Half Dome Trail Visitor Use Monitoring Report

Prepared by:

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Executive Summary

This report details findings from the 2010 study to document visitor use conditions on Half Dome. The impetus for this study was to document the effects on visitor use conditions on and around Half Dome from the recently implemented three-day permit system to limit daily visitor use to 400 people per day. Specifically, this study collected data to answer the following research questions: 1) What are the changes in visitor use conditions on the Half Dome Trail compared to conditions documented in Lawson et al 2009?; 2) Does the 400 daily permit system maintain unimpeded travel conditions on the cable route?; 3) Is a Friday through Sunday permit system effective in maintaining desired conditions?; 4) Is recreational displacement occurring from Monday through Thursday, non-permit days during the 2010 season? 5) What is the amount of use on the summit across various use conditions?

Data were collected on Half Dome from June 23, 2010 to September 14, 2010 and sample days were stratified by permit and non-permit days. The following variables were collected: 1) People-at-one-time (PAOT) on the cable route; 2) PAOT on the summit; 3) Group size; 4) trail encounters with individual people and groups; 5) Overall visitor use levels measured using automated visitor monitors.

Results from this study show a large amount of temporal displacement occurred as a result of the three-day permit system where visitor use on Half Dome is lower on permit days than on non-permit days. Specifically, average daily visitor use in 2010 on permit days (i.e., 301 visitors/day) is similar to average daily visitor use on weekdays in 2008 (i.e., 416 visitors/day). Likewise, average daily visitor use in 2010 on non-permit days (i.e., 635 visitors/day) is similar to average daily visitor use on Saturdays and holidays in 2008 (i.e., 692 visitors/day). Thus, it appears that an unintended consequence of the permit system was the interchange of use levels from weekend to weekdays.

Evaluative data about safety and visitor experience was estimated in the 2008 study and provide a base from which to consider PAOT on the cables in 2010. Specifically, the 2008 study identifies thresholds of: 1) 30 PAOT to provide for unimpeded visitor travel on the cable route, and 2) 70 PAOT when visitors perceive safety issues and unacceptable experiential conditions on the cable route. In 2010 on permit days the 30 PAOT threshold was exceeded only 15% of the time and the 70 PAOT threshold was not exceeded on any sample days. In contrast, on non-permit days the threshold of 30 PAOT was exceeded the majority (65%) of the time and the 70 PAOT was exceeded about one-quarter of the time (23%). Similarly regression models were estimated and strong statistical relationships were found between daily levels of use on Half Dome and visitor use conditions on and around Half Dome (i.e., PAOT on the cable route, PAOT on the summit, and trail encounters in wilderness). These results suggest that the objectives of visitor safety and acceptable experiential conditions on the cable route cannot be provided using a daily visitor use permit system that is implemented only on weekends and holidays.

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1. Introduction

In January 2010, Yosemite National Park (YNP) announced interim measures to actively manage visitor use on the Half Dome cables through a 400 people per day permit system for weekends and holidays. This action was complimented with the initiation of the Half Dome Trail Stewardship Plan Environmental Assessment (EA) to determine a long term management solution for visitor use on the trail, including the cable route. The two year implementation of the interim permit system provides an environment where visitors can manage their own risk, and allows YNP managers to understand the efficacy of the permit system in improving safety and visitor experience dimensions on the Half Dome trail and cable route. Equally, this enables the public to experience aspects of a visitor use management system that are likely to be outlined in one or multiple alternatives within the planning process.

The interim permit system was instituted under superintendent's order for reasons pertaining to visitor safety and experience. The number of hikers on the Half Dome cable route has been shown to influence the travel times of visitors both on the ascent and descent of the cable route (Lawson et al., 2009). This involuntary restriction of visitor movement has produced unacceptable conditions at certain times during peak use conditions. The implementation of the 400 people per day interim permit was established to ensure 'free flow' conditions. 'Free flow' is defined in this report as visitor movement that is unimpeded by the presence of other visitors on the cables. On Half Dome, this has been documented to average 23 minutes for ascension and 19 minutes to descend the cables (Lawson et al., 2009). Maintaining these travel times improves safety measures within this unique wilderness setting, giving visitors the ability to travel on their own terms and manage their own levels of risk.

The 2010 Half Dome Trail Visitor Use Monitoring Program was initiated to compile new data to compare with the discrete variables that were collected in a 2008 study (Lawson et al., 2009). The monitoring results serve as a valuable source of knowledge and are key to understanding visitor landscape interactions post permit implementation. Aside from the original variables examined in 2008, additional variables were collected in 2010 to identify potential relationships across use levels and inform visitor use simulation modeling scenario analyses (using Extend simulation software)currently being developed by Resource Systems Group (RSG). The core questions that YNP managers sought to better understand through monitoring conditions in 2010 included:

1) What are the changes in visitor use conditions on the Half Dome trail in 2010 compared to conditions documented in 2008?
2) Does the 400 people per day permit system maintain 'free flow' travel conditions on the cable route?
3) Is a Friday through Sunday permit system effective in maintaining desired conditions on these traditionally high use days?

4) Is recreational displacement occurring from Monday through Thursday, non-permit days, during the 2010 season?
5) What is the amount of use on the summit across various use conditions?

The data collected during the 2010 field season predominantly included observation variables, methods which have been determined by the National Park Service Social Science Division to not require approval by the Office of Management and Budget according to the Paperwork Reduction Act. Methods for the study components will be outlined in the next section, however, collecting travel time data was the only method that required visitor contact for approval or refusal to physically carry a delay card during the visitor's hike.

The comprehensive list of monitoring components included:

A) Photographic documentation of People-at-one-time (PAOT) on the cable route
B) Observation counts of PAOT on summit
C) Automated visitor counters
D) Regression modeling
E) Wilderness encounters
F) Visitor travel time

In addition to visitor use monitoring, the Half Dome Visitor Use Model developed from the 2008 research will be used by RSG to simulate four different visitor use management scenarios. Results of the simulations will be communicated in tabular format and reported to YNP managers in a separate document by January 2011. The scenario simulations will provide information about crowding and travel times on the cables under four distinct visitor use conditions, including:

1) Scenario 1: 400 people per day, existing interim permit system
2) Scenario 2: Solving for maximum number of people per day while retaining 'free flow' conditions on the cable route, maximizing access within necessary safety parameters
3) Scenario 3: Lightning strike, evacuation descent from summit, travel times to descend the cables in a hurried, mass departure event
4) Scenario 4: Via Ferrata, changes to existing infrastructure and requiring mandatory harness and anchoring for cables travel

The combination of simulation results and the visitor use monitoring thoroughly analyzes the visitor use environment of the Half Dome trail and cable route. Additionally, the information presented in this report provides a thorough understanding of visitor use conditions on Half Dome in order to make informed management decisions. Significant levels of understanding have been captured by documenting the effects of visitor use conditions through monitoring and comparing them to the management objectives for this iconic park feature.

2. Methods

(A) Study Area

Data were collected at the following locations (Figure 1): the summit of Half Dome (denoted as X4), the cable route from the subdome to the summit (segment between X3 and X4), the subdome (polygon directly to the east of X3), the base of the subdome (X2), the trail segment from the Half Dome trail junction to the subdome (light orange colored line), and the trail segment from Nevada Falls to the Half Dome trail junction (dark orange trail segment).

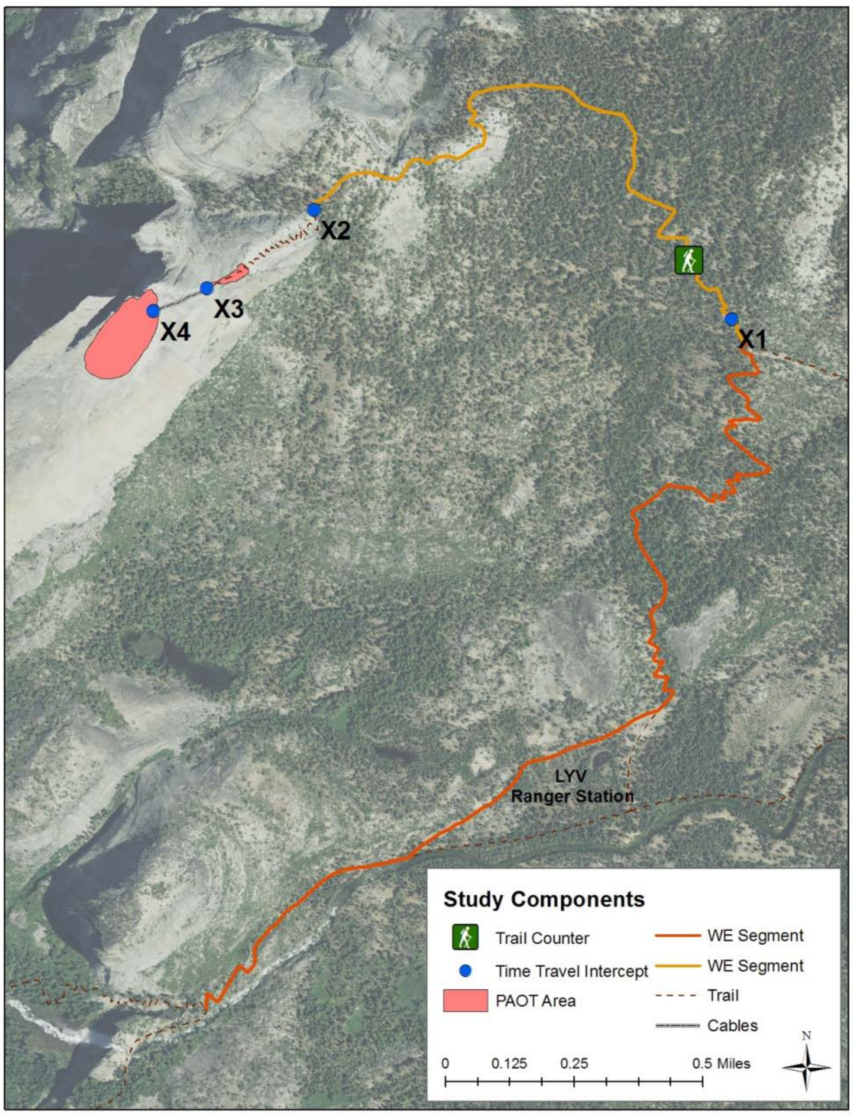

Figure 1. Map of Half Dome study area.

(B) Photographic Observation on Cable Route

PAOT on the Half Dome cable route was recorded using repeat photography on 13 sample days, including weekdays, weekend days, and holidays, from the June 25, 2010 through September 2, 2010 (Table 1). The protocols for photographic documentation of visitor use on the Half Dome cable route were based on previous research conducted by Lawson et al. (2009). Photographic observations, recorded to document PAOT on the cable route, were recorded at the subdome and capture visitor use on the 600 foot portion of the cable route visible from that vantage point.

Photographic observations were recorded in 20 minute intervals from 9:00 AM to 3:40 PM, which produced 21 photographs per day, to estimate PAOT on the cables throughout the busiest seven hour period. A total of 266 photographs were recorded. Photographic observations were recorded using a digital SLR camera, saved as .jpg files, and catalogued using a photographic observation log sheet.

Table 1. Sampling days for Half Dome cable route photographic observation.

