Journal of Park and Recreation Administration
Fall 2012

Volume 30, Number 3
pp. 64-78

Adaptive Management of Visitor Use on Half Dome, An Example of Effectiveness

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EXECUTIVE SUMMARY: Parks and recreation areas are subject to multiple and sometimes competing social pressures and management objectives including demand for recreational use, preservation of resources, and protection of the quality and character of visitor experiences. Adaptive management provides an approach to study, experiment with, and if successful, realize such multiple objectives for common resources. The management of visitor use on Half Dome in Yosemite National Park provides a clear example of an adaptive management program that works. Lessons learned from this program are illustrative and broadly applicable.

Half Dome is Yosemite's most iconic mountain and hiking to its summit is among the park's most popular wilderness excursions. The culmination and experiential high-point of the hike involves ascending the last 400 vertical feet of Half Dome via a cable system that provides hikers some protection from potentially fatal falls. As visitor use has increased, crowding and congestion on the cables compromise visitor safety and the mountain's wilderness character. To realize the competing objectives of recreational access, wilderness preservation, and visitor protection, Yosemite executed a sustained and innovative program of adaptive management.

Adaptive management is characterized by cycles of monitoring, evaluation, planning and action. Four such cycles were executed on Half Dome, each monitoring visitor use and behavior on the cables, evaluating the relationships between use level, wilderness character, and visitor safety, culminating in planning for and taking management action. Beginning with establishment of baseline conditions on the cables and formulation of indicators and standards of quality, the cycles progressed through implementation of an initial interim permit program, simulation modeling of virtual management scenarios, and adaptation of the interim permit program. These cycles have coalesced to inform development of an Environmental Assessment for long-term visitor use management on Half Dome.

The program of visitor use management on Half Dome exemplifies a successful application of adaptive management to parks and recreation areas.

With iterations of simulated and actual management actions, coupled with ongoing monitoring, park managers implemented a process that effectively realizes competing objectives for Half Dome. The process of visitor use management on Half Dome illustrates lessons about the challenges to and execution of adaptive management. As a management program that works, it can serve as an example for other park and recreation areas seeking to reconcile competing objectives for visitor use and resource quality.

KEYWORDS: Recreation, national park, carrying capacity, simulation modeling, adaptive management, risk

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Parks and recreation areas are subject to multiple and sometimes competing social pressures and management objectives—demand for recreational use, preservation of resources, protection of the quality and character of visitor experiences, among them. Adaptive management provides an approach to study, experiment with, and if successful, realize such multiple objectives for common resources. Adaptive management prescribes cyclic monitoring, evaluation, planning and action (Stankey, Clark & Bormann, 2005). Its power for visitor use management stems from it is ability to both respond to observed conditions and work proactively toward desired conditions. Leveraging this power requires sustained commitment. Management of visitor use on Half Dome in Yosemite National Park is an exemplar of both competing objectives and the successful application of adaptive management. Lessons learned from visitor use management on Half Dome are broadly applicable to other parks and recreation areas.

With the granite dome's summit rising nearly 5,000 feet above Yosemite Valley, Half Dome is one of the most prominent and familiar sights in Yosemite National Park. In 1919, the Sierra Club constructed a cable system that provides access to the summit of Half Dome for visitors without technical rock climbing ability. Today, the hike to the summit of Half Dome is arguably the most iconic and popular backcountry excursion for visitors to Yosemite National Park. The culmination and experiential high-point of the hike involves ascending the last 400 vertical feet of Half Dome via a cable system. Historical recollections and modern monitoring suggest that the hike to the summit of Half Dome is increasingly popular (Yosemite National Park [YNP], 2012). For example, average daily visitor use on the cables route on Saturdays has increased from 100 to 200 in the 1980s, to 575 in 1994, and onward to 760 in 2006 and more than 800 in 2008, with peak use levels of well over 1,000 having been observed (Fincher, 2006; Lawson, Choi, Reigner, Newman, & Gibson, 2009; YNP, 2012). This ballooning of use within Yosemite's designated wilderness has been accompanied by a dramatic increase of incidents involving visitor distress, ranger assisted rescues, and fatal accidents (YNP, 2012). Consequently, crowding, congestion and delay induced by visitor use compromise visitor safety, wilderness character, and the mission of the National Park Service during periods of high visitor use.

The pattern of rapidly increasing visitation and consequent experiential and resource impairment occurring on Half Dome is not unique. Parks and wilderness areas throughout the country suffer from patterns of visitor demand and recreation impact that mirror those seen on Half Dome in the first decade of the 21st century (Cole, Watson, Hall, & Spildie, 1997; Manning, 2011). Parks and wilderness managers are charged with multiple social mandates—to preserve, unimpaired, the resources and experiences for which lands were set aside and to facilitate public access for enjoyment, recreation and learning (National Park Service Organic Act, 1916; Wilderness Act, 1964). This dual mission embodies the competing social objectives with which public lands are often invested. Examination of how these competing objectives are manifest, investigated and reconciled on Half Dome provides an example of an adaptive resource management program that works.

