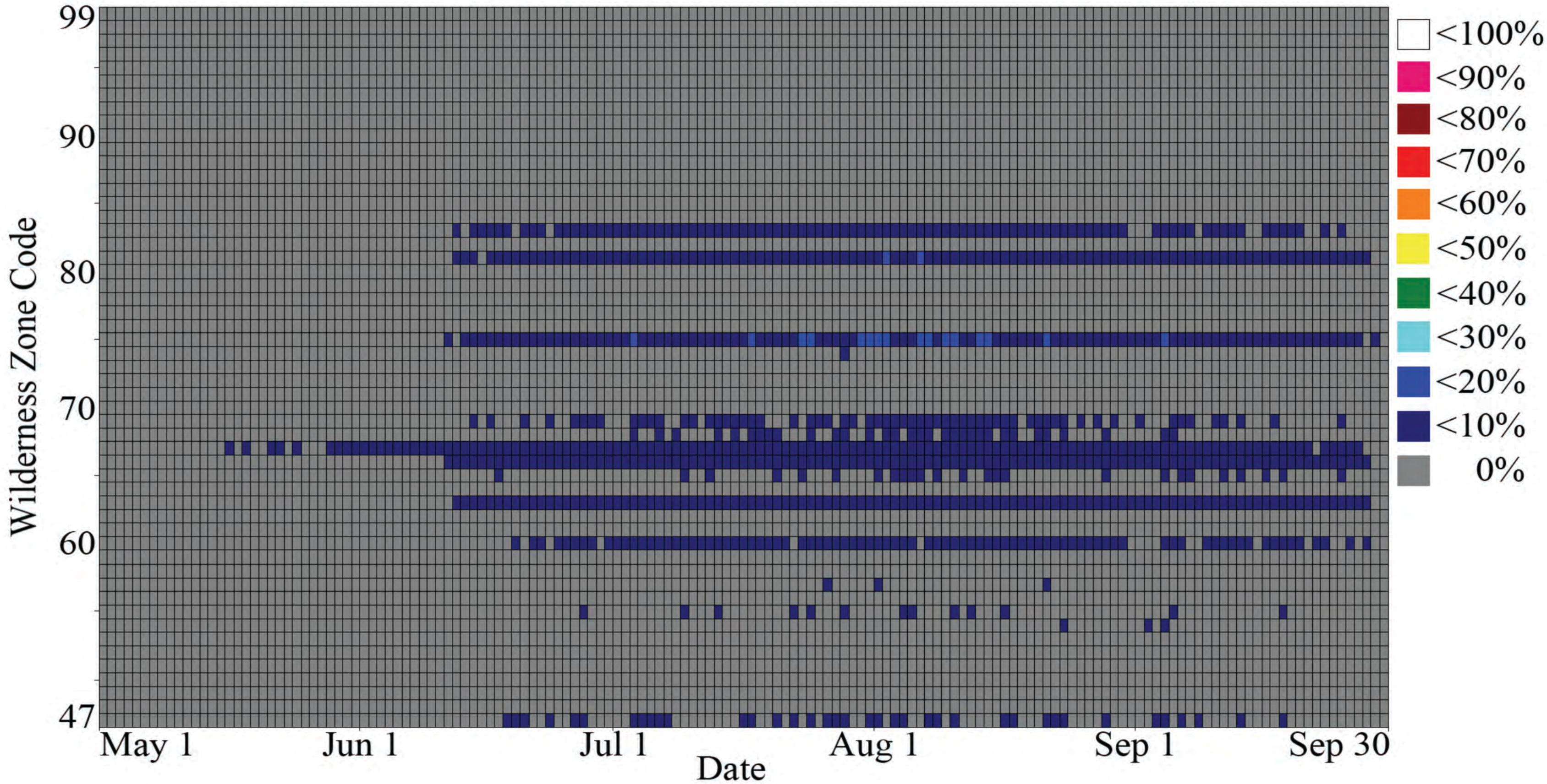

Figure 15. Probability of use exceeding capacity over 1000 simulations of the Reduced Use Scenario.

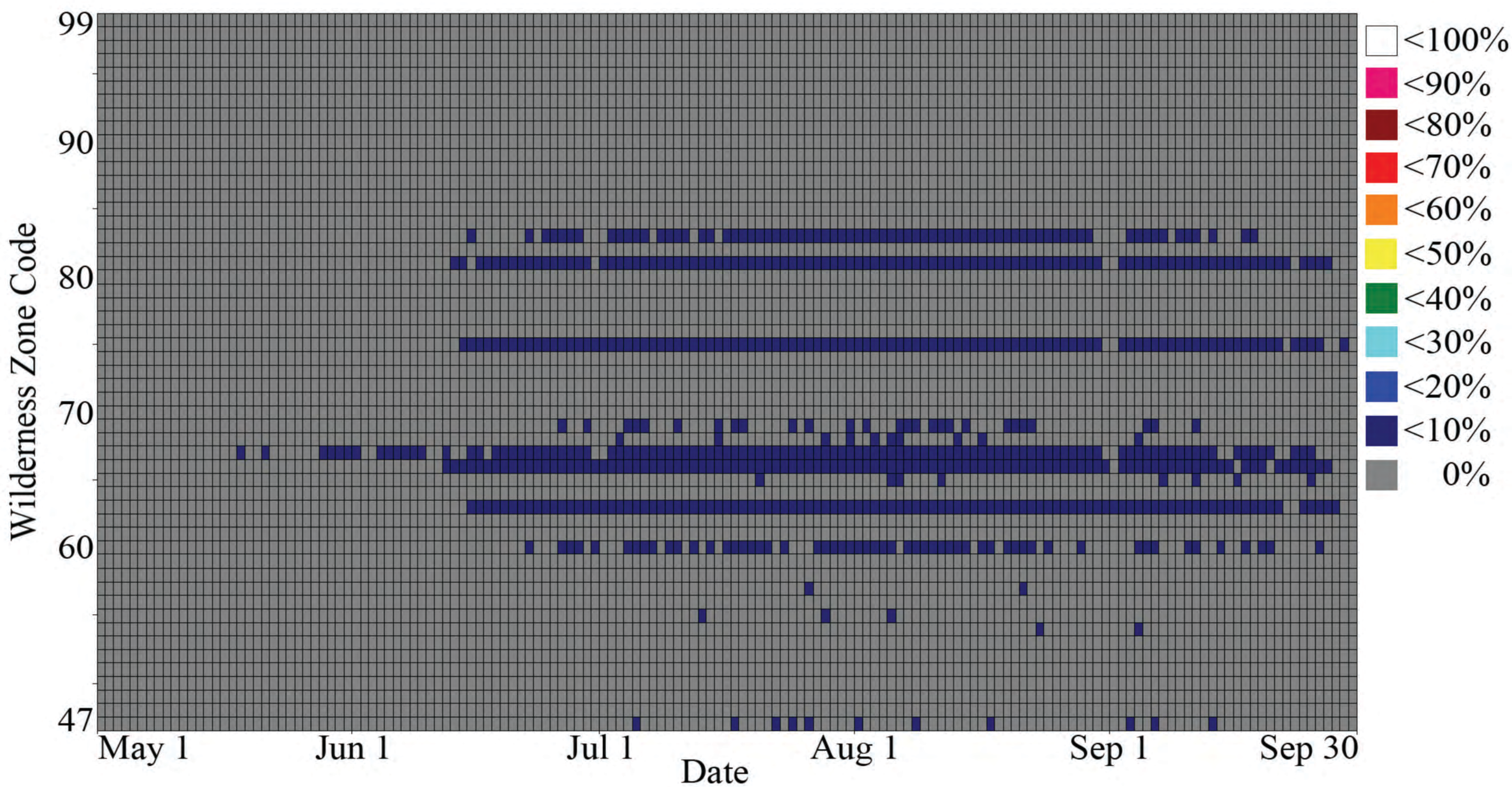

Figure 16. Probability of use exceeding 110% of capacity over 1000 simulations of the Reduced Use Scenario.

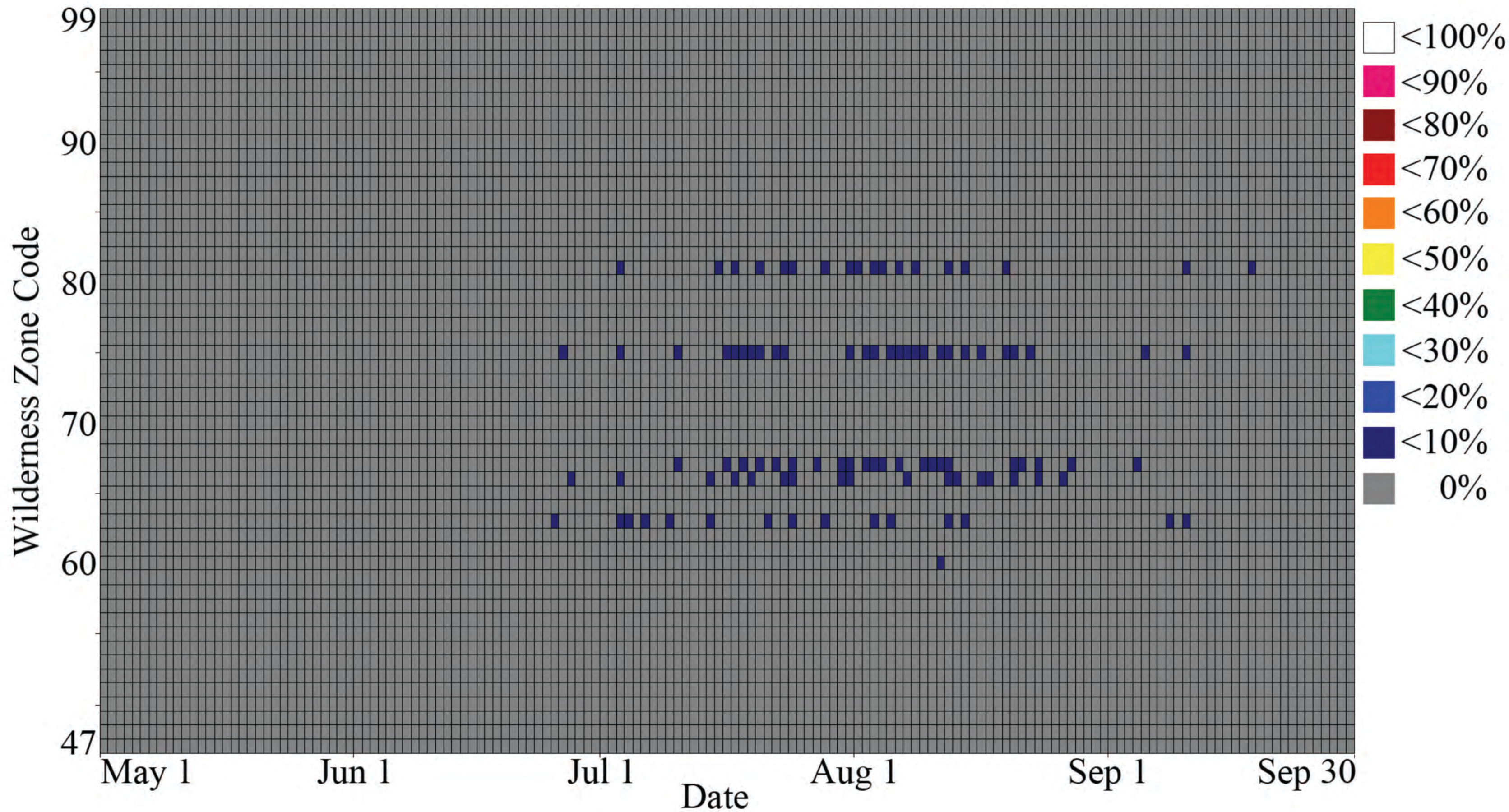

Figure 17. Probability of use exceeding 150% of capacity over 1000 simulations of the Reduced Use Scenario.