Date	Day of Week	Period of Observation	Number of Observations
6/27/2010	Sunday	9:00 AM – 3:40 PM	21
6/28/2010	Monday	9:00 AM – 3:40 PM	21
7/3/2010	Saturday	9:00 AM – 3:40 PM	21
7/4/2010	Sunday	9:00 AM – 3:40 PM	21
7/21/2010	Wednesday	9:00 AM – 3:40 PM	21
7/25/2010*	Sunday	9:00 AM–10:40 AM,12:40 AM–3:40 PM	15
7/26/2010	Monday	9:00 AM – 3:40 PM	21
7/28/2010	Wednesday	9:00 AM – 3:40 PM	21
7/31/2010	Saturday	9:00 AM – 3:40 PM	21
8/4/2010	Wednesday	9:00 AM – 3:40 PM	21
8/7/2010*	Saturday	9:00 AM – 3:20 PM	20
8/20/2010	Friday	9:00 AM – 3:40 PM	21
9/1/2010	Wednesday	9:00 AM – 3:40 PM	21
			Total = 266

* Observations were suspended during hazardous weather conditions and are indicated by incomplete sampling periods

There were a total of 70 days in the sampling period from June 25 – September 2 comprised of 31 permit days and 39 non-permit days. Observations for this study were collected on 7 permit days (23% of all sampling period permit days) and 6 non-permit days (15% of all sampling period non-permit days). Descriptive statistics were calculated using Microsoft Excel and statistical comparisons were estimated using SPSS 18 statistical software.

(C) PAOT on Summit

PAOT data on the Half Dome summit had not been collected previously and was a gap in knowledge about visitor use conditions on Half Dome. PAOT observations on the Half Dome summit were recorded in 2010 by human observation on 17 sample days, including weekdays, weekend days, and holidays, from June 25 through September 2 (Table 2). The PAOT observations on the summit were recorded in 20 minute intervals from 9:00 AM to 3:40 PM, producing 21 PAOT counts per day, to estimate the number of PAOT on the summit throughout the busiest seven hour period. A total of 340 counts were recorded. The protocol involved observers counting the total number of people on the summit of Half Dome while walking from the northeast corner to the southwest corner across the summit. Observers recorded the date and time of the observation along with the total number of people on the summit.

Table 2. Sampling days for Half Dome summit PAOT observation.

Date	Day of Week	Period of Observation*	Number of Observations
6/27/2010	Sunday	9:00 AM – 3:40 PM	21
6/28/2010	Monday	9:00 AM – 3:40 PM	21
7/4/2010	Sunday	9:00 AM – 3:40 PM	21
7/8/2010*	Thursday	9:00 AM – 12:20 PM	11
7/10/2010	Saturday	9:00 AM – 3:40 PM	21
7/12/2010*	Monday	9:00 AM – 1:40 PM	15
7/21/2010	Wednesday	9:00 AM – 3:40 PM	21
7/26/2010	Monday	9:00 AM – 3:40 PM	21
7/28/2010*	Wednesday	9:00 AM–12:20 PM; 1:00 PM–3:40 PM	20
7/31/2010	Saturday	9:00 AM – 3:40 PM	21
8/4/2010	Wednesday	9:00 AM – 3:40 PM	21
8/7/2010	Saturday	9:00 AM – 3:40 PM	21
8/13/2010	Friday	9:00 AM – 3:40 PM	21
8/20/2010	Friday	9:00 AM – 3:40 PM	21
8/22/2010	Sunday	9:00 AM – 3:40 PM	21
8/27/2010	Friday	9:00 AM – 3:40 PM	21
9/1/2010	Wednesday	9:00 AM – 3:40 PM	21
			Total = 340

* Observations were suspended during hazardous weather conditions and are indicated by incomplete sampling periods

There were a total of 70 days in the sampling period from June 25, 2010 – September 2, 2010 comprised of 31 permit days and 39 non-permit days. Observations for this study were collected on 9 permit days (29% of all sampling period permit days) and 8 non-permit days (21% of all sampling period non-permit days). Descriptive statistics were calculated using Microsoft Excel and statistical comparisons were estimated using SPSS 18 statistical software.

(D) Automated Visitor Counters

Equipment

TRAFx (Canmore, Canada) active infrared monitors were used to estimate visitor use on the Half Dome trail approximately ¼ mile beyond the junction with the John Muir Trail (Figure 1). The TRAFx monitor system is comprised of a single infrared scope connected to a small memory unit and stores up to 14,000 hourly counts. The monitor registers a count when the scope detects the infrared signature of a warm moving object. TRAFx units were enclosed inside steel boxes for security and mounted to trees adjacent to trail sections of interest with ¾ inch steel strapping (Figure 2). The Half Dome trail TRAFx monitor was installed on June 23, 2010 and collected data until September 14, 2010.

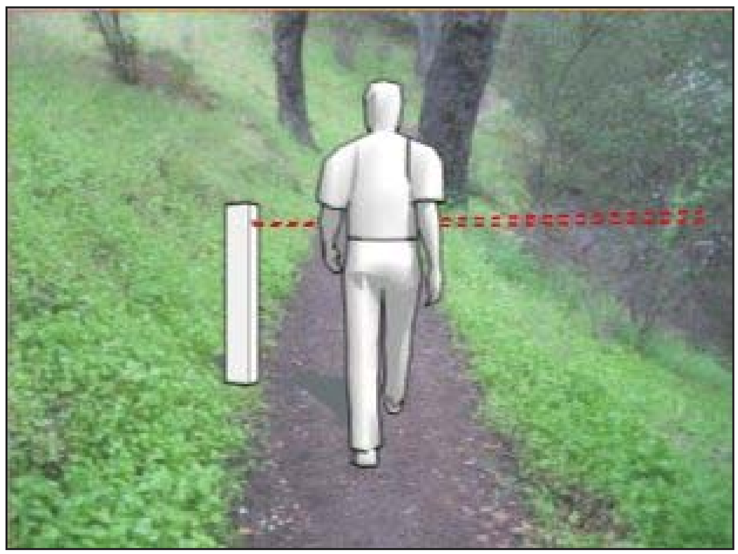

Figure 2. TRAFx visitor counter in lock-box (left) and conceptual example of counter in operation (right).

In addition to the TRAFx unit, an Eco-Counter (Lannion, France) automated counter was installed at the same study location. The Eco-Counter monitoring system detects and quantifies the direction of a hiker's travel as well as recording overall hiker counts. The Eco-Counter, which is capable of storing one continuous year of data (i.e. 365 days), was installed July 22, 2010, and collected data until September 14, 2010.

Monitor Calibration

Monitor locations have unique physical aspects (i.e., trail slope and trail width), and set-up characteristics, that contribute to the amount and variation of monitor counting error. For example, on a wide trail, people walking side by side in groups increases the chances of not all visitors being detected by a mechanical counter. In contrast, narrow trails force people to walk single file and pass a counter one at a time, increasing the chances of an individual being detected by a monitor. Similarly, monitor counts are subject to error from different types of environmental conditions such as heavy snow or blowing vegetation (Vaske & Donnelly, 2007). Thus, raw data from automated counters cannot be treated as reliable and accurate measures of visitor use, rather, calibration through direct observation is required to estimate automated counter data error in order to produce reliable estimates of visitor use (Pettebone et al., 2010a).

Visitor monitors on the Half Dome trail were calibrated via direct observation during July and August, 2010. Observations to calibrate the automated monitors were recorded throughout the course of the day to ensure that the variability of daily visitor use was captured during calibrations. Sixteen hours of observations were obtained for the TRAFx monitor and 6 hours for the Eco-Counter. Based upon direct observation, unique correction factors were calculated for each visitor monitor. Observations were obtained using a convenience based sampling design due to scheduling conflicts with concurrent research projects, however, previous work using automated visitor monitors found that monitor counting errors are consistent regardless of the amount of visitor use passing a monitor (Pettebone et al., 2010a).

Data Management

Data from the TRAFx counter were downloaded directly to a TRAFX G3 Dock (i.e., a field data collector) and then uploaded to a personal computer. These data were in a format where each row in the dataset represents an hourly count. In order to aggregate the raw count data, the data was imported into Microsoft Access and queried using structured queried language (SQL) to examine daily visitation. Data from the Eco-Counter was downloaded using a Personal Digital Assistant (PDA) running Eco-Pocket software and then uploaded to a personal computer. These data were then organized and queried by day and hour using Eco-PC software. Tables from these queries (for both the TRAFx and Eco-Counter) were exported into Microsoft Excel and subsequently into the statistical program ‘R’ to estimate visitor use for each respective time period.

Direction of Travel

Direction of travel needs to be estimated because the number of visitor *arrivals* to a location is used as a proxy for the total number of visitors to an area. Direction of travel was estimated from the Eco-Counter to estimate visitor arrivals at the hourly level. It was assumed that

Analysis

Monitor counting errors were estimated using linear regression techniques. For all automated counters, linear regression models with the regression line forced through the origin were estimated with automated counter measures of hourly visitor use entered as the independent variable and observer-based counts of hourly visitor use specified as the dependent variable. Regression lines were forced through the origin in order to apply ratio estimation techniques to calibrate monitor events. The estimated regression coefficient for the independent variable serves as the correction factor (*r*) for converting raw counter data to estimates of site visitation. To facilitate the analysis, we created a script using the 'R' statistical program to calibrate mean estimates of raw counts in order to estimate mean visitor use at each monitor. Descriptions of the specific steps used to estimate visitor use from automated visitor counters can be found in Pettebone et al., (2010a).

(E) Wilderness Trail Encounters

Wilderness encounter data were collected by trained Yosemite NP Student Conservation Association (SCA) interns to describe and understand wilderness encounter conditions on trails in the vicinity of Half Dome. Observers hiked trail segments within the study area and recorded their encounters with other parties in a standardized data collection pocket notebook. Observers were instructed to hike at the pace of the average hiker, approximately two miles per hour and began data collection for each trail segment by noting the date, time, and trail segment (Table 3).

Table 3. Dates of trail encounter observations.

Date	Permit Day (Y/N)	Time Begin	Time End	Total Hours
Nevada Falls – Half Dome Junction				
Tuesday, July 27[1]	N	9:25 AM	3:17 PM	5.92
Thursday, August 12[1]	N	8:00 AM	4:00 PM	8.87
Friday, August 13	Y	11:00 AM	2:16 PM	3.27
Saturday, August 14	Y	8:30 AM	3:00 PM	6.03
Sunday, August 15	Y	12:30 PM	3:30 PM	3.00
Monday, August 16	N	9:30 AM	1:30 PM	4.18
Saturday, August 21	Y	12:30 PM	3:30 PM	3.00
Monday, August 23	N	11:30 AM	3:00 PM	3.50
Thursday, August 26	N	12:15 PM	3:00 PM	2.75
Saturday, August 28	Y	9:00 AM	11:55 AM	2.12
Thursday, September 02	N	1:00 PM	4:00 PM	2.98
Half Dome Junction - Subdome				
Tuesday, July 27[1]	N	9:22 AM	3:18 PM	5.87
Thursday, August 12[1]	N	8:39 AM	2:59 PM	5.65
Friday, August 13	Y	2:16 PM	5:00 PM	2.73
Saturday, August 14[1]	Y	9:00 AM	2:30 PM	5.95
Sunday, August 15[1]	Y	9:30 AM	3:30 PM	6.00
Monday, August 16	N	8:40 AM	9:329 AM	0.82
Saturday, August 21	Y	9:30 AM	12:30 PM	3.00
Monday, August 23	N	8:30 AM	10:49 AM	1.35
Thursday, August 26	N	9:15 AM	12:15 PM	3.00
Thursday, September 02	N	10:57 AM	1:00 PM	2.98

[1] Multiple observers collected encounter data

Upon completion of the trail segment, the time was recorded. The attributes recorded about each encounter were:1) reference number, 2) time, 3) number of people, 4) number of stock, 5) direction of travel, 6) day or overnight visitor, 7) whether the group was outside of speaking distance (25 feet), and 8) whether the group had been seen previously during the observation period. Observations lasted from 1 – 3.5 hours on each trail segment each day and encounter results were standardized into encounters per hour. Data collection protocols were based on previous wilderness encounter research in Yosemite NP conducted by Broom and Hall (2010). Observers were instructed to conduct observations between 8:00 AM and 6:00 PM. Data was collected from July 27, 2010 – September 02, 2010 with a total of 11 days worth of observations retained, 5 from permit days and 6 from non-permit days, equaling 82.97 hours.