Three primary social objectives lie at the heart of visitor use management for Half Dome: facilitation of public access, preservation of wilderness character, and protection of visitor safety. These objectives are shared for most public lands, particularly those with a focus on recreation and visitor use. Such lands are set aside for public enjoyment and therefore must facilitate access and use to the extent possible. This access must however be balanced against and managed to mitigate the potential for social, ecological and managerial impacts that inevitably accompany recreation use (Hammitt & Cole, 1998). Beyond these classic objectives of resource protection and public access, Yosemite park managers must concern themselves with risk management on Half Dome. Given the risks inherent with wildland recreation, particularly those associated with the Half Dome cables as an element of the park's infrastructure and the divergent perceptions of risk and skill of Half Dome hikers, the National Park Service must include visitor safety as a consideration when developing management programs (Lawson, et al., 2009; Rickard, Sherer & Newman, 2011). Although the pressures placed on wilderness character and risk management by visitor demand may be exceptionally acute for Half Dome and in Yosemite, they are common, in some form, to many national parks and wilderness areas (Fimrite, 2008; Hung & Townes, 2007). During the ten years from 1998 through 2007, National Park Service search and rescue averaged nearly 4,000 incidents annually, many of which occurred in high-use units like Grand Canyon National Park and Gateway and Lake Mead National Recreation Areas (Heggie & Amundson, 2009). Management of visitor use on Half Dome can inform recreation and risk management broadly.

The case of Half Dome illustrates how, when seeking to achieve such competing objectives as access, preservation and safety for public recreation resources, adaptive management can be an effective guiding framework. Adaptive management prescribes an experimental and iterative approach to problem solving. Developed to support efforts in management of large-scale, uncertain ecosystem and resources, adaptive management recognizes that public policy must be informed by science and that scientific understanding is often not complete, either in terms of factual knowledge or democratic representativeness (Gunderson, 2008; Lee, 1993; McLain & Lee, 1996). Rather than be paralyzed by uncertainty or resort to ad hoc trial-and-error, adaptive management suggests a cycling campaign of monitoring, evaluation, planning and action (Figure 1; Lee, 1993; Stankey, Clark & Bormann, 2005).

In this campaign, each management action is considered an experiment designed to yield knowledge. The success and propagation of management actions is contingent upon monitoring and the comparison of post-action conditions with those present before action and desired afterward. If conditions improve, management actions may be judged successful and objectives may be achieved. If conditions do not improve, the action may still be considered successful if information about the system's performance is learned. This knowledge, gathered by systematic monitoring, is used to inform the next iteration of action, helping management to adapt. Such cycles of adaptive management have been applied to reconcile competing objectives for resource use and quality in a broad range of fields including outdoor recreation, endangered species management, water allocation, toxic waste management, climate change, and transportation planning (Chavez, 2002; Doremus, 2001; Lawson, Newman, Choi, Pettebone, & Meldrum, 2009; Thrower & Martinez, 2000; Tompkins & Adger, 2004; White et al., 2010)

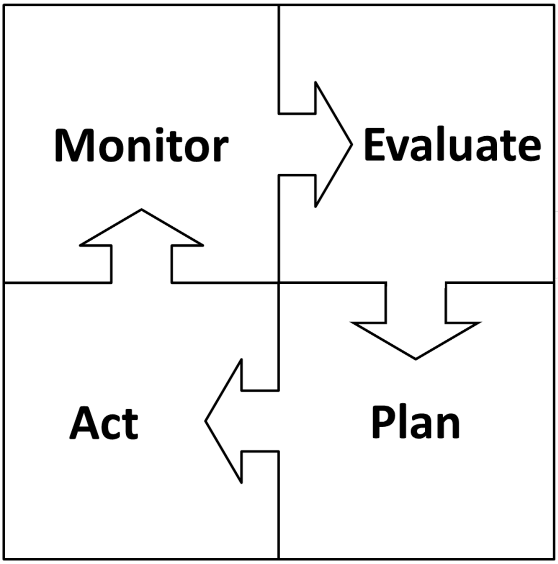

Figure 1. Adaptive Management Cycle. *(Adapted from Stankey, Clark, and Bormann, 2005)*

In public land recreation, where objectives for resource and experiential quality are not just competing but often broadly defined, indicators and standards of quality-based frameworks can lend structure to management (Graefe & Vaske, 1987; Manning, 2001; Stankey, Cole, Lucas, Petersen, & Frissell, 1985). Indicators of quality are variables that serve as proxies for management objectives. They are measureable, manageable, relevant to visitors, sensitive to use level, and synthetically captures resource and experiential conditions (National Park Service [NPS], 1997). Examples for Half Dome include the number of visitors at one time on the cables or the amount of time it takes visitors to ascend or descend the cables. Standards of quality are the minimum acceptable condition of indicator variables at which management objectives are achieved (NPS, 1997). A range of potential standards exists depending upon social, ecological and managerial priorities for a recreation area (Manning, 2011). Selection of a single standard as the target for management action is ultimately a judgment to be made by park managers, yet it should be informed by public norms, administrative capabilities and ecological constraints (NPS, 1997). Potential standards for visitor use level on Half Dome may be formulated to reflect the point at which visitors begin to feel crowded or unsafe or the point at which visitor behavior on the cables changes from that extant during free-flow conditions. An indicators and standards-based framework provides important elements for adaptive management programs – variables for measuring the effects of management actions and benchmarks by which to judge achievement of management objectives.