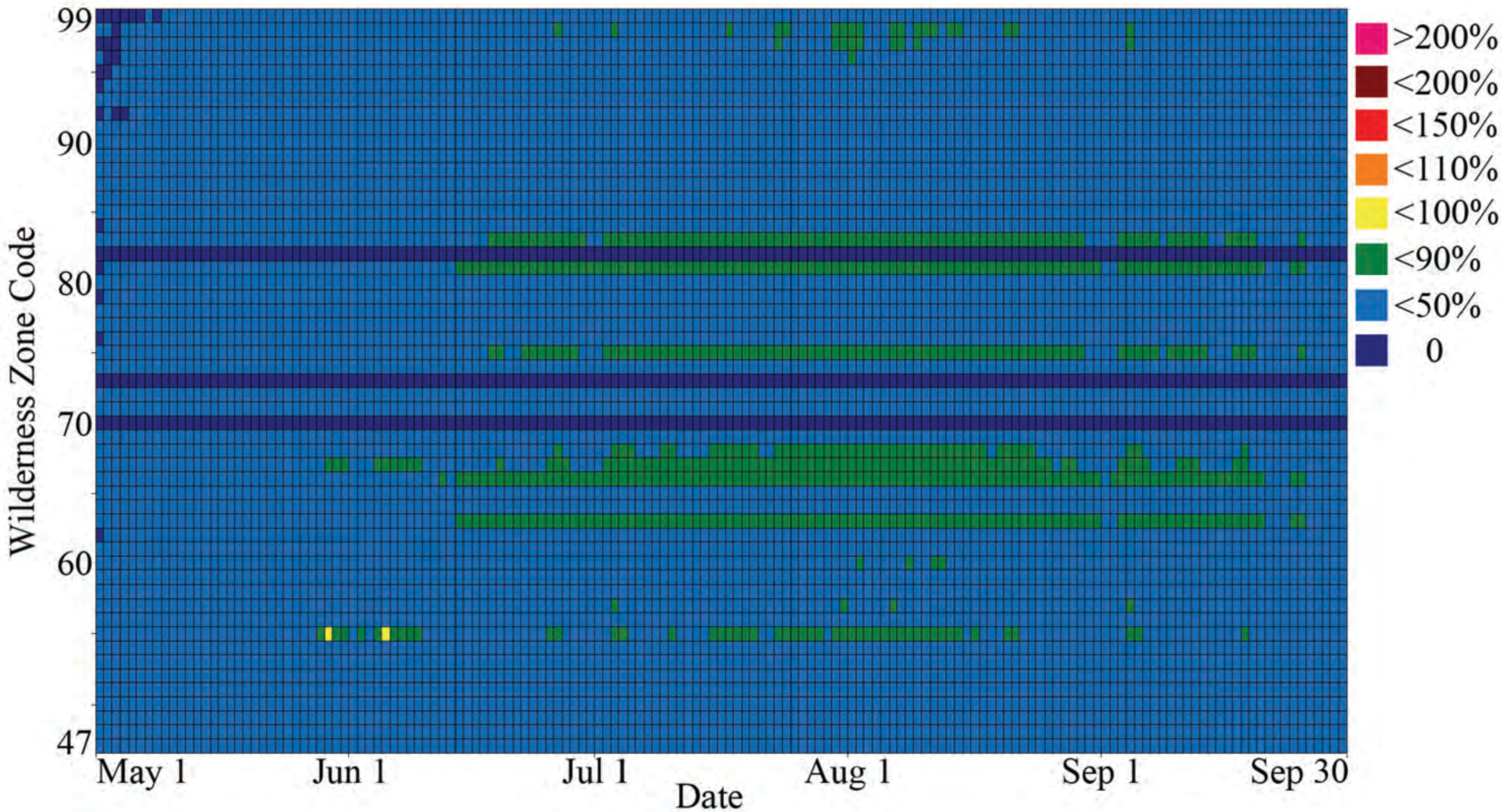

Figure 18. Average zone percent capacity for the Trailhead Reassignment Scenario.

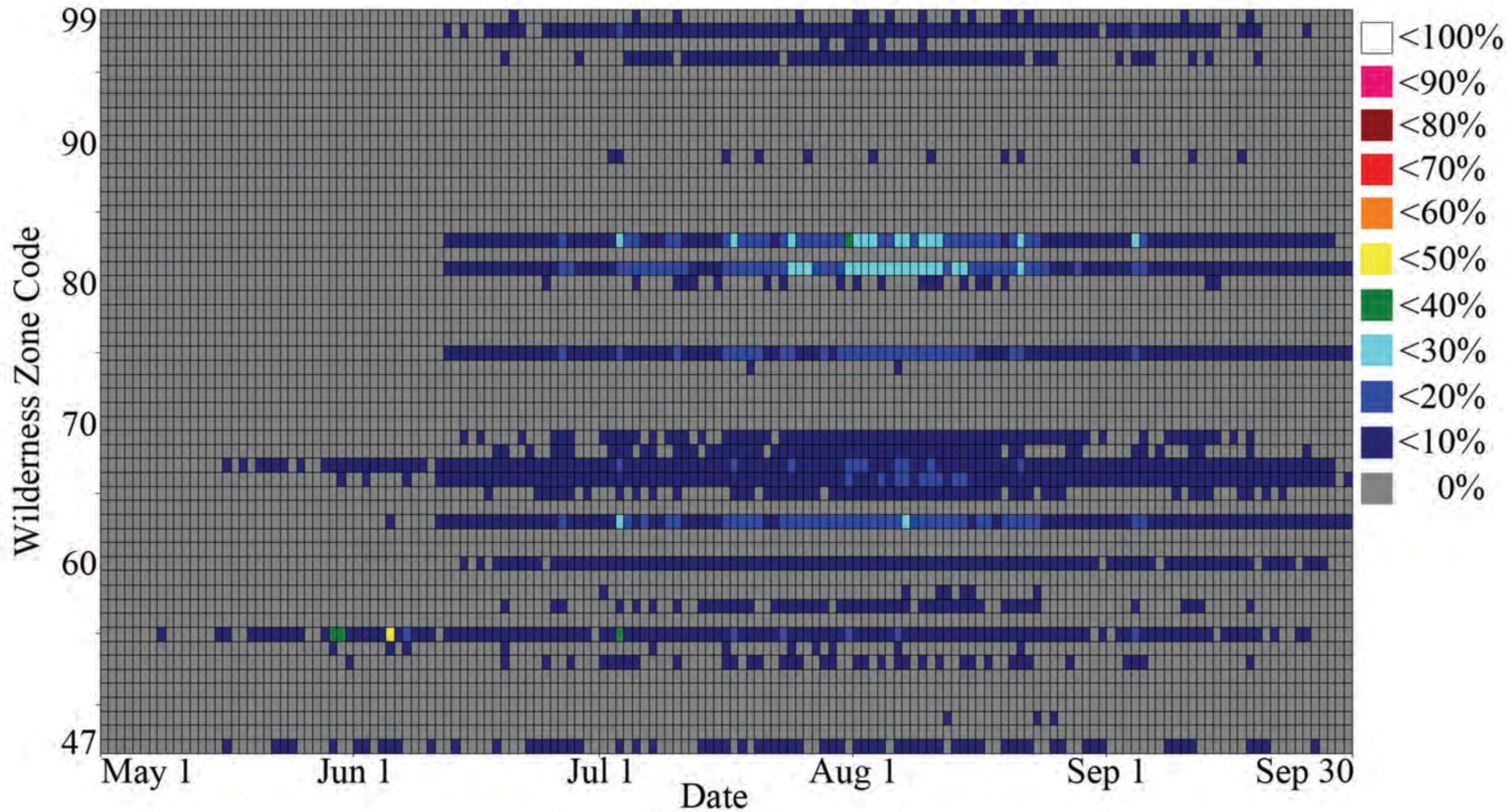

Figure 19. Probability of use exceeding capacity over 1000 simulations of the Trailhead Reassignment Scenario.

use exceeding 110 percent capacity but none is more than 30 percent of simulations (Figure 20). This scenario has no nights in any zone when use exceeds 150 percent of capacity in more than 10 percent of the 1000 simulations (Figure 21). The trailhead contribution to zone use for this scenario is shown in Figure 22.

Maximum Use Scenario

With trailhead quotas set at baseline levels and visitation ramped up in the model so that every quota is met everyday at all trailheads the resulting visitation patterns are evident in the model output (Figures 23, 24, 25, 26). The zones receiving the most visitor use are 55, 67, and 68 (Figure 23). The predominant travel patterns are such that, despite maximum use conditions, visitor use in many zones does not on average, reach 50 percent of capacity (Figure 23) and many of those same lesser-used zones have no nights on which the model predicts any chance of capacities being exceeded (Figure 24). The results indicate a 100 percent probability that Zones 55 and 68 will receive use exceeding 110 and 150 percent of capacity in on nearly every night (Figures 25 and 26). 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 percent of total capacity at full trailhead quotas.

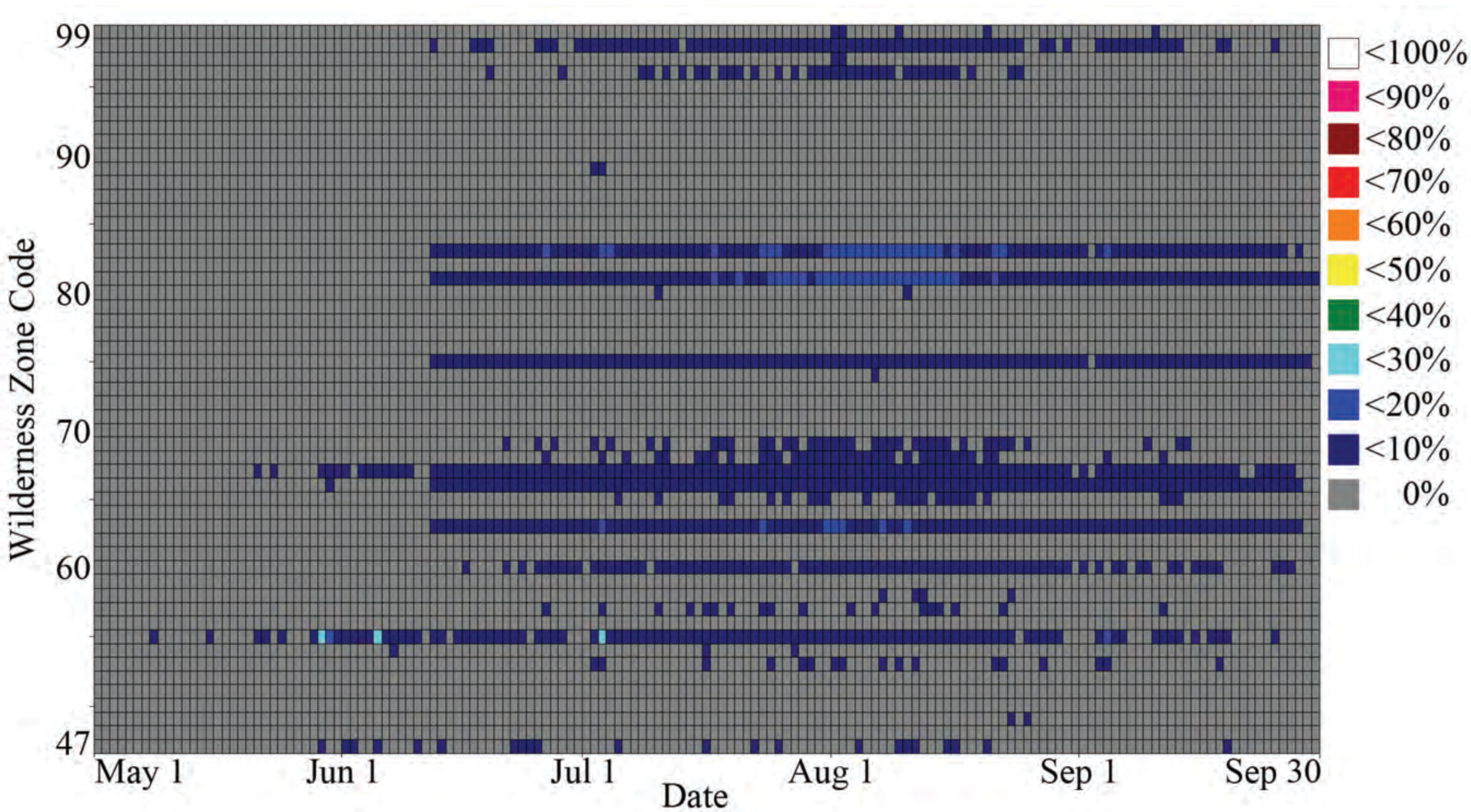

Figure 20. Probability of use exceeding 110% of capacity over 1000 simulations of the Trailhead Reassignment Scenario.