(F) Visitor Travel Time

Travel time data were collected from visitors between the Junction of the John Muir Trail and the Half Dome Trail to the summit of Half Dome. Collection methods included brief visitor contacts requesting approval to participate. Participation consisted of one member of the group physically carrying a delay card (Figure 3) during the hike on the Half Dome trail. Throughout the course of the hiking experience, staff collected the delay card to manually time stamp it.

Four different intercept points were instituted to document the amount of time it took each respondent to physically move between geographic areas of interest to the study. A total of four staff were located at incremental locations to collect temporal data both on hiker ascent and descent from the John Muir Trail junction to the summit of Half Dome, as displayed with intercept locations X1 through X4 in Figure 1. Of primary interest was the data captured through this collection method on visitor movement pertaining to time ascending and descending the cables, and time spent on the summit. However, travel time information was collected on additional trail segments to more comprehensively inform visitor experience considerations. Although there are fewer crowding issues in the lower sections of the trail, some areas are still exposed to lightning/storm events and congestion.

Table 4 displays the sampling days that were captured for visitor travel times. Sampling represents a total of 12 days, stratified across permit (Friday-Sunday and holidays) and non-permit days (Monday-Thursday). Delay card totals were 205 cards for permit days and 286 cards for non-permit days. Differences in solicitations and usable cards came from refusals or unreturned delay cards. No response bias was observed based on group size, a variable observed while interacting with the group.

Half Dome Study 2010

Card #:___________ Date:__________________ Group Size:___________

Location	Current Time *Up* hh:mm:ss	Location	Current Time *Down* hh:mm:ss
Trailhead	Time : :	**Top Cables** ***Enter***	Time : :
Base Sub-dome	Time : :	**Base Cables** ***Exit***	Time : :
Base Cables ***Enter***	Time : :	**Base Sub-dome**	Time : :
Top Cables ***Exit***	Time : :	**Trailhead**	Time : :
		Backpacker	☐Yes ☐ No

Figure 3. The travel time delay card (actual size).

Table 4. Visitor travel time sampling days and returned delay card totals.

Date	Day of Week	Permit Day (Y/N)	Solicitations	Daily Usable Totals
7-9-10	Friday	Y	39	37
7-15-10	Thursday	N	65	45
7-16-10	Friday	Y	51	42
7-17-10	Saturday	Y	55	50
7-18-10	Sunday	Y	38	37
7-19-10	Monday	N	62	47
7-20-10	Tuesday	N	63	45
8-1-10	Sunday	Y	41	37
8-2-10	Monday	N	69	47
8-3-10	Tuesday	N	59	44
8-8-10	Sunday	Y	47	39
8-9-10	Monday	N	63	58

(G) Regression Modeling

Statistical relationships among visitor use data: a) collected via automated counters along the trail to Half Dome, b) PAOT on the Half Dome Cable Route, c) PAOT on the Half Dome summit, and d) wilderness encounters, were explored using various regression techniques. This approach was successfully applied in YNP to estimate visitor use at attraction sites from inbound vehicles measured at entrance gates (Lawson et al., 2009, Pettebone, 2009), and in Devils Postpile National Monument (NM) (Pettebone et al., 2010). For the Half Dome Trail Visitor Use Monitoring study, models at different time scales (i.e., hourly and daily) were estimated to understand how overall use levels are related to PAOT on the cable route and at the summit. The simplest models (i.e., least number of independent variables) that explained the most variability in the dependent variable (e.g., PAOT on the Cable Route and the summit) were identified and reported. Outliers due to the leverage of any single data point (i.e., an unusual level of influence over model estimates) were determined using Cook's test. In addition, residuals from the model were examined for normality using tests for skew and kurtosis. All models presented in this report exhibited no significant leverage and residuals were normally distributed.

3. Results

(A) Photographic Observations on Cable Route

PAOT on the Half Dome cables was variable throughout the course of a day. Figure 3 graphically depicts the changes in PAOT during the hours of highest use and the differences in PAOT between permit and non-permit days. The standard for unimpeded travel conditions on the cable route of 30 PAOT and visitor perceptions of safety and experiential acceptability of 70 PAOT (Lawson et al. 2009) are included in Figure 4.

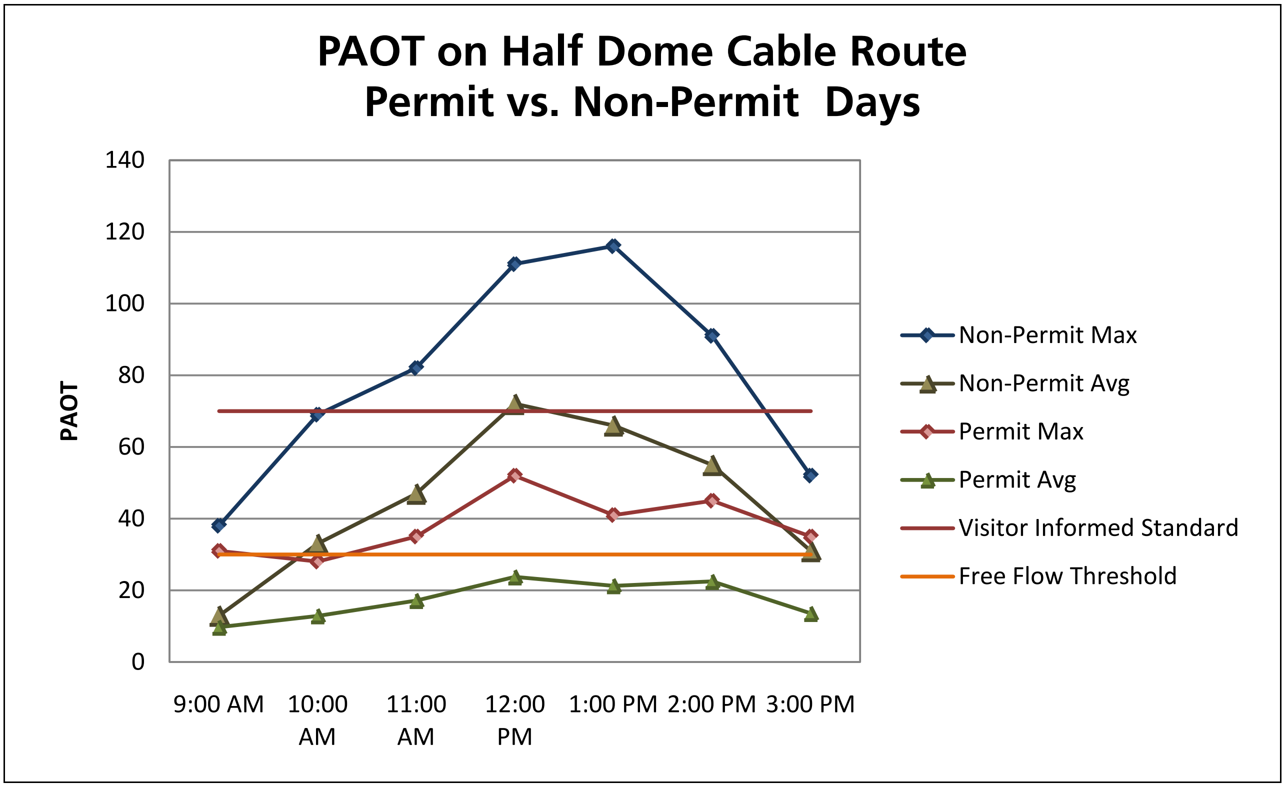

Figure 4. PAOT results for permit and non-permit days on the Half Dome Cable Route.

PAOT on the cable route peaks approximately during the 12:00 PM – 1:00 PM hours on both permit and non-permit days, however, there is a large difference between peak use on permit days compared to peak use on non-permit days. Maximum observed PAOT on a permit day was 52, which occurred on Friday, August 20 at 12:40 PM. Maximum observed PAOT on a non-permit day was 116, occurring on Wednesday, August 4 at 1:20 PM. Figure 5 displays the photographic documentation of PAOT on the cable route during these two time periods. Descriptive statistics of hourly PAOT on the Half Dome cables during the 2010 study are presented in Table 5.

Figure 5. Photographic documentation of maximum PAOT on the Half Dome cable route on a permit day, Friday, August 20 at 12:40 PM (left) and a non-permit day, Wednesday, August 4 at 1:20 PM (right).

Average daily PAOT on the Half Dome cable route was estimated for both permit and non-permit days (Table 6). This dataset was not normally distributed, therefore, we used the Mann-Whitney U non-parametric (Howell, 2007) test to determine if the differences between PAOT on permit and non-permit days were significant. Results indicated statistically significant differences in PAOT on the cable route between permit days and non-permit (Mann-Whitney U = 3,360.5, $p < .001$).

Table 5. Descriptive statistics of hourly PAOT on the Half Dome Cable Route.

Hour/Day Type		Average	Error of Estimation	Median	Min	Max
9:00 AM	Permit	10	±3.40	7	0	31
	Non-Permit	13	±4.19	10	1	38
10:00 AM	Permit	13	±3.13	11	4	28
	Non-Permit	33	±6.88	31	6	69
11:00 AM	Permit	17	±4.12	17	4	35
	Non-Permit	47	±8.98	47	9	82
12:00 PM	Permit	24	±5.39	27	6	52
	Non-Permit	72	±10.47	75	28	111
1:00 PM	Permit	21	±4.37	21	1	41
	Non-Permit	66	±13.68	72	3	116
2:00 PM	Permit	22	±7.40	23	0	45
	Non-Permit	55	±5.36	54	21	91
3:00 PM	Permit	14	±2.71	12	0	35
	Non-Permit	31	±3.67	36	7	52

Table 6. Descriptive statistics of daily PAOT on the Half Dome Cable Route.

Day Type	Average	Error of Estimation	Median	Min	Max
Permit	17.23	±1.71	15.0	0	52
Non-Permit	45.29	±4.44	40.5	0	116

Finally, estimations were calculated for the proportion of time that PAOT standards on the Half Dome cables were violated (Table 7). Results indicate that on permit days, visitor travel on the cable route is unimpeded 85% of the time, and the visitor standard for perceptions of safety and acceptability were not ever exceeded. In contrast, on non-permit days, visitor travel on the cable route was estimated to be impeded 65% of the time and the visitor standard for perceptions of safety and acceptability were exceeded 23% of the time.