Traditional management by indicators and standards may be considered reactive, in that action is taken only when standards are threatened or violated. The use of simulation models has the potential to make this process more proactive (Lawson et al., 2003). Simulation models estimate resource and experiential conditions under hypothetical management programs and corresponding use levels. Such modeling has a long history in park and wilderness management and has been applied to a broad range of contexts (Cole, 2005; Lucas & Shechter, 1977). By testing adaptive management scenarios in model space, the potential political, ecological and economic costs of on-the-ground experimentation may be foreseen, allowing actions to be planned and taken before standards are threatened or violated (Cole, 2005; Lawson, Hallo, & Manning, 2008). Indeed, simulation modeling may be considered an extension of adaptive management, facilitating the planning, action, monitoring, evaluation cycles and minimizing the potential for unintended consequences.

This article presents a program of adaptive management, enabled by an indicators and standards-based framework and empowered by simulation modeling, for management of visitor use on the Half Dome cables. While the specific methods and conclusions presented here may be somewhat unique to Half Dome, the program serves as a model of concerted adaptive management and conscientious planning. This program of research and management begins with monitoring to quantify visitor use and formulate standards. Initial monitoring informs planning and identification of management actions to be applied. This action, in the form of a first interim permit regime, is enacted and resulting conditions are monitored. Through the iterative cycling of monitoring and evaluation, the interim permit regime is adapted and reenacted, again with accompanying monitoring. These cycles of adaptive management, combined with simulation modeling, have culminated in a National Environmental Policy Act (NEPA) Environmental Assessment process that may ultimately lead to permanent adoption of the interim adaptive visitor use management for Half Dome. It is hoped that description of Yosemite's commitment to adaptive management will serve as an example and inspiration to other parks and recreation areas striving to reconcile and manage the competing demands associated with recreation use amid sensitive environments.

Adaptive Cycles for Half Dome Visitor Use Management

Adaptive Management and Indicators of Quality

Although adaptive management programs are inherently iterative, applied programs of management must begin at some point in the evaluation, planning, action and monitoring cycle (Stankey, Clark, Bormann, 2005). When seeking to manage outdoor recreation, where annual cycles of visitation provide a consistent, if ever increasing, pattern of use, monitoring use levels and associated conditions provides a productive starting place (Lawson et al., 2008). Initial monitoring of existing conditions serves several important functions vital to successful adaptive management (Manning, 2007). Through it, measurement methods to observe indicators and evaluate the efficacy of management actions are developed and codified. Further, initial monitoring provides a baseline characterization of use levels and conditions that serve both as inputs to simulation models and benchmarks for evaluating subsequent management action (Lawson et al., 2008).

Indicators of quality are variables that translate visitor use levels and experiential conditions into specific and measurable terms, related to broader management objectives. For monitoring to proceed, indicators of quality must be identified and methods for their measurement developed. Indicators of quality should reflect the objectives park managers and the public seek to achieve. In the case of Half Dome, these are facilitation of visitor access, preservation of wilderness character, and protection of visitor safety. Three indicator variables were identified and monitored to reflect these objectives. The number of people at one time on the cables system ($PAOT_{total}$) serves as a measure of visitor demand and, in light of the Wilderness Act's mandate for solitude, an indicator of wilderness character (Dawson & Hendee, 2009; Manning, 2011; Wilderness Act, 1964). In addition to $PAOT_{total}$, the number of visitors ascending and descending the route outside the protective interior of the parallel cables ($PAOT_{out}$) serves as an indicator of both wilderness character and visitor safety (Figure 2). This indicator is able to serve such a dual purpose because visitor excursions from the cables' interior is often prompted by congestion and increases exposure to hazardous, unarrested falls (Lawson, et al., 2009). Travel time, defined as the average amount of time taken by visitors to ascend and descend the cables route, serves as an indicator of both wilderness character and visitor safety. Along with opportunities for solitude, wilderness areas are charged with providing opportunities for unconfined recreation. Delays in ascent or descent, evidenced by travel times greater than those observed during free-flowing use, indicate compromises of both wilderness character and visitor safety (Budruck & Manning, 2003; Hall & Roggenbuck, 2002; Mermier et al., 1997;

Nieuwenhuys et al., 2008). This suite of indicators ($PAOT_{total}$, $PAOT_{out}$ and travel time) was selected by park managers and researchers because it reflects, in empirically observable variables, the competing objectives for management of visitor use on Half Dome. Similar variables, including counts of use and measures of behavior, can serve as indicators of quality for adaptive visitor management programs in parks and recreation areas generally. Indicators of quality provide the terms by which information is expressed and incorporated into the iterative cycle of adaptive management.