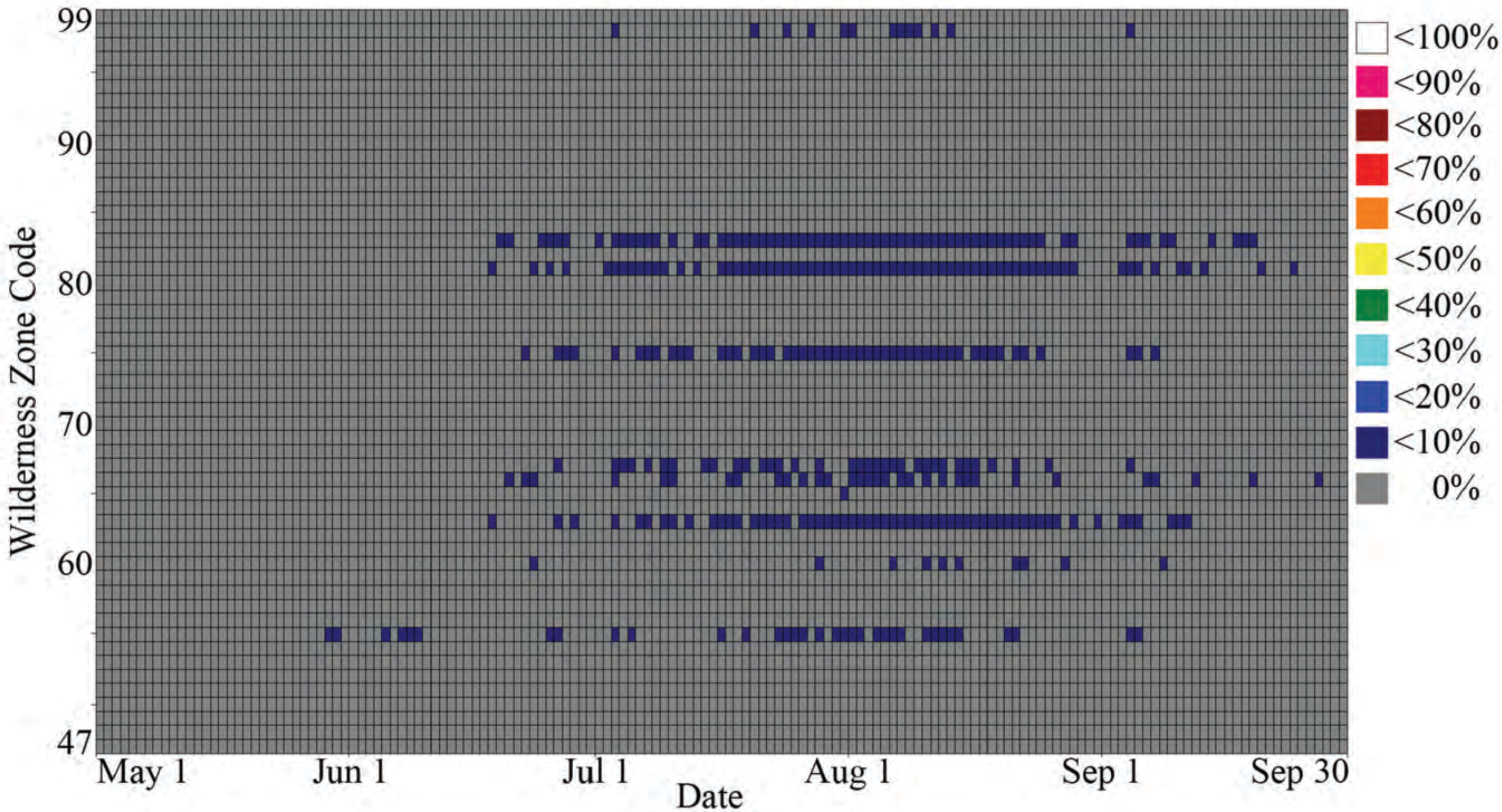

Figure 21: Probability of use exceeding 150% of capacity over 1000 simulations of the Trailhead Reassignment Scenario.

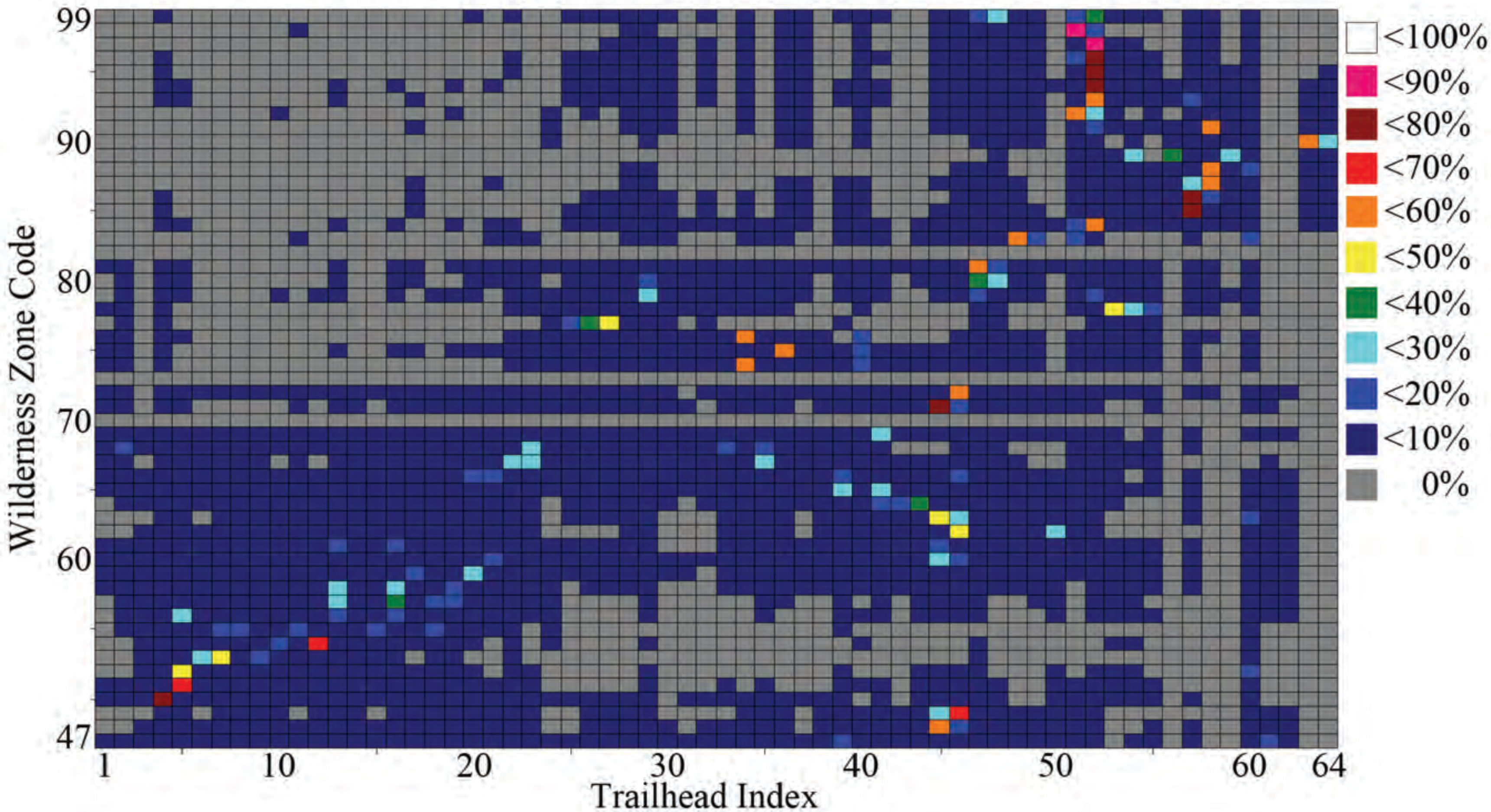

Figure 22. Trailhead contribution to zone use for Trailhead Reassignment Scenario.

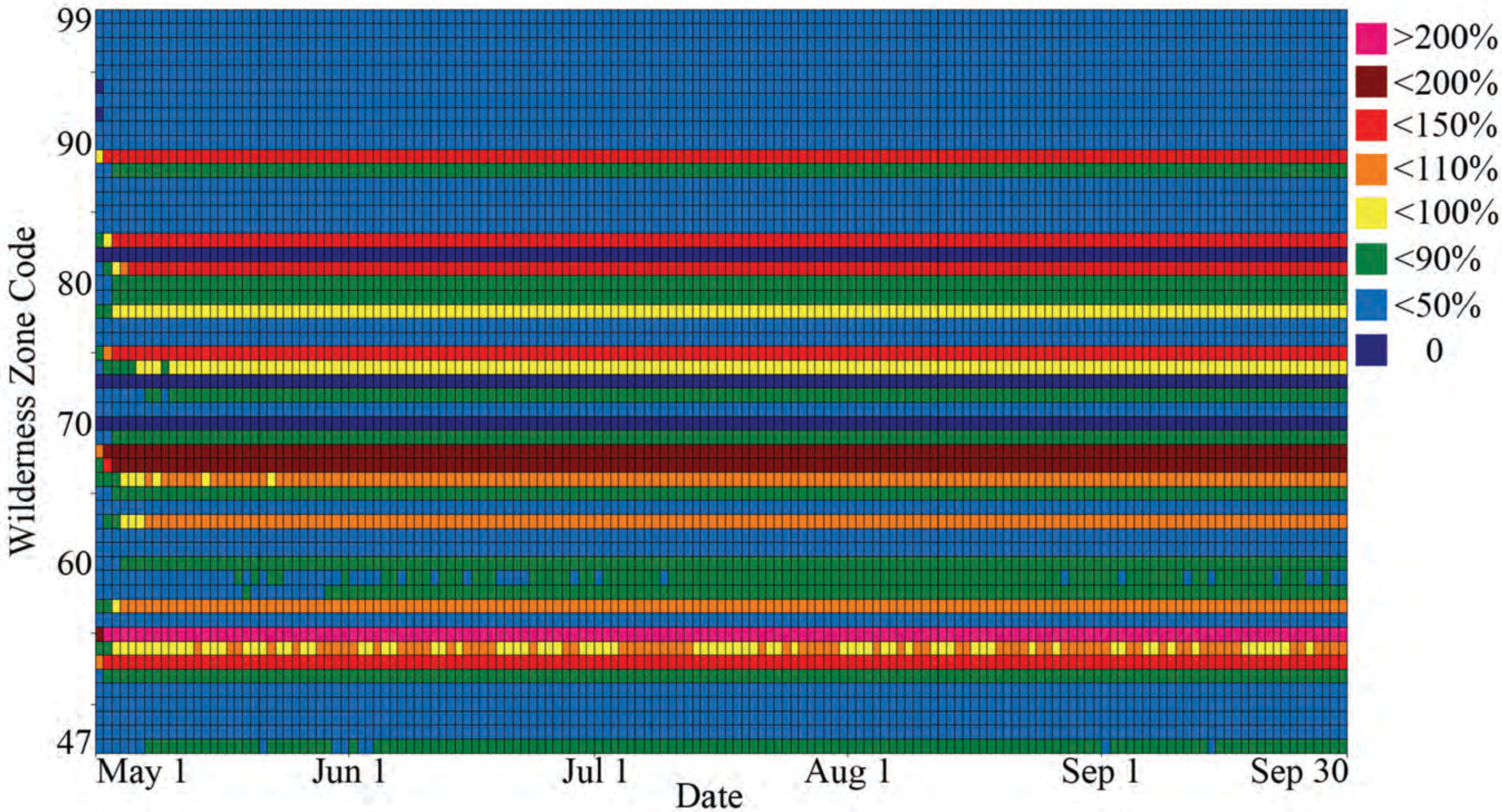

Figure 23. Average zone percent capacity for the Maximum Use Scenario.