Table 7. Proportion of time that PAOT standards on the Half Dome cables are violated.

Day Type		Proportion	Error of Estimation
Permit Days			
	>30 PAOT	15%	5%
	>70 PAOT	0%	0%
Non-Permit Days			
	>30 PAOT	65%	8%
	>70 PAOT	23%	7%

(B) PAOT on Summit

Similar to the Half Dome cable route, PAOT on the Half Dome summit was variable throughout the course of a day. Figure 6 graphically depicts the changes in PAOT during the hours of highest use and the differences in PAOT between permit and non-permit days. PAOT on the summit peaks approximately during the 12:00 PM – 1:00 PM hours on both permit and non-permit days, however, once again there is a large difference between peak use on permit days compared to peak use on non-permit days. Maximum observed PAOT on a permit day was 57, which occurred on Saturday, August 7 at 12:40 PM. Maximum observed PAOT on a non-permit day was 95; this number occurred twice: first on Monday, June 28 at 12:00 PM and again on Thursday, July 8 at 12:20 PM. Descriptive statistics of hourly PAOT on the Half Dome summit during the 2010 study are presented in Table 8.

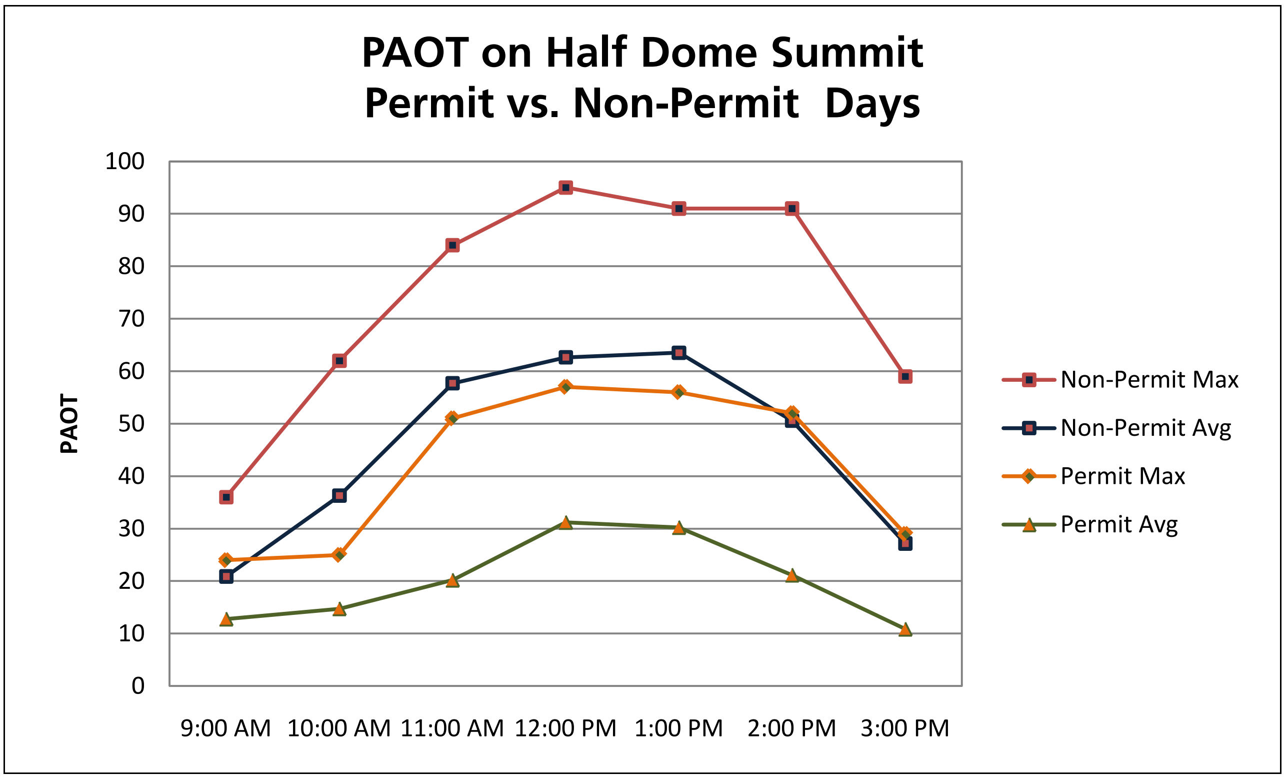

Figure 6. PAOT results for permit and non-permit days on the Half Dome summit.

Average daily PAOT on the Half Dome Cables was estimated for permit and non-permit days (Table 9). These data were not normally distributed, therefore, we used the Mann-Whitney U non-parametric test to determine if differences between average PAOT for permit and non-permit days are significant. Results indicate statistically significant differences in PAOT on the Half Dome summit between permit days and non-permit days (Mann-Whitney U = 4,822, $p < .001$).

Table 8. Descriptive statistics of hourly PAOT on the Half Dome summit.

Hour/Day Type		Average	Error of Estimation	Median	Min	Max
9:00 AM	Permit	12.78	±1.45	12.0	5	24
	Non-Permit	20.88	±3.33	21.0	5	36
10:00 AM	Permit	14.74	±1.64	14.0	5	25
	Non-Permit	36.29	±4.73	35.5	5	62
11:00 AM	Permit	20.19	±3.52	19.0	3	51
	Non-Permit	57.71	±5.85	59.0	24	84
12:00 PM	Permit	31.19	±4.01	29.0	7	57
	Non-Permit	62.64	±8.12	62.5	22	95
1:00 PM	Permit	30.22	±4.39	28.0	10	56
	Non-Permit	63.52	±5.74	64.0	37	91
2:00 PM	Permit	21.15	±4.25	20.0	1	52
	Non-Permit	50.56	±9.58	49.0	16	91
3:00 PM	Permit	10.85	±2.38	9.0	0	29
	Non-Permit	27.17	±6.32	22.5	10	59

Table 9. Descriptive statistics of daily PAOT on the Half Dome summit.

Day Type	Average	Error of Estimation	Median	Min	Max
Permit	16.95	±3.00	17.0	0	57
Non-Permit	42.39	±3.26	45.0	0	95

(C) Automated Visitor Counters

Calibration Results

Calibration observations were collected for automated visitor counters on the Half Dome trail in order to determine correction factors. Fourteen hours of observations determined that (as expected) the TRAFx counter slightly under-counted pass-by events. Five hours of Eco-Counter observations were collected for both inbound and outbound travel. The Eco-Counter slightly over-counted inbound travel but slightly under-counted outbound travel (Table 10).

Table 10. Calibration results for automated visitor counters.

Monitor	*β**	*SE*	R^2	*df*	*F*	*p*
TRAFx	1.08479	0.02846	0.9911	13	1453.0	<.001
Eco-Counter (Inbound)	0.98034	0.06603	0.9778	5	220.4	<.001
Eco_Counter (Outbound)	1.19100	0.12130	0.9507	5	96.4	<.001

* Regression coefficient is used for the correction factor

Total Visitor Use

Total visitor use for the automated counter was estimated at 40,656 (±2,133). This number represents the total number of people who had arrived at the Half Dome trail junction during the study period, June 23, 2010 – September 14, 2010. Of this total, approximately 28%,11,440 (±600), arrived on permit days and 72%, 29,216 (±1,553), arrived on non-permit days.

Daily Visitor Use

Results from the automated counters placed at the junction of the Half Dome Trail and the John Muir Trail show substantially lower levels of use on permit days than non-permit days. Figure 7 shows total daily use estimates, as estimated from the TRAFx counter data, beginning June 23, 2010 and ending September 14, 2010. These results reveal a substantial difference in visitor use levels between permit days and non-permit.

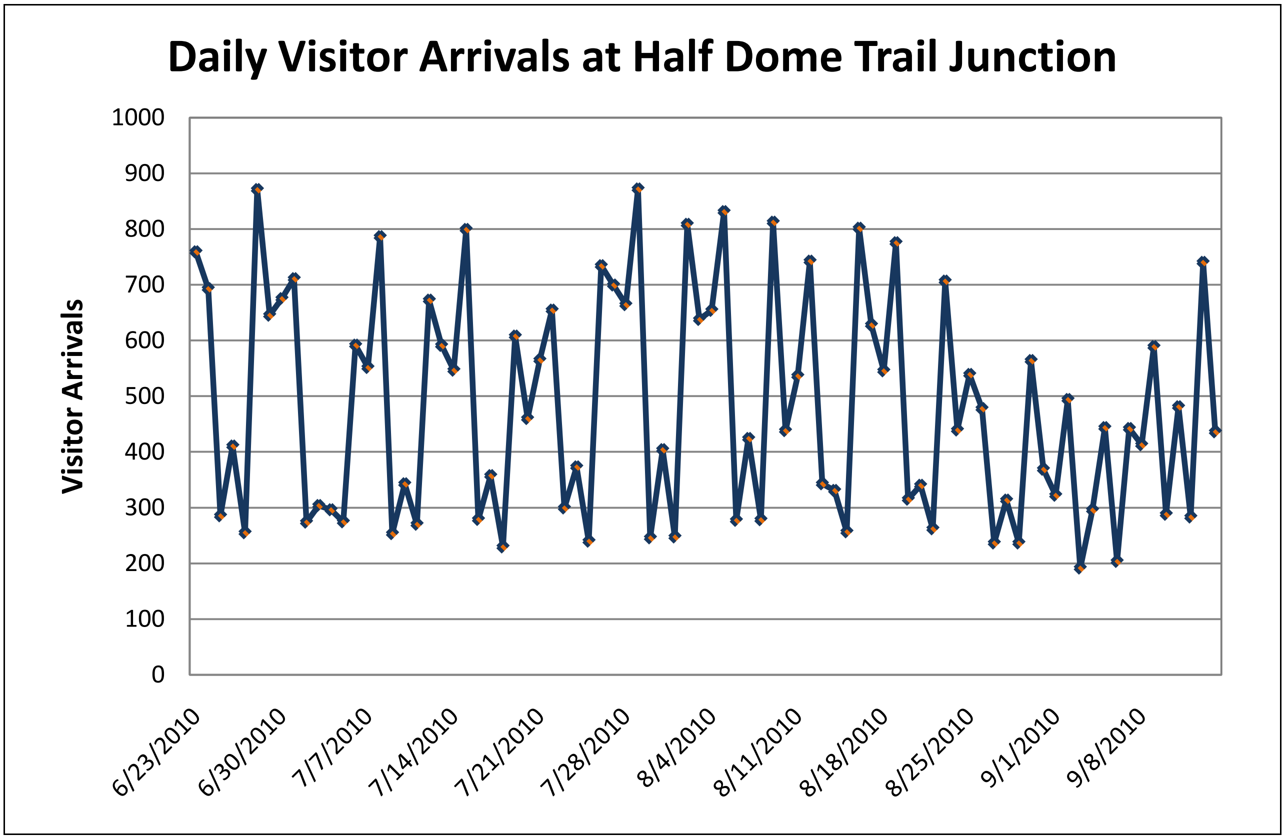

Figure 7. Visitor arrivals at Half Dome Trail Junction from June 23, 2010 – September 14, 2010.