The following subsections of this paper chronologically describe the adaptive management program for visitor use on Half Dome. Beginning with initial monitoring, evaluation and planning in 2008, the park progressed through a weekend-only permit action, accompanied by monitoring and evaluation, and cycle of simulation modeling in 2010, to a 7-day interim permit system in 2011, also accompanied by monitoring and evaluation. Ultimately these four cycles have culminated in planning for long-term visitor use management.

2008: Initial Monitoring, Evaluation and Planning

With indicator variables defined, the first cycle of monitoring was conducted during the summer of 2008 (Lawson et al., 2009). Three methods were employed: photographic observation of visitors on the cables, attendant observation of travel times on the cables route, and calibrated electronic counts of visitor use on the Half Dome Trail. In particular, $PAOT_{total}$ and $PAOT_{out}$ were monitored with photographs of the cables route taken once every twenty minutes throughout the visitor use day on 16 days from July 2nd through August 2nd (N=327; Figure 2). These photos were then coded, generating counts of the total number of visitors ascending and descending the cables ($PAOT_{total}$) and the number of visitors ascending or descending the route outside the two parallel cables ($PAOT_{out}$). Travel time was monitored by having visitors carry delay cards with them during their hike to Half Dome's summit on 11 days from July 2nd through August 2nd during the summer 2008 monitoring period (N =976). As visitors entered and exited the cables route research attendants time-stamped the cards, generating travel time data for each visitor's ascent and descent of the cables route. Daily visitor use of Half Dome was calculated from electronic counts of hikers on the Half Dome Trail. Averages and sample sizes from initial monitoring for these indicator variables are presented in Table 1. In addition to developing measurement methods, 2008 initial monitoring establishes baseline conditions of visitor use, wilderness character and visitor safety on the cables route. This monitoring constitutes the first element of Yosemite's adaptive management program for Half Dome.

Table 1

Half Dome Cables Indicator Monitoring: Averages and Sample Sizes

	Unit	Weekends Friday – Sunday		Weekdays Monday – Thursday	
		Average	***N***	***Average***	***N***
2008 Initial Monitoring (Lawson, Choi et al., 2009)					
$PAOT_{total}$	individuals	35	202	22	126
$PAOT_{out}$	individuals	2	202	1	126
Travel $Time_{ascent}$	minutes	27	464	24	275
Travel $Time_{descent}$	minutes	22	417	21	267
Daily Use[a]	individuals	692	13	416	17
2010 Weekend Interim Permit (YNP, 2010)					
$PAOT_{total}$	individuals	17	140	45	126
$PAOT_{out}$	individuals	not reported			
Travel $Time_{ascent}$	minutes	29	161	41	131
Travel $Time_{descent}$	minutes	24	189	37	156
Daily Use[a]	individuals	301	38	635	43

[a] Sample sizes are the number of days counters were deployed on the Half Dome Trail.

Following collection of initial monitoring data, adaptive management approaches prescribe evaluation of the relationships among indicator variables (Stankey, Clark, & Bormann, 2005). Within indicators and standards-based frameworks, such analyses can inform the formulation of standards by park managers. For Half Dome, evaluation focused on identifying levels of visitor use beyond which wilderness character and visitor safety are compromised to an unacceptable degree. Regression and ANOVA analyses were used to estimate statistical relationships among $PAOT_{total}$, $PAOT_{out}$ and travel time. A quadratic regression analysis predicting $PAOT_{out}$ from observations of $PAOT_{total}$ evaluates the relationship between visitor use of the cables and the number of visitors going outside the cables. ANOVA was used to evaluate the effects of $PAOT_{total}$ on the amount of time spent ascending and descending the cables. Generally, results suggest that wilderness character and visitor safety are indeed compromised as visitor use on the cables increases. Specifically, results of the regression suggest a statistically significant relationship between visitor use of the cables and the number of visitors ascending or descending the Half Dome cables route outside of the parallel cables (Cohen, 1992; Lawson et al., 2009). At use levels of 30 or more visitors, at least one visitor can be expected to travel outside the cables (Figure 3). Additionally, the ANOVA suggests that visitors take significantly longer to ascend and descend the cables when visitor use levels exceed 30 $PAOT_{total}$ (Table 2; Lawson et al., 2009).