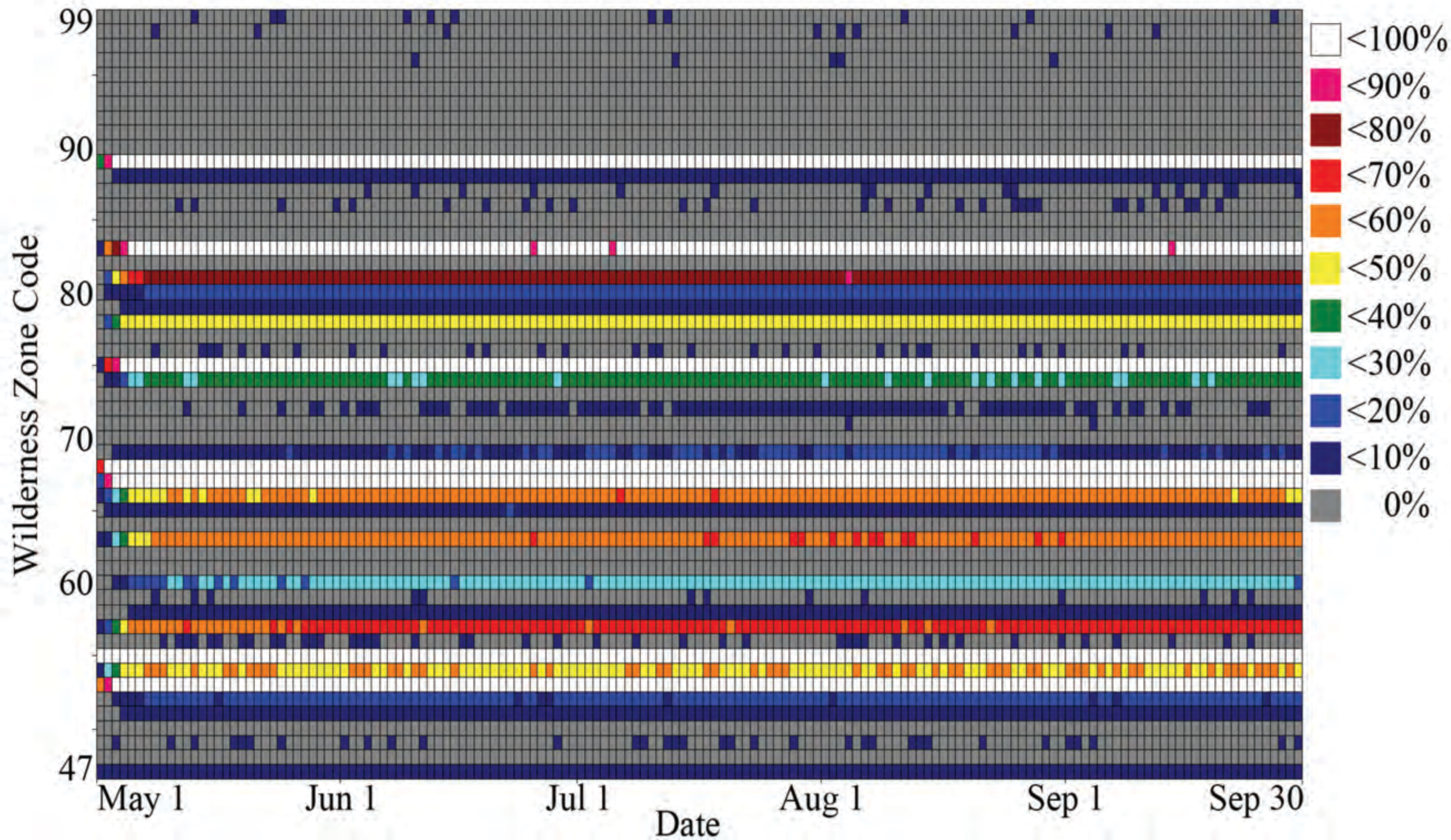

Figure 24. Probability of use exceeding capacity over 1000 simulations of the Maximum Use Scenario.

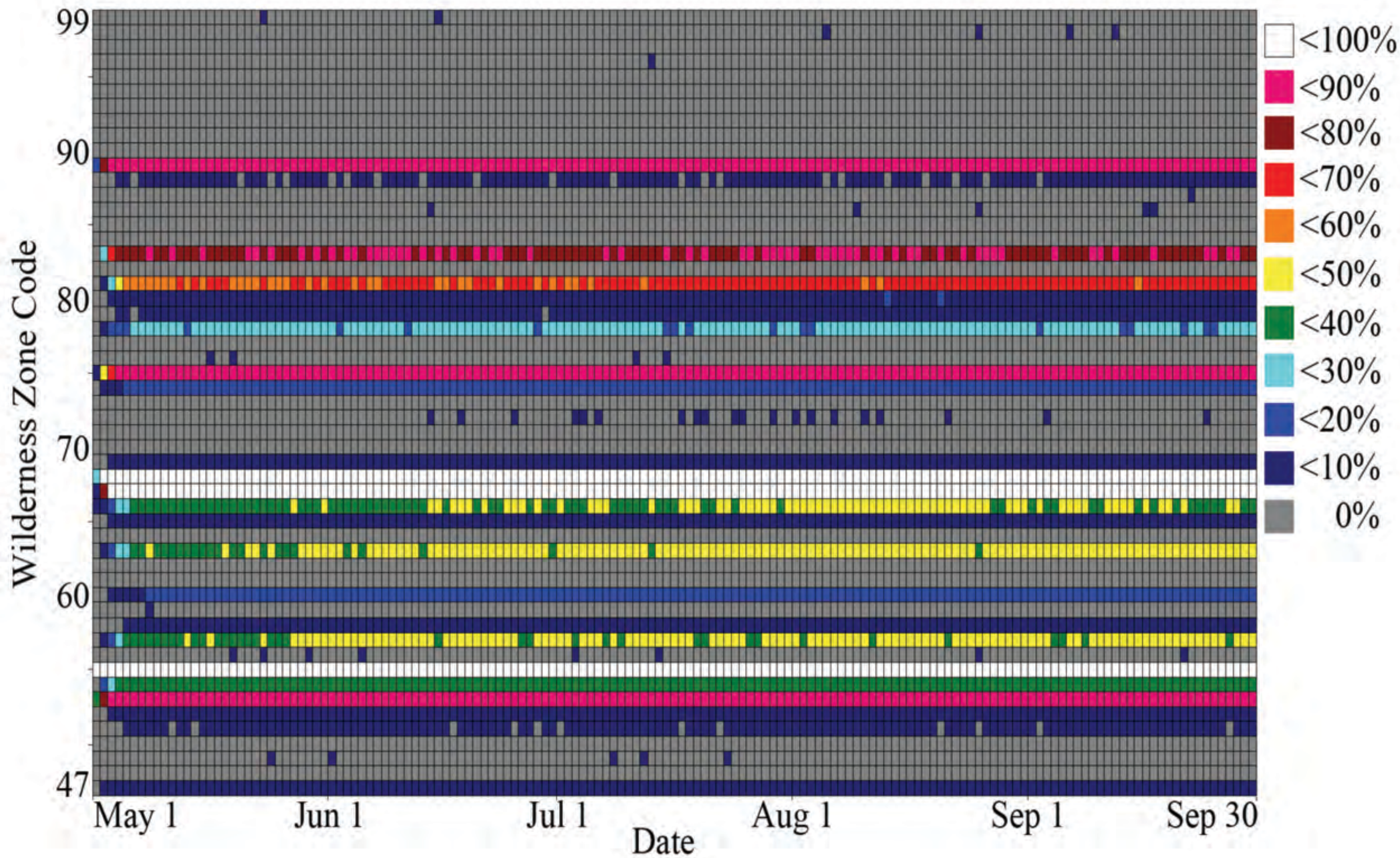

Figure 25. Probability of use exceeding 110% of capacity over 1000 simulations of the Maximum Use Scenario.

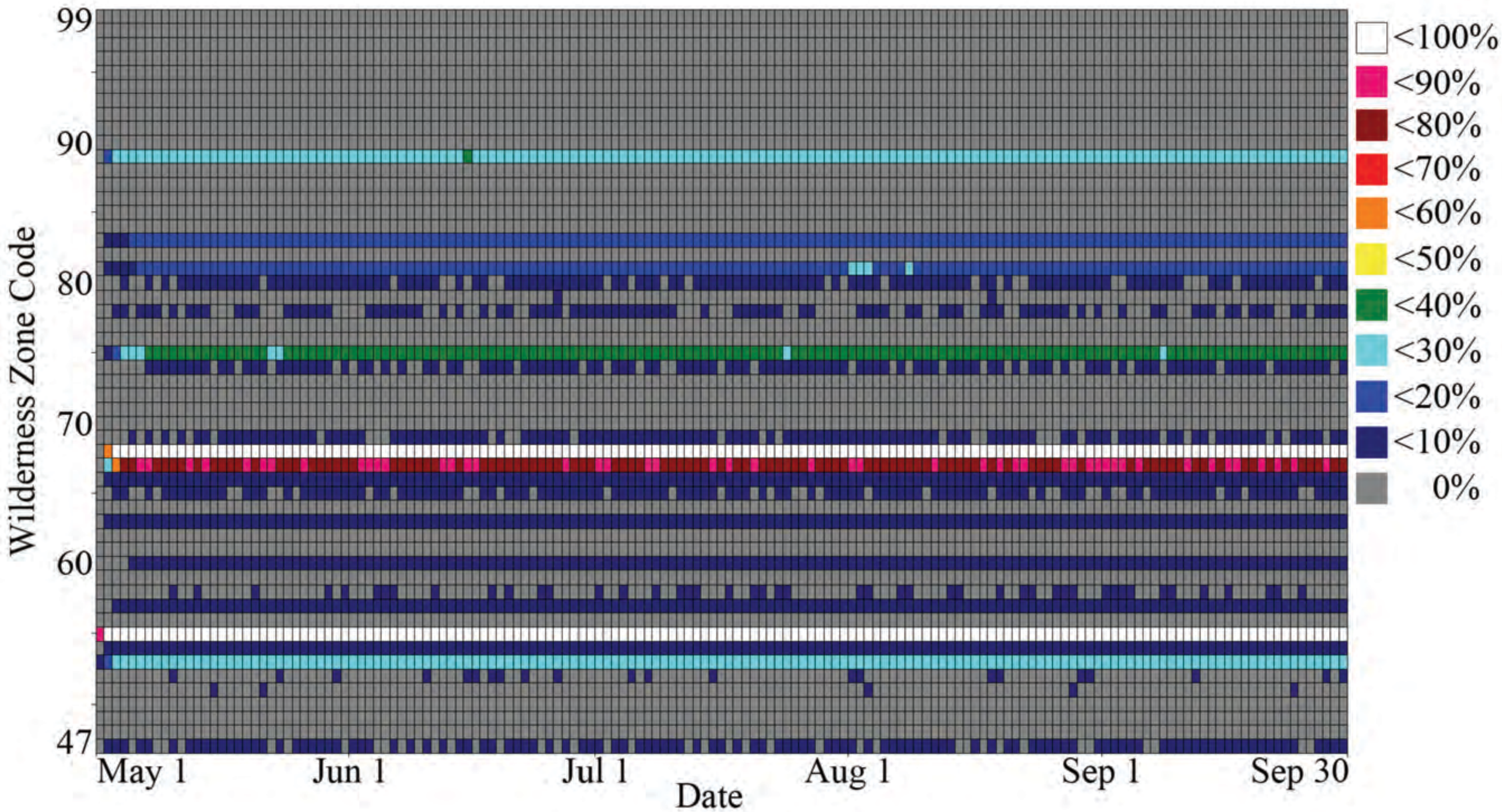

Figure 26. Probability of use exceeding 150% of capacity over 1000 simulations of the Maximum Use Scenario.