Visitor use by weekday varies slightly. Saturdays are the busiest permit day while Mondays and Thursdays are the busiest non-permit days. Weekday use estimated in 2008 and 2010 are compared in Figure 8. The 2010 estimates are based on data collected from June 23 – September 14 and the 2008 data was collected from July 11- August 10. The 2008 data shows substantially higher levels of visitor use on weekends, particularly Saturdays, compared to weekdays. Visitor use on Mondays and Thursdays in 2010 is comparable to visitor use on Saturdays in 2008 (excluding outliers). Descriptive statistics of weekday results from 2010 are presented in Table 11.

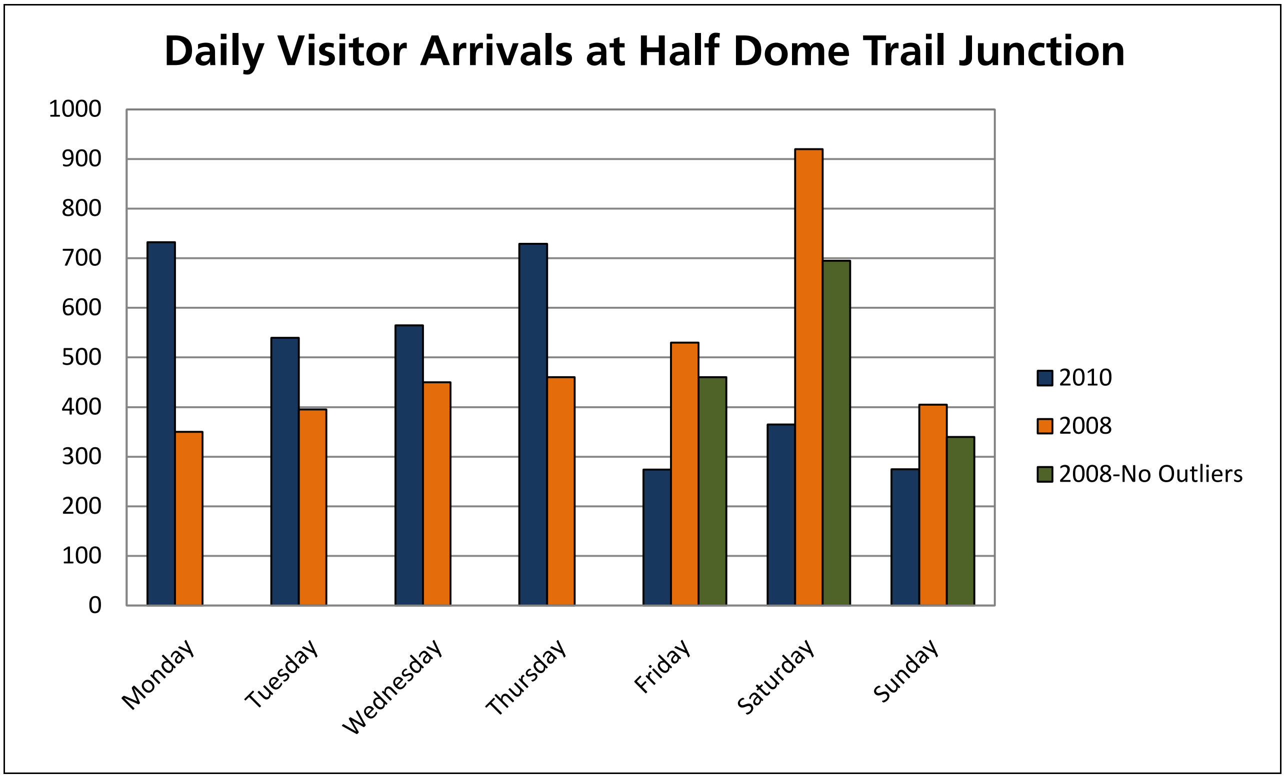

Figure 8. Visitor arrivals at Half Dome Trail junction by weekday.

Table 11. Descriptive statistics of visitor arrivals at Half Dome trail junction.

Day of Week	n	Average	Error of Estimation	Median	Min	Max
Non-Permit Days	43	635.14	±33.33	633	203	872
Monday*	10	732.02	±38.41	737	564	872
Tuesday	11	539.50	±28.31	526	369	700
Wednesday	12	564.41	±29.62	549	322	759
Thursday	10	729.23	±38.26	727	478	872
Permit Days*	38	301.06	±15.80	287	191	481
Friday	12	273.95	±14.37	278	191	343
Saturday	12	364.76	±19.14	350	296	481
Sunday	12	274.81	±14.42	259	229	444

* Holidays (non-permit days) were removed from visitor use estimations for Mondays (July 5 and September 6) and included in estimates for Permit Days

Hourly Visitor Use

Visitor arrivals at the Half Dome junction vary greatly throughout the course of a day with peak arrivals occurring from 10:00 AM – 11:00 AM. The same general arrival trend holds true between permit and non-permit days, however, overall arrivals tend to be much higher on non-permit days than on permit days. Figure 9 provides a comparison between arrival data collected in 2008 and data collected in 2010. The dates of data collection are the same as those described for daily arrivals presented in Figure 7. Peak arrivals for non-permit days in 2010 are comparable to arrivals on Saturdays in 2010 (excluding outliers). Peak arrivals on permit days in 2010 are substantially lower than all other estimates of arrivals presented here. All hourly arrival estimates are presented in Table 12. For the sake of brevity, errors for averages are not presented. The estimated error for the 2010 data is approximately 5.2%, however, estimates are not available for the 2008 data.

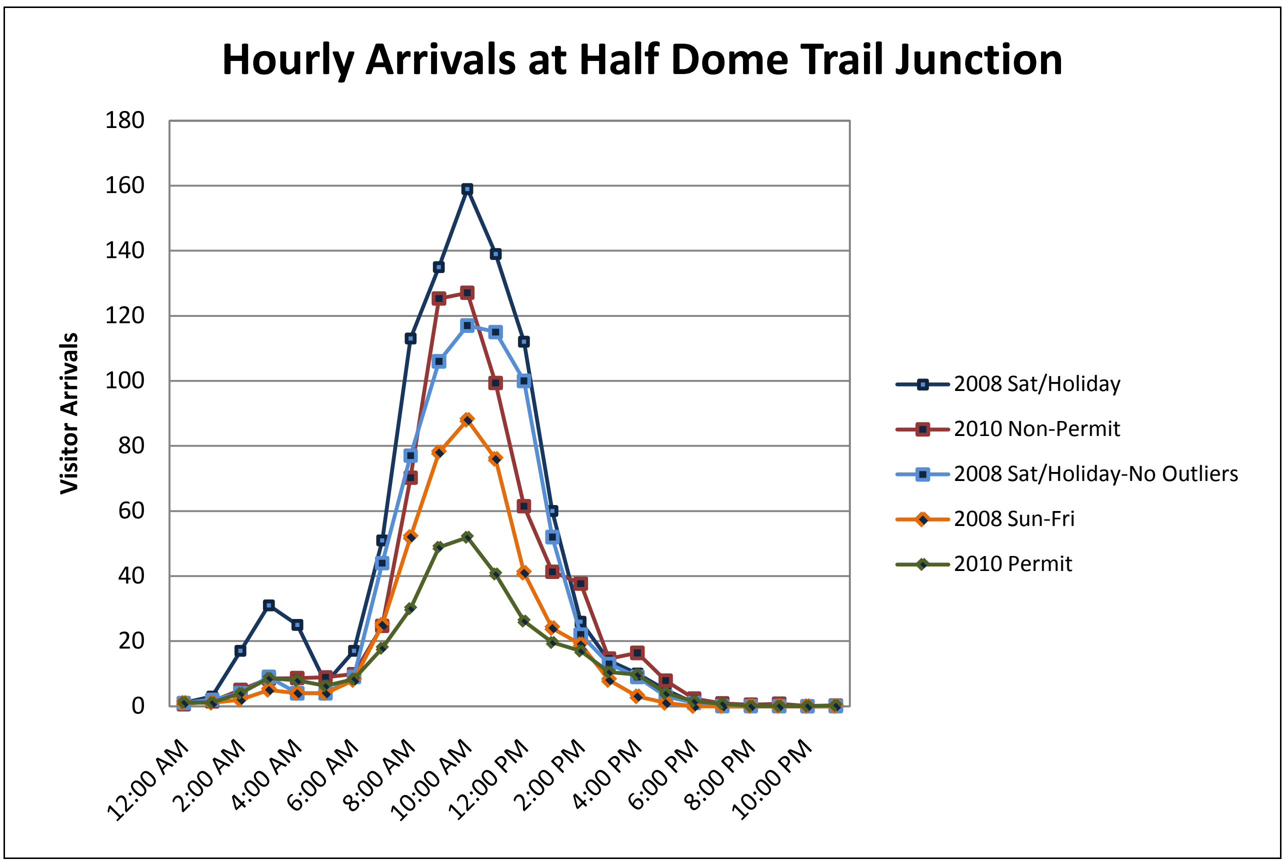

Figure 9. Visitor arrivals at Half Dome trail junction by hour.

Table 12. Average hourly arrivals at the Half Dome trail junction, 2010 and 2008.

Hour	2010 Non- Permit	2010 Permit	2008 Sat/Holiday	2008 Sat/Holiday- No Outliers	2008 Sun-Fri
12:00 AM	0.65	1.17	1	1	1
1:00 AM	1.51	1.11	3	2	1
2:00 AM	5.02	3.96	17	4	2
3:00 AM	8.49	8.61	31	9	5
4:00 AM	8.66	7.95	25	4	4
5:00 AM	8.87	6.30	7	4	4
6:00 AM	9.86	8.36	17	9	8
7:00 AM	24.71	17.84	51	44	25
8:00 AM	70.23	29.99	113	77	52
9:00 AM	125.31	48.80	135	106	78
10:00 AM	127.09	51.89	159	117	88
11:00 AM	99.36	40.62	139	115	76
12:00 PM	61.47	26.17	112	100	41
1:00 PM	41.34	19.60	60	52	24
2:00 PM	37.69	16.98	26	22	19
3:00 PM	14.61	10.52	14	13	8
4:00 PM	16.38	9.71	10	9	3
5:00 PM	7.87	3.96	5	3	1
6:00 PM	2.31	1.53	1	1	0
7:00 PM	0.88	0.77	0	0	0
8:00 PM	0.44	0.06	0	0	0
9:00 PM	0.75	0.09	0	0	0
10:00 PM	0.04	0.09	0	0	0
11:00 PM	0.21	0.27	0	0	0

(D) Wilderness Encounters

About 83 hours of data were collected to estimate wilderness encounter rates for permit days (35.10 hours) and non-permit days (47.87 hours). Results indicate that wilderness encounters with individual people tended to be lower on permit days than on non-permit days along both the trail segment from Nevada Falls to the Half Dome trail junction, and the trail segment from the Half Dome trail junction to the base of the Subdome (Table 13). The encounter data were not normally distributed, therefore, the Mann-Whitney U non-parametric test was used to detect significant differences between hourly encounter rates with individual people on permit and non-permit days. Results indicate statistically significant differences for encounters with individuals between the Half Dome trail junction and the base of the subdome (Mann-Whitney U = 0.00, p = .004). However, results indicate that differences between encounters with individuals hiking along the Nevada Falls – Half Dome trail junction segment on permit and non-permit days is not significant at the 95% confidence interval (Mann-Whitney U = 0.00, p = .052). Caution should be used in interpreting these results due to the small sample size collected for this portion of the study (Broom and Hall, 2010).

Table 13. Descriptive statistics of people encountered along trails in wilderness near Half Dome.