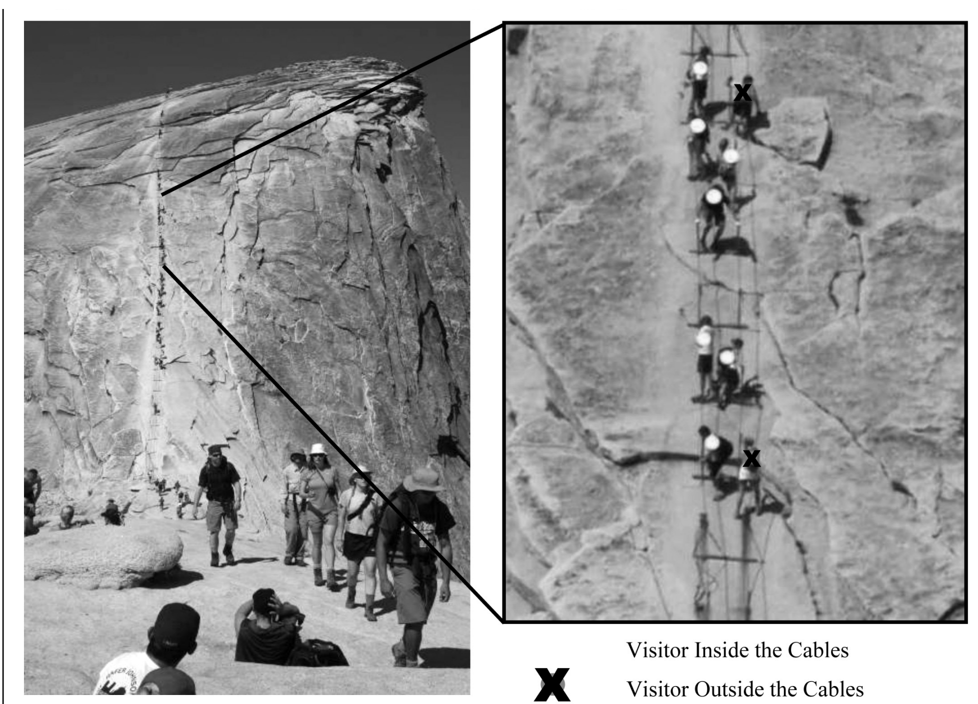

Figure 2. Half Dome Cables and Coding of Photographic Observations

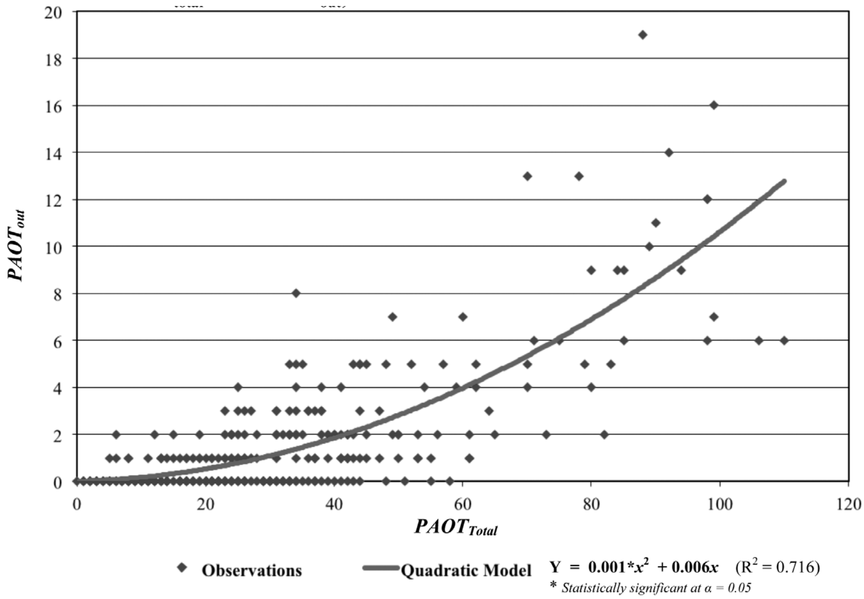

Figure 3. Photographic Observation Data and Regression Model Plots of $PAOT_{total}$ and $PAOT_{outs}$ 2008

Table 2

Mean Travel Times for Visitors on the Half Dome Cables, 2008

$PAOT_{total}$	N	Mean Travel Time
	Ascent	
0-9 people	48	20:19[a]
10-19 people	110	21:25[a]
20-29 people	136	22:58[a,b]
30-39 people	149	24:49[b,c]
40-49 people	108	26:21[c,d]
50-79 people	100	28:56[d]
80-89 people	31	38:54[e]
90+ people	25	38:01[e]
	Descent	
0-9 people	13	16:55[a, b, c, d, e, f]
10-19 people	78	16:04[a]
20-29 people	118	18:43[a, b, d, e]
30-39 people	147	21:22[b, d, e, f, h, j]
40-49 people	120	20:39[b, e, f, k]
50-79 people	113	23:00[c, f, g, h, j]
80-89 people	31	26:13[h,i, j]
90+ people	45	24:56[h, j, k]
Note: Superscripts denote statistically similar mean travel times at α=0.05.		

In both of these relationships, indicators of wilderness character and visitor safety vary significantly with changes in visitor use. Indeed, these significant changes both occur when visitor use reaches and exceeds 30 $PAOT_{total}$. The convergence of significant changes in $PAOT_{out}$ and travel time at 30 $PAOT_{total}$ is suggestive of a potential management standard. When 30 or fewer visitors use the cables at one time, their behavior is free from the influence and constraint of others – i.e. visitors are able to behave as if they were alone on the cables. This freedom satisfies wilderness character and visitor safety objectives for Half Dome. Maintaining free-flow conditions on the cables while maximizing visitor access can constitute realization of objectives for visitor use management on Half Dome. For this reason, park managers selected 30 $PAOT_{total}$ as a standard of quality. With formulation of this standard, the evaluation phase of the first adaptive management cycle for Half Dome is complete.