DISCUSSION

Comparison of Historical and Contemporary Data

This study is analogous to research conducted previously in Yosemite National Park. van Wagtendonk and Benedict (1980) surveyed 1088 backcountry users in 1976, 1977, and 1978. Because they did not contact parties that obtained permits but did not enter the backcountry, this category was removed from the 2010 data so that results could be directly compared (Table 3). A Chi-square test for independence showed that the distribution of deviation types differed between the 1970s and 2010 ($\chi^2 = 28.7$, df = 3, $P < 0.001$). The primary difference was that a greater proportion of parties reported spatial-only deviations in 2010 than in the 1970s. Correspondingly, a smaller fraction of parties reported temporal-only deviations in 2010. Post-hoc proportion tests with Bonferroni's correction for multiple comparisons ($\alpha = 0.05/3$, two-sided alternative) showed that there was no difference between the two datasets in the fraction of trips that did not deviate at all ($z = 1.71$, $P = 0.087$). However, there was a significantly smaller proportion of trips reporting some sort of temporal deviation in 2010 ($z = 2.48$, $P = 0.013$) and a significantly larger proportion of trips reporting some sort of spatial deviation in 2010 ($z = 3.85$, $P < 0.001$). This latter difference could be due to different ways of defining spatial deviations between the two studies.

This study was conducted, in part, based on the supposition that current wilderness visitor use consists of a larger number of shorter duration trips. Table 4 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 in size. These

Table 3. Comparison of sample trip deviations between 1970s[a] and 2010.

Deviation type	1970s	2010
Spatial only	226 (20.8%)	328 (30.3%)
Temporal only	154 (14.1%)	102 (9.4%)
Spatial and temporal	298 (27.4%)	283 (26.1%)
No deviation	410 (37.7%)	370 (34.2%)
Total	1088	1083

[a]Source: (van Wagtendonk and Benedict 1980)

Table 4. Yosemite Wilderness trip attributes, 1970s[a] and 2010.

	1972 - 1979	2010
Mean group size (persons)	3.2	2.9
Mean intended duration (nights)	2.9	2.5
Mean actual duration (nights)	2.7	2.1

[a]Source: (van Wagtendonk 1981)

findings support the recommendation made by van Wagtendonk and Benedict (1980) that managers monitor visitor travel patterns intermittently for changes.

Computer Simulation Modeling as a Planning Tool

The findings of this study and the simulation model allow the park a better, and more quantitative, understanding of existing conditions. The vastness of the wilderness resource, and its many access points limits the ability of managers to precisely monitor visitor use conditions, particularly the number of visitors camped overnight in any given wilderness zone. The model provides managers with reliable estimates of these hard to measure variables. The spatiotemporal model outputs allow managers to identify the place and time that use occurs, especially when and where there is concern that concentrated use could lead to conflicts among different user types or impacts to fragile ecological resources or wildlife habitat (Lawson 2006).

With this model resource managers 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 results from the *Baseline Scenario* provide park managers information about current use conditions to inform the establishment of a baseline of wilderness character as mandated by the recently revised Director's Order 41 on Wilderness Stewardship (NPS 2011a). The other scenario results (excluding the *Validation Scenario*) provide "sideboards" that may help facilitate the prescriptive process of selecting management alternatives.

The *Reduced Use Scenario* simulates visitor flows under only one of any number of trailhead quota schemes. It provides managers with a starting point for the development of alternatives, allowing them to create various trailhead quota strategies that result in acceptable desired spatiotemporal distributions of visitor use. It also informs managers of the degree to which public access to the wilderness resource would be limited under such quota configurations. The *Trailhead Reassignment Scenario* gives managers of glimpse of visitor use distribution under the assumption that if visitors cannot access their first-choice trailheads, then those visitors would choose to use trailheads with the greatest probability of being under quota. It gives one set of any number of possible solutions whereby the current visitor use level is accommodated within defined capacity standards. Therein lies the beauty of the interactive model – it provides managers the ability to try out any number of possible solutions in a simulation environment, allowing them to choose and implement the solution most likely to succeed in protecting wilderness resources and experiential values such as solitude. The *Maximum Use Scenario* is helpful in that it demonstrates the effects of the upper bound of visitor use in which visitor entries into the wilderness fully fill all trailhead quotas.

Freedom to Roam and Regulatory Rationales

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

This study also found that that on some nights, a portion of the wilderness management zones likely receive use exceeding their set numerical user carrying capacities. This study produced a tool for Yosemite National Park that allows managers to find combinations of trailhead quotas that bring visitor use levels in those overused zones back down to capacity while still accommodating the same overall amount of wilderness visitor use. It is ultimately up to park managers to decide how best to use the modeling tool provided, but it may be worth noting that a previous study using stated-choice modeling found that Yosemite wilderness visitors would be willing to accept a lower chance of receiving a permit in order to receive improvements in other conditions such as having fewer encounters during their trips (Newman et al. 2005). It is also worth noting that a study in Oregon and Washington found that wilderness visitors are more supportive of use limits if the rationale given is protection of the environment rather than protection of experiences (e.g. solitude) (Cole and Hall 2008a). Therefore, if the park implements an alternative trailhead quota configuration that reduces use, actual visitors are more likely to accept it in regard to what they may gain experientially, while the public at large (including non-visitors) may be more likely to support it in consideration of resource preservation. Also, past comparisons of wilderness visitors at high-use trailheads to visitors at trailheads receiving moderate use found that at very high-use trailheads fewer people feel that solitude is critical to an authentic wilderness experience, those visitors were more likely to report that trail encounters did not matter to them, and that more encounters would be tolerable since those visitors had more lenient standards. This suggests that visitors to high-use destinations make “psychological adjustments to heavy use” (Cole and Hall 2008b).

Considerations

It was not within the scope of this study to evaluate certain aspects of wilderness management and use in Yosemite National Park. The overnight zone capacities determined in the 1970s by park scientist Jan van Wagtendonk were not examined or questioned. Some wilderness researchers maintain that the accuracy of capacity estimates could be increased if more varied information is considered to enable the refinement of estimates based on new and potentially better information. The accuracy of capacity estimates should also consider all management actions being taken. Making trails more durable, improving wilderness facilities, and teaching Leave-No-Trace techniques may increase capacity if such actions reduce the effects of per capita use (Cole and Carlson 2010).

The High Sierra Camps exist as enclaves surrounded by, but not actually a part of, the Yosemite Wilderness. The camps are a popular destination in the park and offer visitors a chance to enjoy the resource while retaining access to such amenities as canvas walled tents, raised beds, and prepared meals. The capacities of the zones in which the camps are located do not account for the occupancy of the High Sierra Camps and overnight visitors to the camps do not obtain wilderness permits. Therefore, while those visitors, along with the mule-trains that resupply the camps, surely affect the resource and experience of other visitors, those effects are beyond the scope of this study.

Implications of Trailhead Permit Quota Reduction

The trailhead permit allocation shown in Table 2 gives a quota configuration that the simulation model predicts will meet the defined acceptability standard of no zones with nights on which capacity is exceeded in more than 30 percent of 1000 simulations. Taking the most direct approach of iteratively lowering quotas at trailheads contributing most to zone capacity exceedances produced only one of any number of possible trailhead quota schemes that could result in patterns of use deemed acceptable in terms of visitor experiences and resource protection. Figure 13 reveals that the zone most frequently receiving average over capacity use (66, Figure 8) is fed primarily by the Happy Isles, Sunrise Lakes, and Cathedral Lakes trailheads (lighter blue cells in row 66). The necessary adjustments to those trailheads to produce "acceptable" results equates to daily reductions from 235 to 139 daily issued permits for those trailheads, which is a reduction of 40.9 percent. It is difficult to predict how visitors seeking permits would react to such a large reduction in access. Quotas could be increased at other trailheads to allow for the same total amount of wilderness access, but those other trailheads are clearly not as popular with visitors. Would visitors accept a less preferred trailhead, one that likely would not lead to their desired destination? Would they decline to take a wilderness trip at all if they could not gain access via their preferred trailhead?

Certain highly desired or iconic destinations in the Yosemite Wilderness have a "gravity" effect on visitors, so it is also possible that even with reduced quotas at certain trailheads, visitor use patterns could adjust such that the probabilities of zone-to-zone transitions change from the current condition to reflect the draw those iconic destinations such as Half Dome have on visitors. Demand to reach that summit is so great now that visitors seeking first come first serve permits to Little Yosemite Valley (LYV) are willing to accept permits for the Illilouette Creek drainage where they spend a "layover" night before being assured of camping at LYV the next night in preparation for their Half Dome ascent.

Another possible outcome of greatly reducing use at certain popular trailheads is that visitor use could increase in other portions of the Yosemite Wilderness that are currently more lightly used. This could have the effect of increasing visitor use impacts to resources in those more pristine portions of the wilderness, as well as decreasing opportunities for solitude. In the long term, this could have the effect of narrowing the range of conditions and opportunities available in the Yosemite Wilderness.

Factors Associated with Overuse

The *Baseline Scenario* simulations give evidence that Yosemite Wilderness visitor capacities are likely being exceeded on some nights in a portion of management zones throughout the high-use period. It is the estimation of this researcher that certain specific factors lead to these exceedances. Little Yosemite Valley (Zone 59, Figure 9) receives much more visitor use than the other zones. The 2010 permit data have that one zone receiving 12.3 percent of all visitor nights in the high-use period. The capacity of LYV is 150 persons per night and at current use conditions it has no nights on which the probability of capacity exceedance is greater than ten percent (Figure 10). It has such a high capacity (considering its comparatively smaller size) because it has a regulated, designated, backpacker campground with chemical toilets and bear proof metal food lockers. It is also the most likely overnight camp for the many visitors who intend to climb the increasingly popular Half Dome, because it is the nearest site with restroom facilities and a ranger station. Therefore, it stands to reason that adjacent zones likely receive increased levels of visitation.

Sunrise Creek (Zone 66, Figure 9, Figure 27), just north of LYV has 59 nights when mean visitor use exceeds capacity (Figure 8). That equates to 38.6 percent of nights (59 out of 153) during the high-use period when average occupancy of the Sunrise Creek drainage exceeds capacity. Of all of the visitor nights that accumulate in Zone 66, between 20 and 30 percent are attributable to visitors who began their trip with a permit for Happy Isles to Little Yosemite Valley. Those wilderness permits are meant for visitors intending to spend their first night in the Little Yosemite Valley (LYV) backpacker campground. Between 10 and 20 percent of visitor nights in Zone 66 are attributable to trips with Happy Isles to Sunrise / Merced Lake pass through permits. Those permits are for visitors using the Happy Isles trailhead intending to spend their first night either to the north or east of LYV. This means that 30 to 50 percent of all nights spent in the most overused zone (66) are attributable to visitors originating at the Happy Isles trailhead.