Location/Day Type	*n*	Average	Error of Estimation	Median	Min	Max
Nevada Falls-Half Dome Trail Junction						
Non-Permit Days	6	117.13	30.51	99.10	81.21	180.83
Permit Days	5	67.64	15.62	65.30	48.00	100.63
Half Dome Trail Junction-Subdome						
Non-Permit Days	6	150.51	37.96	135.23	104.00	245.93
Permit Days	4	52.82	10.64	47.56	36.60	73.78

Group encounters were estimated for permit and non-permit days based on the delay card component, administered as part of this overall study. Group size was found to average 4 people on permit days and close to 3 people (2.93) on non-permit days (Table 14).

Table 14. Half Dome hiking group size.

Sample Day	Average	Median	Standard Deviation
All Sample Days	3.42 (N=523)	2.00	4.93
Permit Days	4.00 (N=237)	2.00	7.04
Non-Permit Days	2.93 (N=286)	2.00	1.74

Based on these estimates group encounters were found to be lower on permit days compared to non-permit days (Table 15). These data were not normally distributed, therefore, the Mann-Whitney U non-parametric test was used to determine if significant differences exist between hourly encounter with groups on permit and non-permit days. Results indicate statistically significant differences for hourly encounters with groups between the Half Dome trail junction and the base of the subdome (Mann-Whitney U = 0.00, p = .006) on permit and non-permit days. Results also indicate statistically significant differences between encounters with groups hiking along the Nevada Falls – Half Dome trail junction segment on permit and non-permit days (Mann-Whitney U = 0.00, p = .006).

Table 15. Descriptive statistics of group trail encounters in wilderness near Half Dome.

Location/Day Type	*n*	Average	Std. Error	Median	Min	Max
Nevada Falls-Half Dome Trail Junction						
Non-Permit Days	6	39.98	10.41	33.82	27.72	61.56
Permit Days	5	16.91	3.91	16.33	12.00	25.16
Half Dome Trail Junction-Subdome						
Non-Permit Days	6	51.37	12.96	46.15	35.49	83.93
Permit Days	4	13.21	2.66	11.89	9.15	18.45

(E) Visitor Travel Time

This section outlines visitor travel time data, compared across permit and non-permit days, collected during the 2010 monitoring season. As shown in Figure 10, four intercepts were used to document the travel times of visitors on the Half Dome Trail. Group sizes averaged 3.42 for all day types (Table 15). It is important to note that group size was observed only at the first intercept (X1) and not incrementally along the trail. Thus, attrition rates of groups cannot be understood from these results. Equally, group sizes could have been larger earlier in the trail, with some members turning around or deciding not to continue before the Half Dome Trail Junction. For permit days, group size was 4.0 and may have been heavily influenced by visitors organizing for permit reservations since four is the maximum number of visitors allowed per permit. Visitors who reported group sizes larger than four people could have their group comprising of multiple reserved permits.

Of particular interest are the mean travel times for segments X3-X4 and X4-X4, as displayed in Table 16. These two segments represent ascent times on the cable route, and the time visitors spent on the summit. Comparing the cable route ascent time (X3-X4), permit days exhibited an average time of 28 minutes and 56 seconds, while non-permit days exhibited an average time of 40 minutes and 47 seconds, a difference of nearly 12 minutes on the cables. Interestingly, time on the summit (X4-X4) was longer for permit days than non-permit days.

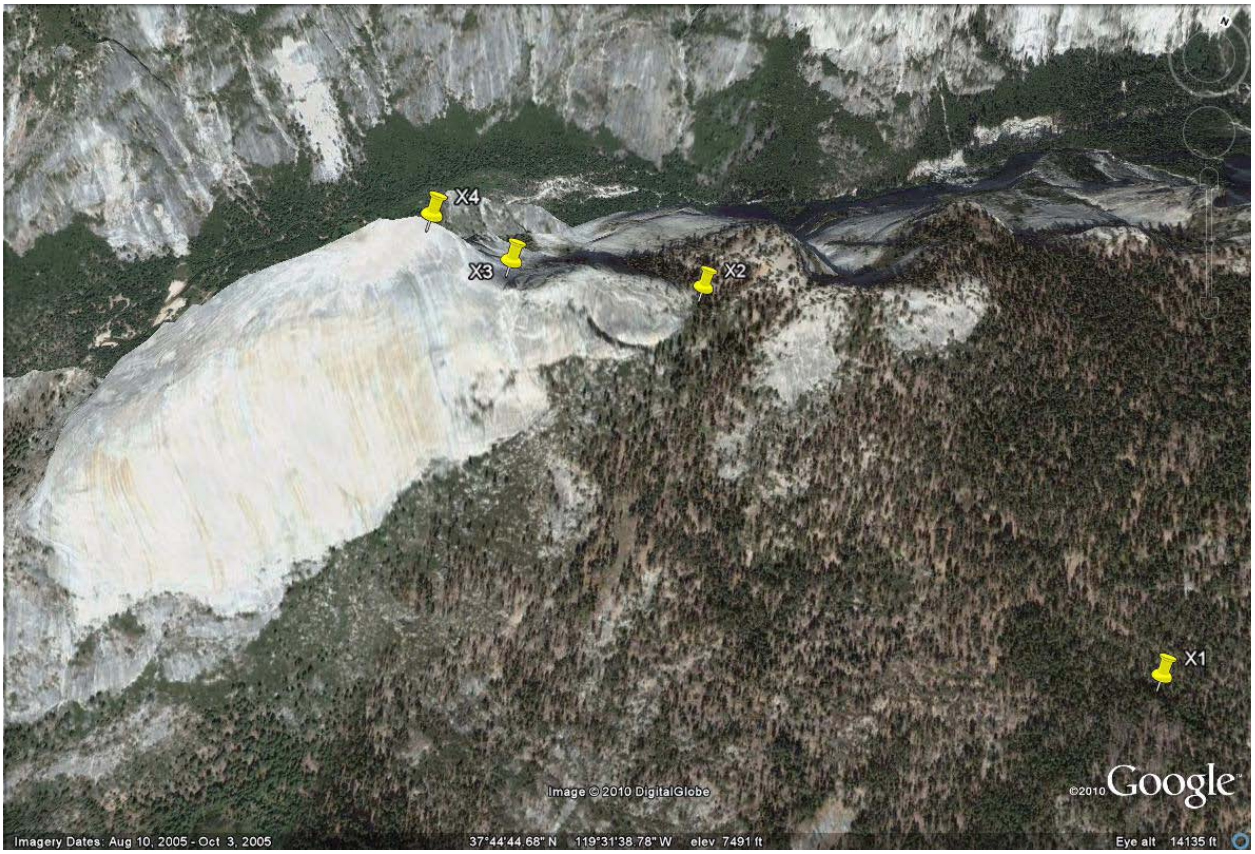

Figure 10. Half Dome Trail segments and travel time intercepts.

Table 16. Mean travel times across day types and trail segments.

Sample Day	X1-X2	X2-X3	X3-X4	X4-X4	X4-X3	X3-X2	X2-X1
All Days	1h03m13s (N=396)	38m41s (N=420)	35m20s (N=350)	50m28s (N=311)	26m57s (N=287)	25m16s (N=266)	43m54s (N=219)
Permit Days	1h00m36s (N=187)	38m21s (N=185)	28m56s (N=161)	52m54s (N=146)	23m57s (N=131)	26m38s (N=130)	42m31s (N=117)
Non-Permit Days	1h05m33s (N=209)	38m57s (N=235)	40m47s (N=189)	48m35s (N=165)	37m15s (N=156)	23m57s (N=136)	45m34s (N=102)

Table 17 outlines the mean times for circuitous ‘out and back’ travel from intercept points. These results are less applicable to crowding and its effects on safety and visitor experience on the cables. For example, if more visitors are encountered on the trail, general movement is typically not slowed, rather, faster visitors will walk around a slower party. As a result, it is not expected that larger differences in travel times would be evident, however, they are important to note for the purposes of storm events, hiker preparedness, and trip planning/communication considerations.

Table 17. Circuitous travel times.

Sample Day	X1 up – X1 down	X2 up – X2 down	X3 up – X3 down
All Days	4h05m33s (N=267)	2h36m02s (N=338)	1h51m28s (N=316)
Permit Days	3h59m40s (N=137)	2h26m38s (N=167)	1h39m57s (N=143)
Non-Permit Days	4h11m45s (N=130)	2h46m07s (N=171)	2h00m59s (N=173)

(F) Regression Analyses

Regression analyses were estimated between daily arrivals at the Half Dome trail (collected by the automated visitor counters) and: 1) PAOT on the Half Dome cable route, 2) PAOT on the summit, and 3) hourly group encounters. In addition, relationships between visitor use on the cable route and the summit were explored. For these analyses *average* and *maximum* PAOT on the cable route reflect visitor use on the cables from 9:00 AM – 4:00 PM.

PAOT on the Half Dome Cable Route ~ Arrivals at Half Dome Trail Junction

Strong statistical relationships were found between daily visitor arrivals at the Half Dome junction and 1) *average* PAOT on the cable route and 2) *maximum* observed PAOT on the cable route. Simple ordinary least squares (OLS) models produced the best fit for estimating the relationship between: 1) *average* PAOT on the cable route and arrivals at the trail junction ($F(1,10)=131.2$, $p<.05$, $R^2=0.9292$), and 2) *maximum* PAOT on the cable route and arrivals at the trail junction ($F(1,10)=63.98$, $p<.05$, $R^2=0.8648$)(Table 14). The minimum arrival count collected by the automated counter for this analysis was 240 and the maximum count was 871.

Table 18. Model parameters to estimate average and maximum PAOT on the Half Dome cable route from daily arrival counts at the Half Dome trail junction.

Variable		β	*SE*	*p*
Average PAOT				
	Intercept	-10.229	3.858	0.024
	Daily Arrivals	0.085	0.007	<0.001
Maximum PAOT				
	Intercept	-10.038	9.883	0.334
	Daily Arrivals	0.152	0.019	<0.001

The coefficient of these models (β) can be interpreted as follows: for every 100 additional visitor arrivals at the Half Dome trail junction *average* PAOT on the cable route increases by about 9 (.085) and *maximum* PAOT on the cable route increases by about 15 (.152). In other words, *maximum*

PAOT on the cable route increases at a higher rate than *average* PAOT on the cable route based on the number of visitors arriving at the Half Dome trail junction.

These results indicate that PAOT on the cables is strongly related to the number of daily Half Dome hikers. The relationship between the number of daily Half Dome hikers and PAOT on the cable route is depicted in Figure 11. The standard for unimpeded travel conditions on the cable route and the visitor standard for perceptions of safety and crowding are included in Figure 11 to allow comparison between how the number of people using the Half Dome trail per day influence desired management conditions on the cable route. Error bars that represent the 95% confidence interval are included with predicted values for maximum and average PAOT.

It is important to note that Figure 9 displays predicted values beyond the range of the data used to estimate the model and that predicted values below 240 arrivals and above 871 arrivals should be interpreted with some caution.