Planning for action follows monitoring and evaluation in the adaptive management cycle (Stankey, Clark, & Bormann, 2005). Simulation modeling is a key tool employed in the planning process, enabling alternative actions to be tested in an experimental way free from the costs and consequences of ad hoc trial and error (Johnson, 1999; Lawson et al., 2003; Lawson, Hallo and Manning, 2008). Using routing and travel time data collected in 2008, a simulation model of the Half Dome Trail and cables route was constructed in ExtendSim Version 6, a general purpose simulation software package produced by Imagine That (Lawson et al., 2009). This model estimated $PAOT_{total}$ under varying, user-specified visitor use levels and behavioral parameters.

The simulation model served two planning purposes; one purpose was for this first, cycle of adaptive management (in 2008), whereas the other was for a later, "virtual" adaptive management cycle conducted in 2010 and described below. In the initial adaptive management cycle, the simulation model was used to estimate indicators of visitor use on Half Dome. The simulation model estimated that average weekday $PAOT_{total}$ and travel times on the cables in 2008 did not violate the formulated standard of 30 $POAT_{total}$ and associated free-flow travel conditions (Lawson et al., 2009). These estimated indicator values are associated with observed average daily Half Dome use by approximately 400 visitors. Thus, the program of monitoring, evaluation and planning executed using the 2008 data suggested that a use limit of 400 visitors/day for Half Dome may effectively reconcile competing access, preservation and safety objectives. Enacting such a policy would represent a 42% reduction of use on weekend days, the most popular days to hike Half Dome. While such a reduction may have posed certain political risks, the monitoring, evaluation and planning of adaptive management provides Yosemite with informed, scientific rationale for action.

2010: Weekend Interim Permit (Action), Monitoring, and Evaluation

In 2010 Yosemite park managers took the final step in the first iteration of their adaptive management program for Half Dome—taking action. An interim permit program was enacted for the 2010 summer season allowing only 400 visitors to access the Half Dome cables route on Fridays, Saturdays and Sundays. The goal of this permit requirement was to facilitate maximum visitor access while preserving wilderness character and protecting visitor safety. Yosemite managers restricted the permit requirement to weekends, the days demonstrated by initial monitoring to regularly violate the preservation and protection standard of 30 $PAOT_{total}$. Management's choice to restrict permits to weekends rather than require permits every day of the week serves two purposes in the adaptive program. First, it is a conservative approach, limiting the imposition of regulation that can compromise wilderness character and experiential quality (Bullock & Lawson, 2007; Dawson & Hendee, 2009). Second, it provides an embedded experiment to generate knowledge about the Half Dome visitor use system and further adaptive management efforts. By first trying a more limited permit requirement, the effectiveness of permits and the required extent of the restriction could be evaluated.

Institution of the 2010 interim permit program constituted the conclusion of the first adaptive management cycle initiated for Half Dome in 2008. The second cycle begins with monitoring and evaluation of the interim weekend permit requirement's effects. During the summer of 2010, Yosemite National Park repeated monitoring with the methods and indicators formulated in the initial phases of the program described here (YNP, 2010). Results of indicator monitoring are reported in Table 1.

Two effects of the weekend permit program are revealed from this monitoring and evaluation. First, the permit requirement effectively reduced $PAOT_{total}$ and travel times on the cables in comparison to non-permit days in 2010, helping to realize wilderness character preservation and visitor safety protection objectives. Second, visitor use was displaced from permit days to non-permit days, as evidenced by the shift in high average daily visitor use from weekends in 2008 to weekdays in 2010 (Figure 4). The result of the weekend only permit experiment suggests that management actions, specifically the intra-week extent of permit requirements, must be adapted.

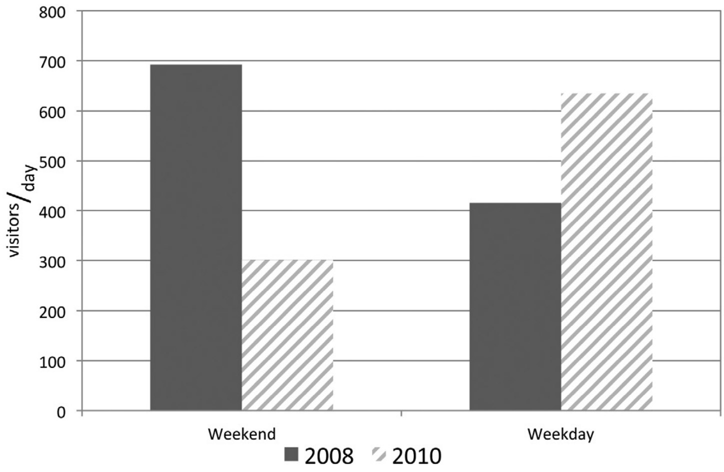

Figure 4. Average Daily Visitor Use on Half Dome

Simulation Modeling: A "Virtual" Adaptive Management Cycle

As described, the second cycle of monitoring and evaluation suggests that the permit program was effective in some ways but needed adaptation in others. To build upon the lessons learned and plan for refined action, the simulation model was again employed, this time to mimic visitor use under several experimental management programs and evaluate the results. In a sense, the simulation modeling can be thought of as a self-contained, virtual adaptive management program (Lawson et al., 2003; Lawson, Newman et al., 2009). By enabling experimentation and evaluation in a virtual sphere, the simulation model helps reduce the uncertainty and costs associated with ad hoc, on-the-ground action (Lawson, Hallo, & Manning, 2008). The Half Dome visitor use model was used to estimate:

1) Mean and maximum $PAOT_{total}$ and travel times on the Half Dome cables when daily visitor use is restricted via a permit quota of 400 people per day.