There are two prominent peaks within a one day hiking distance from their

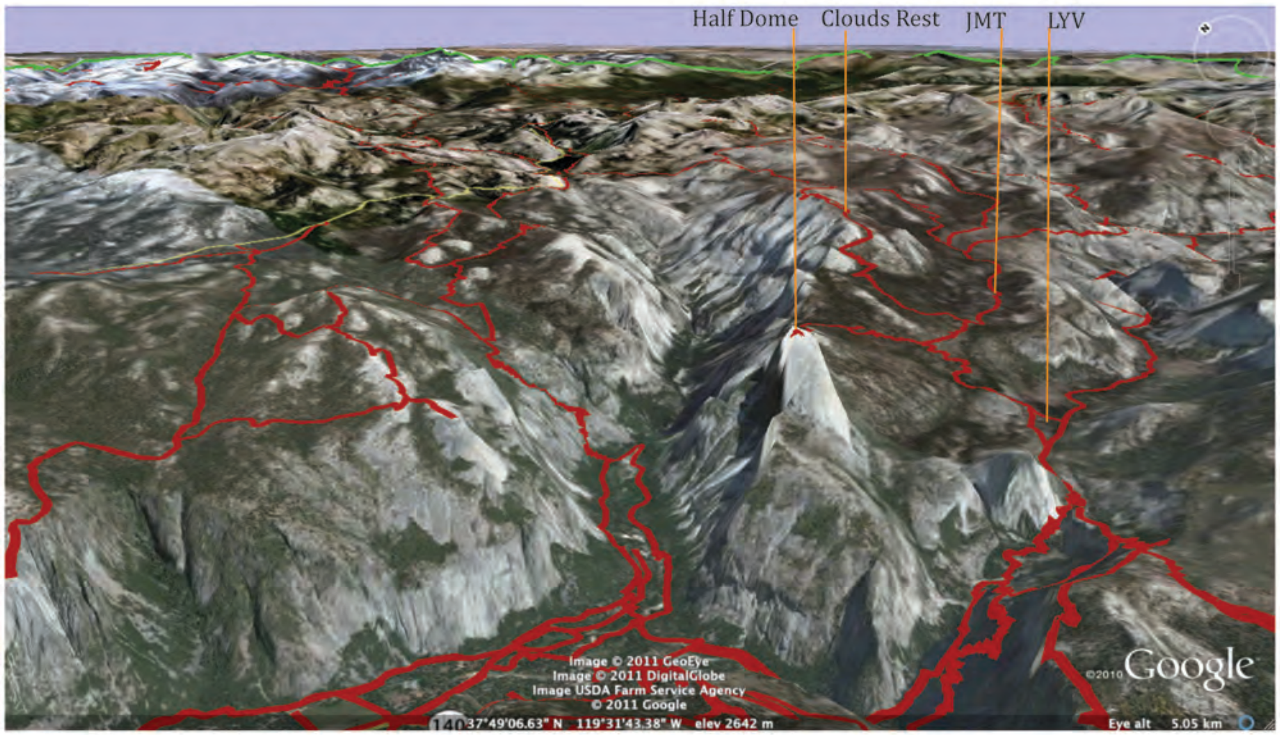

Figure 27. North by northeast vantage of features drawing use to the Sunrise Creek drainage (Zone 66).[a]

[a]Source: Sunrise Creek drainage. 37°49’06.63” N and 119°31’43.38” W. Google Earth.

nearest trailheads that are attracting a substantial amount of visitor use to the Sunrise Creek zone. Half Dome is likely the most iconic feature in Yosemite National Park and Clouds Rest is quickly becoming one of the most highly sought destinations. The immense “gravity” of Half Dome attracts so many visitors that the park has recently implemented a day use permit system during the high-use period, limiting use to a daily quota of 400 persons allowed to summit in order to manage for safety and experiential factors (NPS 2011b). It is no wonder then, that such highly sought peaks would draw visitor use to the feature vicinities as they do. Sunrise Creek is fed by streams draining off the southeastern flank of Clouds Rest and the zone offers a prime location for a backpacking campsite from which the visitor could make day hikes to the summits of both Half Dome and Clouds Rest (Figure 27).

The other two trailheads contributing most to Zone 66 are along the Tioga Road in the park’s “high country.” The Sunrise Lakes trailhead is approximately 11 km by trail from the Clouds Rest Summit. It would seem that Clouds Rest is also attracting use from the north from visitors who “bag the peak” then spend nights in Zone 66.

The increasing popularity of the John Muir Trail (JMT) may also be contributing to capacity exceedances. The 338 km route that begins in Yosemite Valley and ends at the summit of Mount Whitney has been called “the best hike ever” and America’s most beautiful hike (Bastone 2010). The same two trailhead permits that most contribute to Zone 66’s use are also the highly coveted permits for visitors beginning the JMT. Backpackers seeking a first-come first-serve permit have been known to arrive at the Wilderness Center in Yosemite Valley as early as 3:00 am in the morning to be first in line when the permits become available at 7:30 am. The JMT bisects Zone 66 so it follows that much of its overnight use is attributable to trekkers on the John Muir Trail.

Zone 81 (Glen Aulin, Figure 9), according to the *Baseline Scenario*, has three nights on which visitor use exceeds capacity and 24 on which visitor use exceeds 90 percent of capacity. Glen Aulin is a popular "high country" destination in the park. The 2010 permit data has 5.2 percent of all visitor nights occurring there. The relatively short distance (8.5 km by trail) and its mostly downhill slope make the hike from the trailhead parking lot along the Tuolumne River to the backpacker camp at Glen Aulin very attractive to wilderness visitors. Also, the designated backpacker camp at Glen Aulin has a chemical toilet and food storage lockers, which add comfort to the experience of most visitors. The lockers' presence allows visitors to avoid the necessity of carrying the extra weight of a bear-proof food storage canister. A previous Yosemite study found that 43 percent of wilderness visitors who did not carry a canister purposely limited their trips to destinations with the lockers to avoid being regulated to use a canister (Martin and McCurdy 2009). Zone 75 (May Lake, Figure 9) also has a designated backpacker campground with facilities. According to 2010 permit data, 4.3 percent of all wilderness visitor nights during the high-use period accumulated in that zone. The *Baseline Scenario* modeling predicts that mean visitor use exceeds 90 percent of capacity on 11 nights.

This study provides evidence that contemporary visitor use consists of a larger number of shorter duration trips than in the late 1970s at the inception of the trailhead quota system. It stands to reason that trips of a shorter duration allow visitors less time to travel further into the wilderness. The fact that three of the four zones with the most nights of mean visitor use approaching or exceeding capacity are adjacent to trailheads (Zones 81, 75, and 67) supports the notion that relative ease of access is related to capacity exceedance.

Comparing the most visited zones in the 1970s to those in 2010 further illustrates the increased intensity of use that the most easily accessed, front country adjacent wilderness zones are receiving. In 1979 the eight most heavily used zones accounted for 36.9 percent of all wilderness visitor nights (van Wagtendonk 1981). The eight most heavily visited zones in 2010 amount to 47.7 percent of all wilderness visitor nights during the high season according to permit data. There are four of the eight most heavily used in 2010 that did not rank in the most used in 1979. Zones 68, 67, 75, and 74 (Yosemite Creek, Snow Creek, May Lake, and Ten Lakes, respectively; Figure 9) have all increased in popularity since the 1970s and are all adjacent to trailheads except the Ten Lakes zone which is only 4.5 km by trail from the nearest trailhead. A combination of decreasing variation in the spatial distributions of wilderness visitors and increasing popularity of iconic destinations, along with an apparent increased visitor preference for campsite amenities, has resulted in more concentrated use in peripheral zones, zones containing established backpacker camps, and zones with popular routes such as the trails that connect the Yosemite Valley with the Tioga Road.

Further Research

To best assess the validity of the model developed for this study one would ideally compare model output data to actual data from the system this model is designed to replicate. Researchers would use similar methods to gather itinerary and spatiotemporal deviation information and compare results to those predicted by the model (Lawson et al. 2006).

To further enhance the accuracy of the model researchers could gather more detailed information about wilderness use not documented in the permit database (i.e. data on non-permitted trips and trips originating from outside the park). To enhance the ability of the model to predict visitor behavior it is advisable that park managers seek more information about how visitors select trailheads, and the visitor response to full quotas, in order to better understand visitors' decision-making processes. With such information managers could make more informed choices when evaluating different visitor use scenarios to simulate with the model. For example, rather than a trailhead-reassignment scenario in which denied visitors are automatically reassigned to low-use trailheads, managers could create a trailhead reassignment procedure by which visitors are reassigned to trailheads in a more realistic fashion. This could also help managers improve their own decision-making processes when choosing between education or regulation strategies for wilderness management (Lucas 1990). While our model simulates *how* visitors interact with the resource, it would be improved if we learned more about *why* visitors choose places to visit in the Yosemite Wilderness.