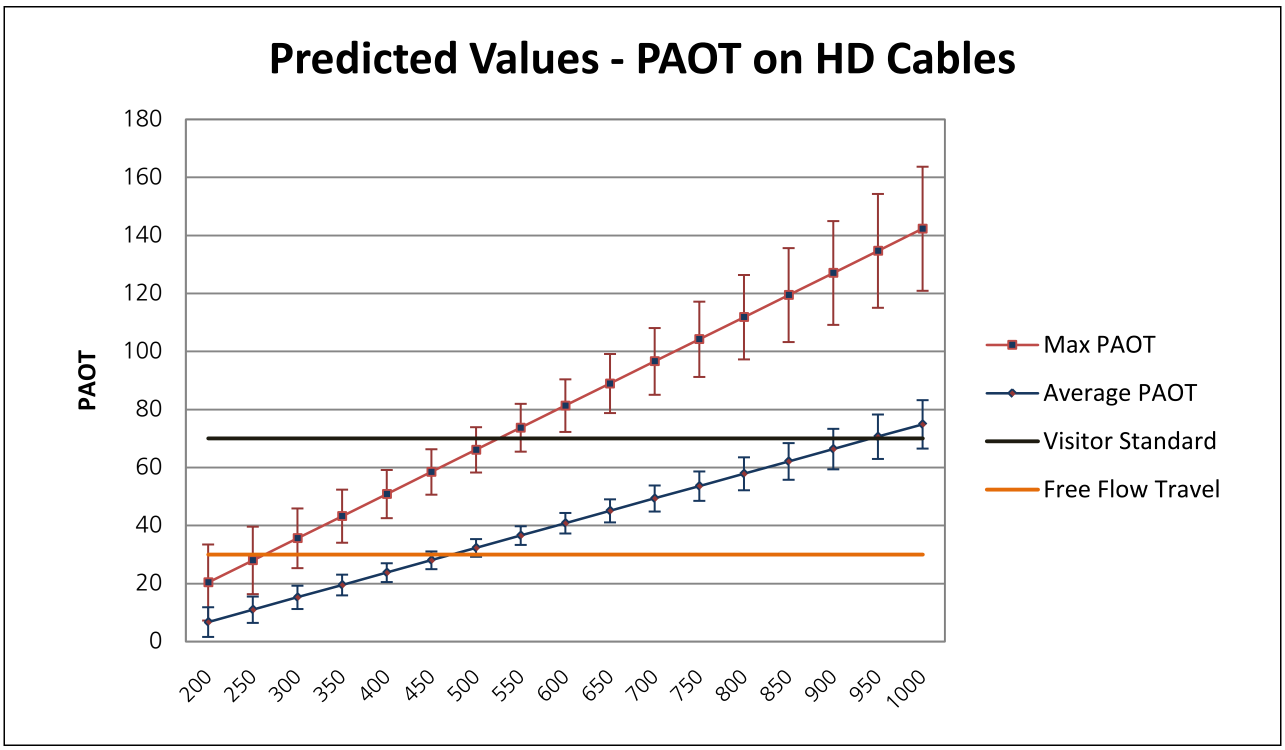

Figure 11. Predicted values for PAOT on the Half Dome cable route.

The model indicates that unimpeded travel conditions are violated during periods of *maximum* PAOT that are related to relatively low numbers of daily Half Dome hikers (i.e., ~300 arrivals).

Average PAOT on the cable route violates unimpeded travel conditions at moderate levels of visitor arrivals at the Half Dome junction (i.e., ~500 arrivals).

Table 19. Predicted values for average and maximum use on Half Dome cable route.

Arrival Count	Average PAOT	Error of Estimation	Maximum PAOT	Error of Estimation
200	6.80	±5.12	20.44	±13.10
250	11.06	±4.54	28.05	±11.62
300	15.32	±4.01	35.67	±10.28
350	19.58	±3.57	43.29	±9.15
400	23.83	±3.24	50.91	±8.30
450	28.09	±3.06	58.53	±7.83
500	32.35	±3.05	66.15	±7.81
550	36.61	±3.22	73.77	±8.24
600	40.87	±3.54	81.38	±9.06
650	45.12	±3.97	89.00	±10.18
700	49.38	±4.49	96.62	±11.50
750	53.64	±5.06	104.24	±12.97
800	57.90	±5.68	111.86	±14.54
850	62.16	±6.32	119.48	±16.19
900	66.41	±6.98	127.09	±17.88
950	70.67	±7.66	134.71	±19.61
1000	74.93	±8.34	142.33	±21.38

PAOT on the Half Dome Summit ~ Arrivals at Half Dome Trail Junction

Similar to the Half Dome cable route analysis, strong statistical relationships were found between daily arrivals at the Half Dome trail junction and 1) *average* PAOT on the summit and 2) *maximum* observed PAOT on the summit. Simple OLS models produced the best fit to estimate the relationship between *average* PAOT on the summit and visitor arrivals at the trail junction ($F(1,13)=189.6$, $p<.05$, $R^2=0.9358$) and *maximum* PAOT on the summit and visitor arrivals at the trail junction ($F(1,13)=99.59$, $p<.05$, $R^2=0.8845$) (Table 20). The minimum arrival count collected by the automated counter for this analysis was 255 and the maximum count was 871.

Table 20. Model parameters to estimate average and maximum PAOT on the Half Dome summit from daily arrival counts at the Half Dome trail junction.

Variable		β	*SE*	*p*
Average PAOT				
	Intercept	-2.841	2.839	0.335
	Daily Arrivals	0.072	0.005	<0.001
Maximum PAOT				
	Intercept	8.141	5.957	0.195
	Daily Arrivals	0.109	0.011	<0.001

The coefficient of these models (*β)* can be interpreted as follows: for every 100 additional visitor arrivals at the Half Dome trail junction *average* PAOT on the summit increases by about 7 (.072) and *maximum* PAOT on the summit increases by about 11 (.109). In other words, *maximum* PAOT on the summit increases at a higher rate than *average* PAOT on the summit based on visitors arriving at the Half Dome trail junction.

These results indicate that PAOT on the summit is strongly related to the number of daily Half Dome hikers. The relationship between the number of daily Half Dome Hikers and PAOT on the summit is depicted in Figure 10. Error bars represent the 95% confidence interval. Standards for visitor safety and visitor experience on the Half Dome summit have not yet been developed.

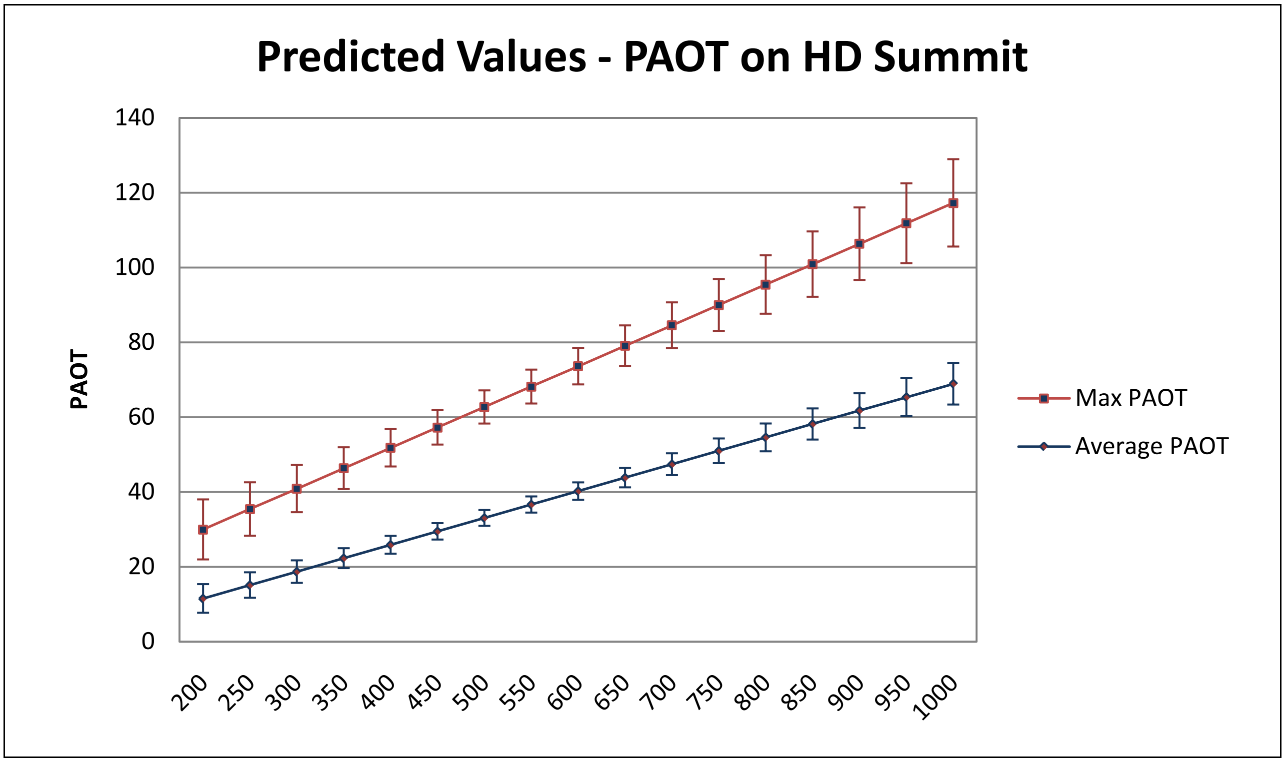

Figure 12. Predicted values for PAOT on the Half Dome summit.

Table 21. Predicted values for average and maximum use on Half Dome summit.

Arrival Count	Average PAOT	Error of Estimation	Maximum PAOT	Error of Estimation
200	11.51	±3.82	29.96	±8.02
250	15.09	±3.40	35.41	±7.14
300	18.68	±3.01	40.87	±6.31
350	22.27	±2.66	46.32	±5.59
400	25.85	±2.38	51.78	±5.00
450	29.44	±2.19	57.23	±4.59
500	33.03	±2.11	62.69	±4.43
550	36.62	±2.16	68.14	±4.53
600	40.20	±2.33	73.60	±4.88
650	43.79	±2.59	79.05	±5.43
700	47.38	±2.92	84.50	±6.13
750	50.96	±3.30	89.96	±6.93
800	54.55	±3.72	95.41	±7.81
850	58.14	±4.16	100.87	±8.73
900	61.72	±4.62	106.32	±9.69
950	65.31	±5.09	111.78	±10.67
1000	68.90	±5.56	117.23	±11.67

PAOT on the Half Dome Summit ~ PAOT on the Half Dome Cable Route

A strong statistical relationship was found between PAOT on the Half Dome cable route and PAOT on the Half Dome summit. A model was estimated for this relationship from *average* hourly PAOT counts, where PAOT on the cable route was input into the model as an explanatory (independent) variable for PAOT on the summit. The term *average* hourly PAOT is used because hourly estimates are based on the *average* of three PAOT observations over the course of one hour documented systematically in 20 minute intervals. *Average* hourly counts were correlated with no time lag. In other words, PAOT counts from 12:00 PM – 1:00 PM on the cable route were correlated with PAOT counts from 12:00 PM – 1:00 PM on the summit. As with the models described in the previous sections, simple OLS models produced the best fit to estimate this relationship ($F(1,77)=239.4$, $p<.05$, $R^2=0.7566$) (Table 22). The minimum *average* hourly PAOT on the cable route in this analysis was 0 and the maximum *average* hourly count on the cable route was 95.

Table 22. Model parameters to estimate average hourly PAOT on the Half Dome summit from average hourly PAOT on the cable route.