2) The maximum daily visitor use that can be accommodated on the Half Dome cables without exceeding mean "free flow" (i.e., unimpeded) ascent times, as measured during the 2008 visitor use study.

3) The maximum daily visitor use that can be accommodated on the Half Dome cables without exceeding 30 $PAOT_{total}$ under ordinary circumstances.

4) The total amount of time it would take all visitors on the Half Dome summit and cables to descend the cables in case of a weather event or other circumstances requiring all visitors to descend at one time.

5) The maximum daily visitor use that can be accommodated, in the case of implementing a *via ferrata* system (i.e., a protection system tying visitors to the cables) on Half Dome, without exceeding the "free flow threshold" of 30 PAOT.

Ultimately, the 2010 interim permit quota of 400 visitors/day to the Half Dome cables was acknowledged as a scenario able to balance the competing objectives (Lawson, Kiser, & Reigner, 2011). With these results from the simulation experiments, Yosemite National Park adapted its plan for managing visitor use on Half Dome in 2011 (YNP, 2012).

2011: 7-Day Interim Permit System and Planning for Long-term Actions

Following the evaluation and planning conducted via simulation modeling, the cycles of adaptive management for Half Dome continued. In 2011, Half Dome visitor use management was adapted based on learning from the temporal displacement that resulted from its weekend permit experiment of 2010; in particular, park managers enacted a 7 day-a-week permit program. This adaptation was accompanied by indicator monitoring and followed by evaluation to assess the effects of the refined permit program. The knowledge gained from the integrated adaptive management cycles (2008 initial monitoring, 2010 interim weekend permit, 2010 simulation modeling, and 2011 interim 7-day permit) has been incorporated into a NEPA Environmental Assessment process in which alternative actions are considered and their potential to achieve objectives evaluated. Learning and experimentation from previous management cycles suggests that permanent adoption of the interim Half Dome permit program may be successful, providing an informed and scientific basis to plan for implementation and institute ongoing monitoring protocols (YNP, 2012). Through iterative experimentation and learning, Yosemite National Park's management of visitor use on Half Dome will better balance the competing objectives of public access, wilderness preservation, and visitor protection.

Discussion and Implications

Adaptive management seeks to reconcile competing social objectives for common pool resources. Often, this competition is accompanied by uncertainty or incomplete knowledge about the performance of resource systems and the relationships among their ecological, social, and managerial dimensions (Gunderson, 2008; Johnson, 1999; Manning, 2011; McLain & Lee, 1996). To address such uncertainty and reconcile competition among objectives, adaptive management prescribes an iterative cycle of monitoring, evaluation, planning and action (Lee, 1993; Stankey, Clark, & Bormann, 2005). Through conscious and careful experimentation, this cycle seeks to generate knowledge that can inform the questions asked and answers proposed by the public and resource managers.

The need for and application of adaptive management is exemplified by visitor use management on Half Dome in Yosemite National Park. Under extraordinary demand for high quality recreation experiences, managers at Yosemite are expected to simultaneously facilitate access to the mountain's summit, preserve its wilderness character, and protect visitors' safety. Beyond posing competing objectives for management, the levels of use that compromise wilderness character and visitor safety on Half Dome were not known. Additionally, at the outset of the efforts reported here it was unclear whether or which management action could successfully reconcile objectives for access, preservation and protection. In the face of such competing objectives and uncertainties, adaptive management's iterative cycles and explicit focus on learning provided a mechanism for framing questions and approaching solutions.

To approach reconciliation and realization of these competing objectives, Yosemite National Park embarked on a program of research, planning, action, monitoring, learning, and adaptation that illustrates the strengths and applications of adaptive management. This program was situated within an indicators and standards of quality based framework, which allowed the park's broad and conceptual objectives for Half Dome to be codified in measurable, manageable variables. Beginning with initial monitoring of visitor use in 2008, the program identified indicator variables able to describe and quantify visitor use in terms relevant to wilderness character and visitor safety. With initial conditions of use, wilderness character, and visitor safety documented, standards of quality at which wilderness character and visitor safety are compromised by use level were formulated (Lawson, Choi et al., 2009). These standards, and their related daily use levels, formed the basis for visitor use planning and management action on Half Dome (YNP, 2012). An interim permit system designed to constrain use within wilderness character and visitor safety standards was implemented for weekends in 2010 (YNP, 2010). Conditions of visitor safety and wilderness character were monitored, their relationships to use evaluated, and the results incorporated into park planning (YNP, 2010). Additionally, simulation experiments were conducted to test the effectiveness of alternative management scenarios (Lawson, Kiser, & Reigner, 2011). The experience from the 2010 permit system and knowledge from the simulation experiments, combined to inform planning and implementation of a new and more robust permit system in 2011 (YNP, 2012). Following the iterative cycling of adaptive management, visitor use, wilderness character, and visitor safety were again monitored and this knowledge was incorporated into a NEPA Environmental Assessment that may ultimately lead to permanent implementation of a permit system for Half Dome (YNP, 2012). The adaptive management program enacted on Half Dome has been successful on two counts. It has informed managers and the public about the performance of the park's visitor use and management systems, as well as helped reconcile and realize competing objectives for the mountain.