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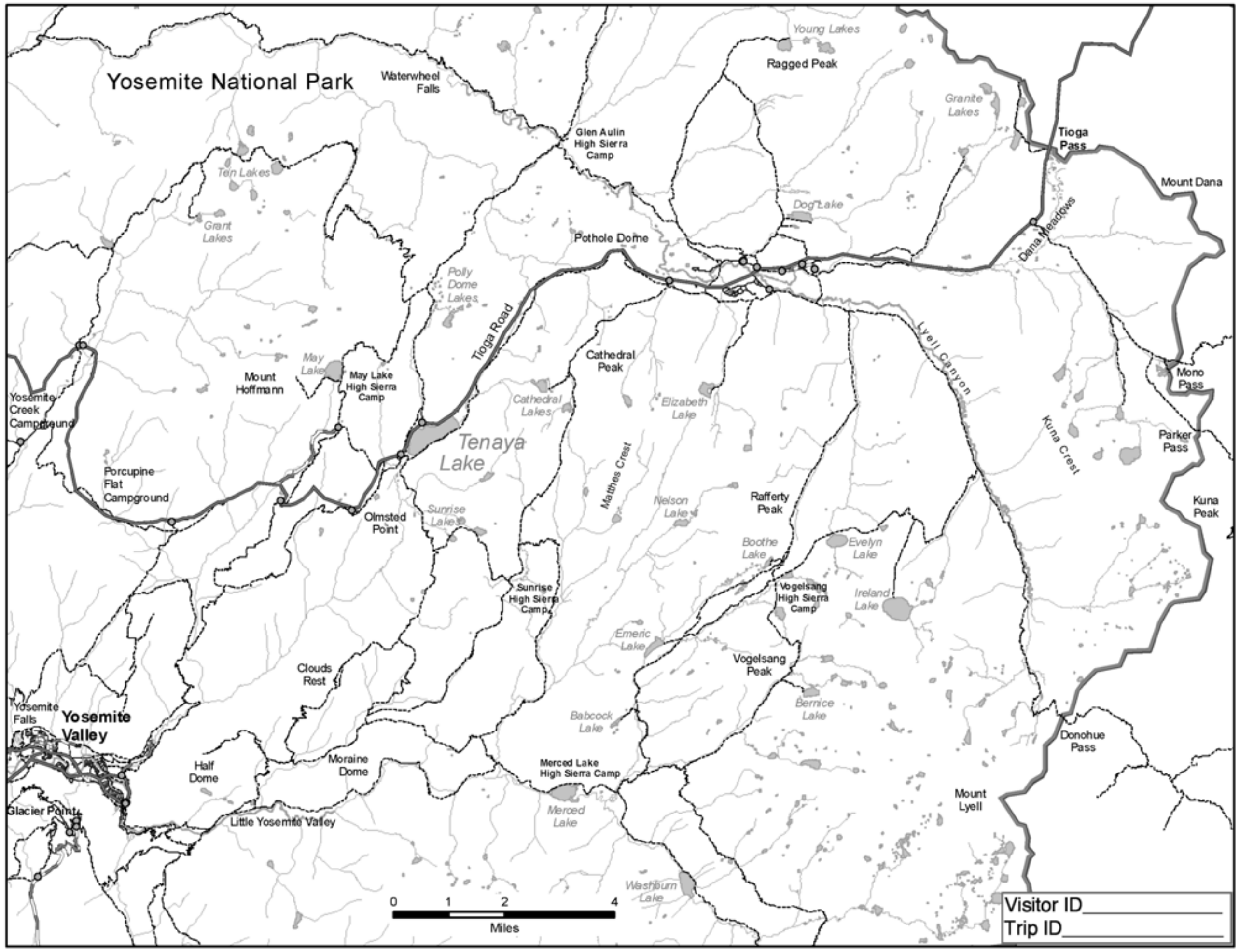
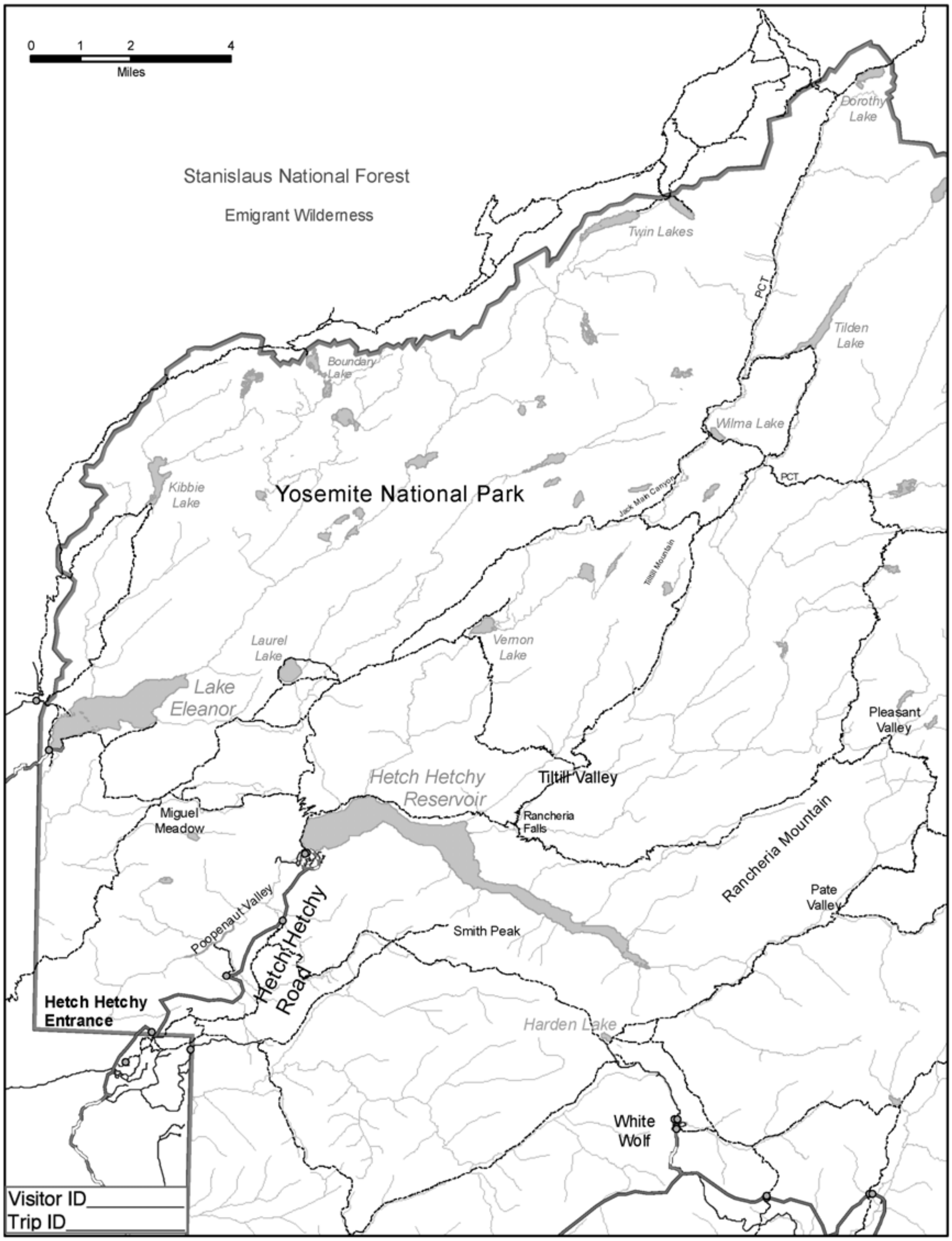
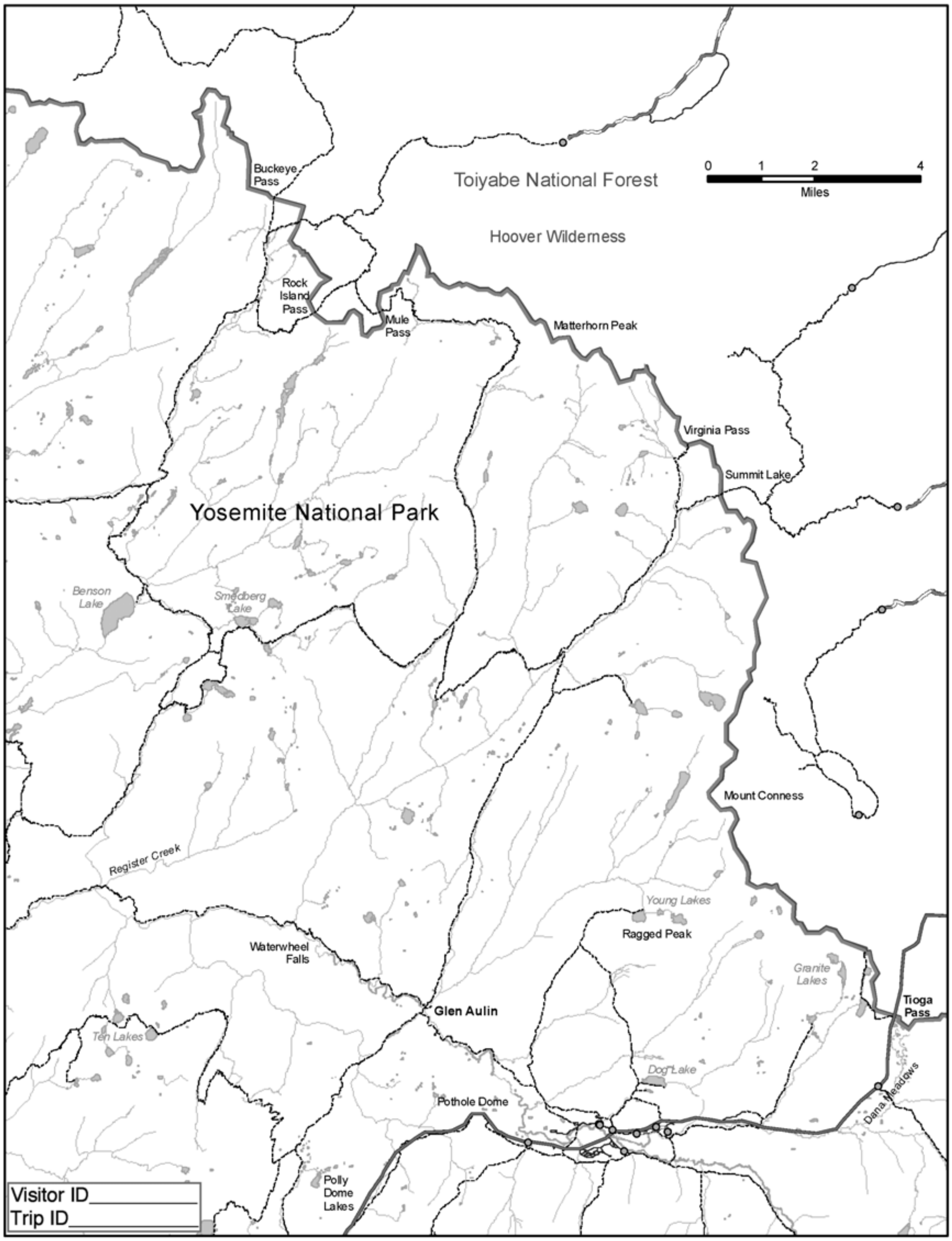


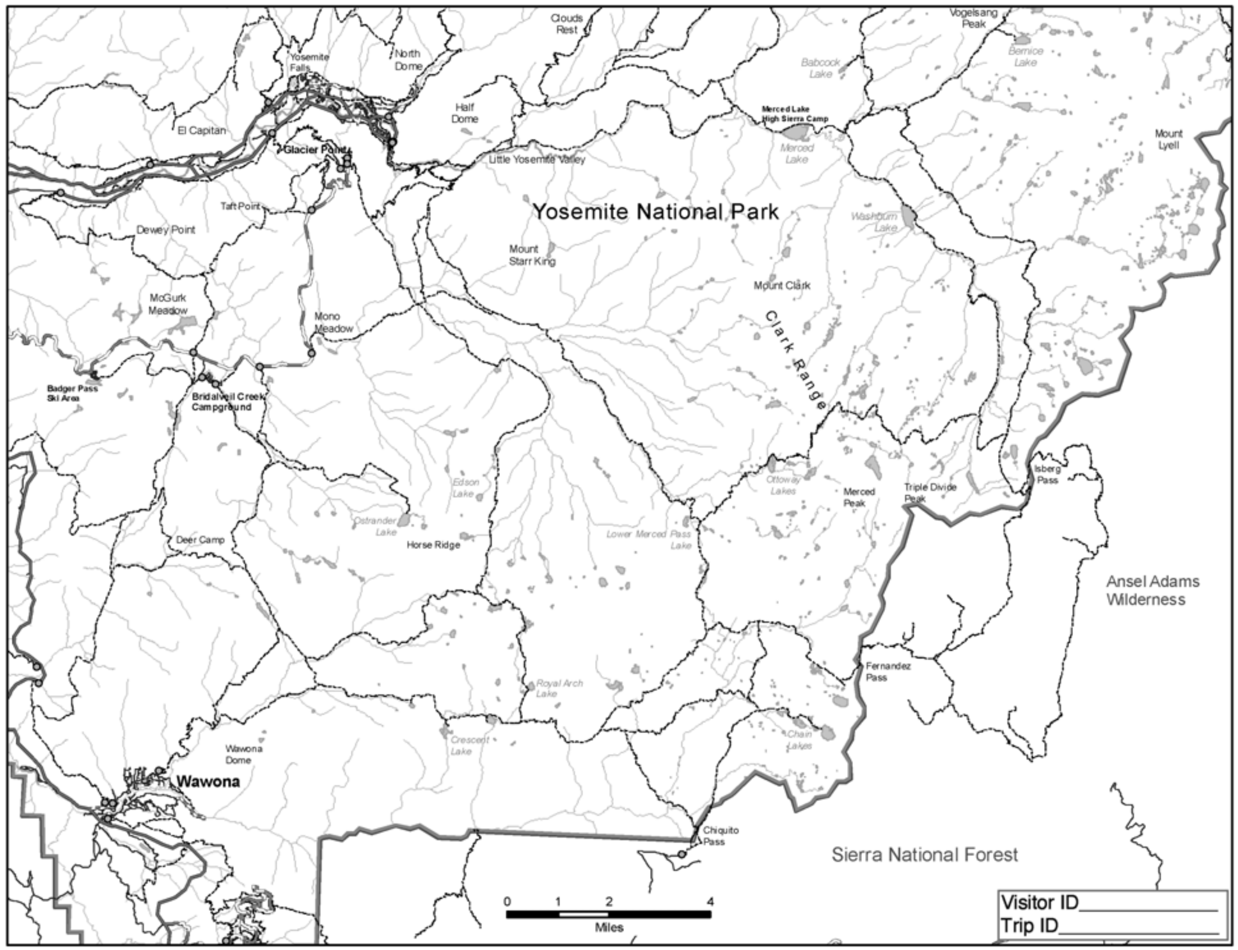
Appendix A. Cathedral Lakes sector survey instrument.

Appendix B. Hetch Hetchy sector survey instrument.

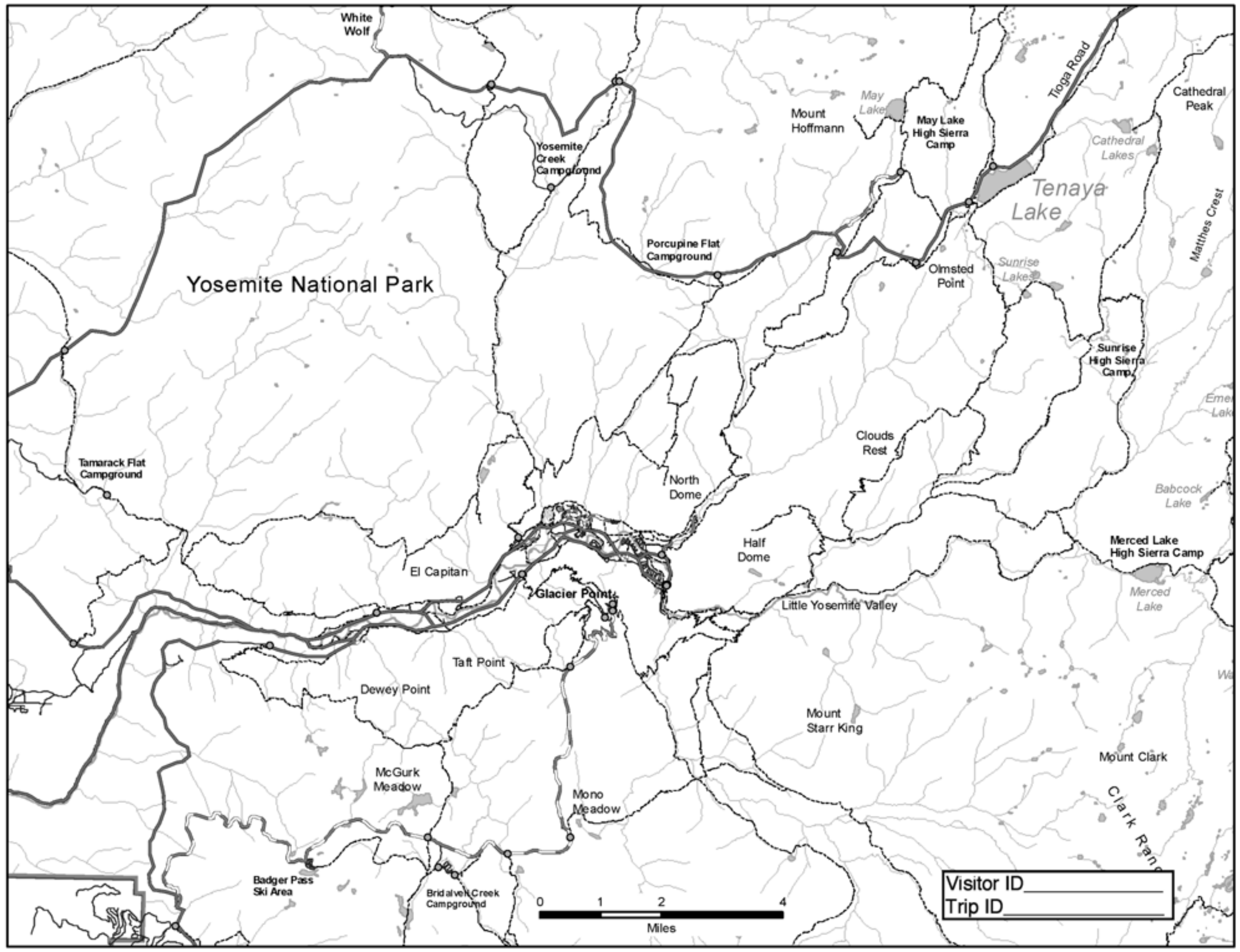


Appendix C. Tuolumne Meadows sector survey instrument.





Appendix D. Wawona sector survey instrument.



Appendix E. Yosemite Valley sector survey instrument.

Appendix F. Survey instrument reverse.

OMB # 1024-0224 (NPS # 09-014)
Expiration Date: 12/31/2010

We know that people's plans change once they get out into the wilderness. That's okay. Park managers benefit from accurate information about people's camping locations. This type of data has not been collected from Yosemite visitors for 30 years. The park is updating its data on people's hiking routes and campsite locations in order to know where crowding or camping impacts might occur.

On the map on the reverse side, please trace your hiking route with a solid line and mark the location of each of your campsites with a circled number corresponding to the night of your trip. If you stay in the same location multiple nights, add a circled number for each individual night of your trip. If you are carrying a GPS, provide the coordinates of your campsites if you wish.

Trace your route from entry trailhead to campsite to campsite to exit trailhead. You do not need to mark the route of any day hikes or side trips you take. Please remember to mark each of your campsite nights with a circled number corresponding to the night of your trip.

When you exit the wilderness, return the bagged map by leaving it in your rental food storage canister (if you have one), or by dropping it directly in the clearly marked bear canister drop box outside any station that issues wilderness permits (Yosemite Valley Wilderness Center, Tuolumne Meadows Wilderness Center, Hetch Hetchy Entrance Station, Big Oak Flat Information Station, Wawona Visitor Center at Hill's Studio), or in the box marked for recycled park maps and wilderness surveys at an Entrance Station as you exit the park. If exiting north or southbound on the Pacific Crest Trail, please deposit the bagged map in the marked box at Dorothy Lake Pass, Bond Pass, or Donohue Pass. **Please be sure to trace your route and number each of your campsites and return the map to us.**

If you forget or are unable to return the map before leaving the area, please mail it to: Dr. Steven R. Martin, ENRS Dept., Humboldt State University, 1 Harpst St., Arcata, CA 95521. This information will help park managers protect the Yosemite Wilderness. Please also answer the two questions below, and **thank you** for your assistance and cooperation.

On this trip in the Yosemite wilderness, in addition to hiking and camping, in which of the following activities did you or your group participate? Please check (√) **all** that apply.

_______ Climbing

_______ Fishing

_______ Other (Please specify) ____

While in Yosemite National Park before and after the backpacking portion of your visit, in which of the following activities did you or your group participate? Please check (√) **all** that apply.

_______ Take a scenic drive

_______ View roadside exhibits

_______ Day hike

_______ Eat in park restaurant / deli / cafe

_______ Other (please specify)____

_______ Camp in developed campground

_______ Stay in park lodging

_______ Visit visitor center

PRIVACY ACT and PAPERWORK REDUCTION ACT statement: 16 U.S.C. 1a-7 authorizes collection of this information. This information will be used by park managers to better serve the public. Response to this request is voluntary. No action may be taken against you for refusing to supply the information requested. An agency may not conduct or sponsor, and a person is not required to respond to, a collection of information unless it displays a currently valid OMB control number. BURDEN ESTIMATE statement: Public reporting burden for this form is estimated to average 5 minutes per response. Direct comments regarding the burden estimate or any other aspect of this form to: Bret Meldrum, Yosemite National Park, 5083 Foresta Rd, RMS Bldg., El Portal, CA 95318, (209) 379-1216, Bret_Meldrum@nps.gov.

Appendix G. Non-response e-mail reminder one.

Hello,

Earlier this summer you took a camping trip into the Yosemite wilderness. When you picked up your permit at a permit issuing station, you may have been given a map and asked to trace your route and mark/number your campsites. At this time we have no record of having received your completed map. I urge you to complete the map and questionnaire and return it by (ten days post date sent). This information is important for park managers to better manage the park's wilderness, so we would greatly appreciate receiving your completed map.

If you no longer have the map and cannot print the attached PDF version, we'd be happy to send you a replacement, if you are willing to complete it and return it to us. To request a replacement map, please e-mail me at mdouglas@humboldt.edu and tell us which trail or trailhead you used, and we'll send the correct map to you. Please provide your mailing address.

Please mail your completed map, with your hiking route and numbered campsite locations, to:

Dr. Steven R. Martin
ENRS Dept., Humboldt State University
1 Harpst Street
Arcata, CA 95521.

If you're technically savvy, feel free to digitally alter the attached document to represent your route and campsite locations. You could also print, then alter the document, scan, and e-mail the completed map survey back to us. It's your choice. Should you have questions, or if you need a replacement map, please contact me at mdouglas@humboldt.edu.

If perhaps you receive this message in error, and were never offered a map survey at the time you received your permit, or have already returned your survey, please respond accordingly. I'll remove you from my contact list, and all apologies for the unwarranted contact.

Thank you kindly,

Mark Douglas
Research Assistant, Humboldt State University
Collaborative Researcher, Yosemite National Park

Appendix H. Non-response e-mail reminder two.

Hello,

I'm e-mailing you about the survey of Yosemite wilderness users that you may have agreed to participate in this summer. The waiting period for incoming maps is almost over, and we have not yet received yours. I would appreciate you completing one, unless you mailed it back within the past few days.

The staff of Yosemite National Park is anxiously awaiting the survey results. They want the information you provide (we've not collected this data in almost 40 years) to best manage the park's wilderness and enable enjoyable visitor experiences. I urge you to complete the map and two questions and return it by (ten days post date sent). If you do not feel you can accurately recall the locations of your campsites then we would ask you to at least respond to this message reporting the total number of nights your party spent in the Yosemite Wilderness. Your contribution to the success of this study is greatly appreciated.

If you no longer have the map and cannot print the attached copy, we'd be happy to send you a replacement hard copy, if you are willing to complete it and return it to us. To request a replacement map, please e-mail us at mdouglas@humboldt.edu and tell us which trail or trailhead you used, and we'll send the correct map to you. Please provide your mailing address.

Please mail your map with your hiking route and numbered campsite locations to:

Dr. Steven R. Martin
ENRS Dept., Humboldt State University
1 Harpst Street
Arcata, CA 95521

If you're especially technically savvy, you may alter the attached document digitally and e-mail it back, or print, alter, scan, and respond with an attached file. Should you have questions, or if you need a replacement map, please contact me at mdouglas@humboldt.edu.

If, perhaps, you've received this message in error, or have already submitted your survey, we do sincerely apologize for the unwarranted contact.

Thank you kindly,

Mark Douglas
Research Assistant, Humboldt State University
Collaborative Researcher, Yosemite National Park

Appendix I. Non-response e-mail reminder three.

Hello,

I'm e-mailing you about the survey of Yosemite wilderness users that you may have agreed to participate in this summer. The waiting period for incoming maps is over, and we have not yet received yours. I would appreciate you providing one piece of information, unless you mailed the survey back within the past few days.

Reply to this message reporting the total number of nights your party spent in the Yosemite Wilderness during your trip, which originated (trip start date), 2010.

The information you provide will help better manage the park's wilderness and enable enjoyable visitor experiences.

Should you have questions, please contact me at mdouglas@humboldt.edu.

If, by chance, you've received this message in error, or have already submitted your survey, I do sincerely apologize for the unwarranted contact.

Thank you kindly,

Mark Douglas
Research Assistant, Humboldt State University
Collaborative Researcher, Yosemite National Park