As a focus for competing resource use and social objectives, Half Dome is not unique among park and wilderness areas. Indeed, such competition is characteristic in all parks and recreation areas. At the highest level, this competition is enshrined in the National Park Service's mandate to both protect resources unimpaired and provide for their enjoyment by the public. More practically, competing objectives for recreation resources often manifest in conflict among users of varying motivations, expectations and activities, between ecological and human values, and/or along boundaries between public land and neighboring private interests (Meretsky, Wegner, & Stevens, 2000; Pettengill et al., 2012; Reigner & Lawson, 2009, Stern, 2010; Vaske, Needham, & Cline, 2007). Adaptive management programs, while not a sole or complete solution for reconciling these objectives, provides a framework within which competing interests can be simultaneously considered, knowledge of their effects and relationships generated, and actions tested (Ruhl, 2008). A benefit of this approach is the insurance that commitment to consistent observation and collective reflection will at least generate knowledge, even if objectives are not immediately achieved (Gunderson, 1999; Lee, 1993; Stakey, Clark, & Bormann, 2005).

Key to the learning process enabled by adaptive management, and demonstrated through the Half Dome visitor use management program, is experimentation – a willingness on the part of management and the public to consider, implement and monitor the effects of alternative actions. However, experimentation, particularly with large scale, complex and ecologically and socially sensitive systems, may be perilous (Johnson, 1999; Lee, 1993; McLain & Lee, 1996). Simulation modeling is a tool that can help adaptive management's experimentation avoid some of the costs and consequences associated with taking action in the face of uncertainty. With their ability to estimate the outcomes of alternative management actions from empirical data and theoretical prediction in a virtual model space, simulations can mitigate some of the threat adaptive experimentation places on sensitive resources (Cole, 2005; Lawson et al., 2008; Skov-Petersen & Gimblett, 2008). Beyond informing managers of and insulating resources from the unknown effects of alternative actions, simulation models can be used to educate and solicit input from the public about resource management decisions. By illustrating the competing objectives for resource use and the consequences or advantages of management action and objective prioritization, simulation models can bolster the effectiveness and success of public participation processes (Hunt et al., 2010; White et al., 2010). As illustrated by the role it played in Half Dome visitor use management, simulation modeling can be an effective tool to augment, enhance and make more feasible the experimentation required by adaptive management.

While the case of Half Dome suggests adaptive management is a powerful framework for reconciling competing objectives and promoting learning, its effective application does face some challenges. As discussed earlier, the experimentation and action prescribed by adaptive management can have real consequences when applied to sensitive resources. When action is taken without full or certain knowledge of the consequences, resource and experiential qualities can be compromised and political interests incensed (McLain & Lee, 1996; Johnson, 1999). This challenge can be met, in some degree, through the generation of information and social learning inherent in the cyclic monitoring, evaluation and planning of adaptive management, as well as by the use of simulation techniques (Lee, 1999; Lawson et al., 2003; Lawson et al., 2009; Stankey, Clark, & Bormann, 2005). Along with the potential unintended or unwanted consequences of uncertain actions, the administrative resources required for their successful execution can challenge adaptive management programs. Because of their iterative nature, adaptive management programs extend through time as conditions are monitored and evaluated, plans formulated, action taken, effects monitored, and management adapted. In some cases, managers or resources may not have the luxury of adequate time to endure this process. Conversely, circumstances likely to incur public criticism or legal challenge may warrant and benefit from the time necessary for iterative, science-based adaptive planning and management. Regardless of circumstances management programs require a commitment to repeated monitoring. Such monitoring involves ongoing investments of time, money and staff. Even in the face of these challenges, however, adaptive management offers the potential for evolving knowledge and effective action that can benefit a diversity of park and wilderness management endeavors.

Conclusion

The program of visitor use management on Half Dome exemplifies the successful application of adaptive management to parks and wilderness recreation areas. When faced with competing demands of public access, wilderness character preservation, and visitor safety protection, Yosemite National Park embarked on a four-year long campaign of monitoring, evaluation, planning and action. Through this process, indicators of quality were identified to characterize use, wilderness character, and visitor safety. The relationships among these indicators were studied and standards of quality that balance the competing objectives were formulated. With iterations of simulated and actual management action, coupled with ongoing monitoring, park managers implemented a process that effectively accomplishes its objectives for Half Dome. The process of visitor use management on Half Dome, and the lessons it teaches about the challenges to and execution of adaptive management, can serve as an example for other park and recreation areas faced with reconciliation of competing objectives for visitor use and resource quality.

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