Variable	β	*SE*	*p*
Intercept	9.786	1.887	<.001
PAOT on cable route	0.714	0.046	<.001

The coefficient of these models (*β)* can be interpreted as follows: between the hours of 9:00 AM and 4:00 PM an increase in PAOT of 10 on the cable route results in an increase in PAOT on the summit of about 7 (.714).

These results indicate that PAOT on the summit is strongly related to PAOT on the cable route. Figure 13 graphically depicts the relationships between PAOT on the cable route and PAOT on the summit. Error bars represent the 95% confidence interval. Predicted values above the maximum observed PAOT count of 95 should be interpreted with some caution, however, this information is presented in order to provide some understanding of the maximum levels of PAOT observed on the cable route in this study (i.e., 116 PAOT). At low levels of PAOT on the cables (i.e., <30 PAOT) there is a higher level of PAOT on the summit. At 30 PAOT on the cable route there is about 30 PAOT on the summit. When PAOT is higher than 30 on the cable route PAOT tends to be lower on the summit relative to the cable route.

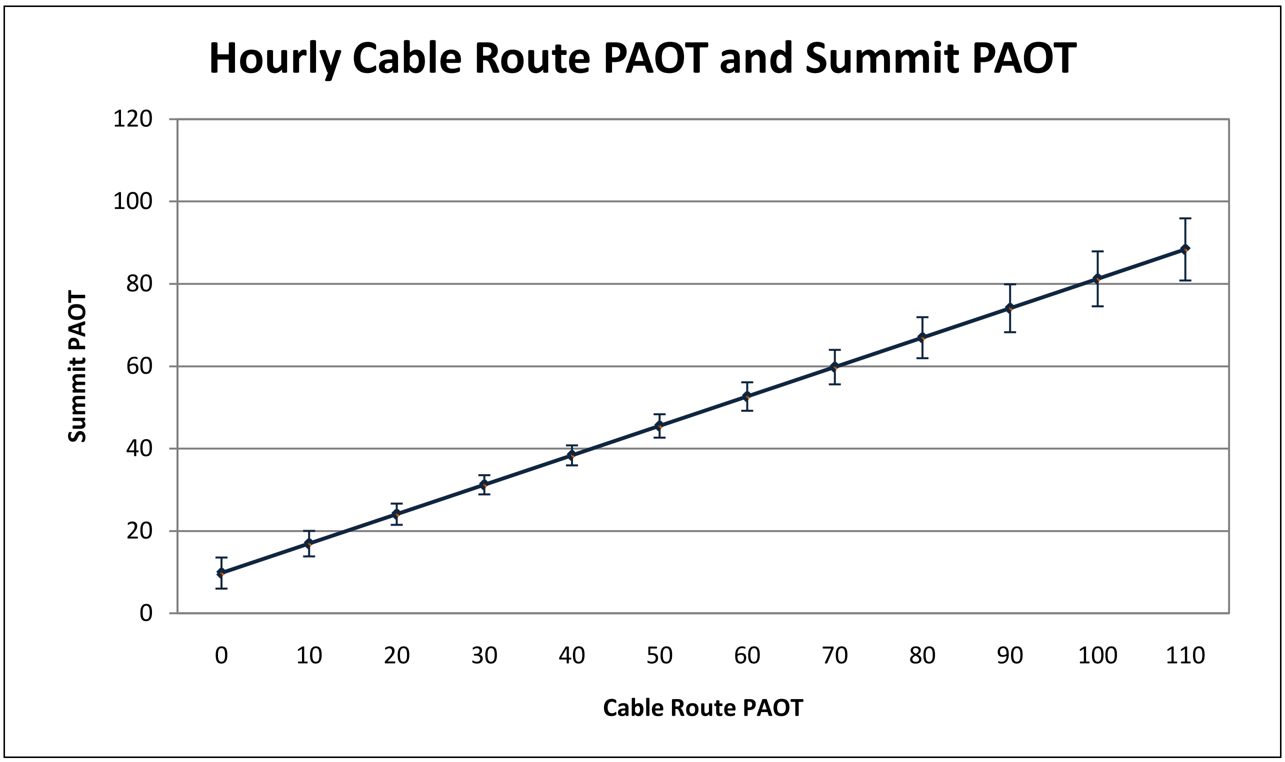

Figure 13. Predicted values for PAOT on the Half Dome summit.

Table 23. Predicted values for average PAOT on the Half Dome summit.

Average Hourly PAOT on Cable Route	Average Hourly PAOT on Summit	Error of Estimation
0	9.79	±3.77
10	16.93	±3.10
20	24.07	±2.58
30	31.21	±2.33
40	38.36	±2.43
50	45.50	±2.84
60	52.64	±3.46
70	59.78	±4.19
80	66.92	±4.98
90	74.07	±5.81
100	81.21	±6.67
110	88.35	±7.54

Group Encounters (Nevada Falls to Half Dome Trail Junction) ~ Visitor Arrivals at Half Dome Trail Junction

A strong statistical relationship was found between group encounters on the trail segment from Nevada Falls to the Half Dome trail junction and daily Half Dome hikers. However, attempts to model this relationship using OLS resulted in models with that exhibited statistically significant leverage. This condition was alleviated by using a negative binomial modeling approach (Zeilis, et al., 2008)($\chi^2 = 15.03$, $df = 2$, $p<0.001$, Pseudo $R^2=0.7495$) (Table 24). The minimum arrival count collected by the automated counter for this analysis was 257 and the maximum count was 802.

Table 24. Model parameters to estimate hourly group encounters on the trail segment from Nevada Falls to the Half Dome trail junction.

Variable	β	*SE*	*p*
Intercept	2.170	0.234	<0.001
Hourly Group Encounters	0.002	<0.001	<0.001

The coefficient of this model represents a positive log-linear relationship which suggests that as the number daily Half Dome hikers increase the rate of increase in group encounters along the trail segment between Nevada Falls and the Half Dome trail junction increases (Figure 14).
These results indicate group encounters along the trail segment between Nevada Falls and the Half Dome trail junction is related to the daily number of Half Dome hikers. Predicted values from 100 to 900 visitor arrivals are presented to provide some understanding of group encounters along this trail segment at a large range of potential visitor use, however, predicted values beyond the range

of the visitor arrivals used to estimate this model (i.e., 257 – 802) should be interpreted with caution. As expected group encounters increase with higher amounts of visitor arrivals to the Half Dome trail. It is important to note that the relationship between group encounters and visitor use levels is not linear (i.e., group encounters tend to increase at a higher rate with more daily Half Dome hikers). To illustrate this point, the increase from 200 - 300 daily Half Dome hikers increases hourly group encounters by 3.8 from 13.71 to 17.51 group encounters per hour. However, the same 100 visitor arrival increase from 600 – 700 increases group encounters by 8.43 from 33.56 to 41.99 group encounters per hour.

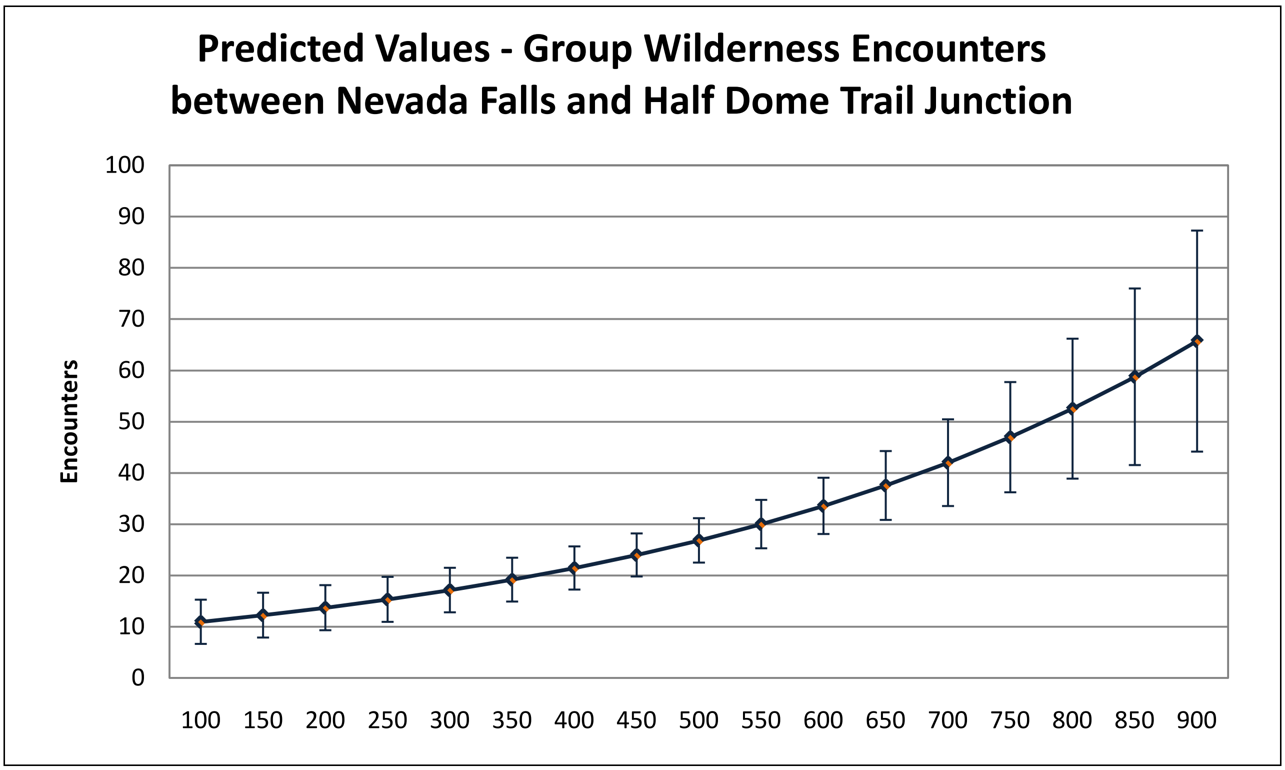

Figure 14. Predicted values for hourly group wilderness encounters on trail segment between Nevada Falls and Half Dome trail junction.

Table 25. Predicted values for hourly group encounters on the trail segment from Nevada Falls to the Half Dome trail junction.

Daily Visitor Arrivals	Group Trail Encounters	Error of Estimation
100	10.96	4.31
150	12.26	4.37
200	13.71	4.40
250	15.33	4.39
300	17.15	4.34
350	19.18	4.27
400	21.45	4.21
450	23.99	4.20
500	26.83	4.33
550	30.01	4.72
600	33.56	5.49
650	37.54	6.71
700	41.99	8.45
750	46.96	10.75
800	52.52	13.65
850	58.74	17.22
900	65.70	21.55

Group Encounters (Half Dome Trail Junction to the base of the Subdome) ~ Visitor Arrivals at Half Dome Trail Junction

Similar to the previous wilderness encounter model, a strong statistical relationship based on a negative binomial model was found to explain group encounters on the trail segment from the Half Dome trail junction to the base of the subdome (χ^2 = 18.22, *df* = 2, p<0.001, Pseudo R^2=0.8366) (Table 26). The minimum arrival count collected by the automated counter for this analysis was 257 and the maximum count was 802.

Table 26. Model parameters to estimate hourly group encounters on the trail segment from the Half Dome trail junction to the base of the subdome.

Variable	β	*SE*	*p*
Intercept	1.780	0.283	<0.001
Hourly Group Encounters	0.003	<0.001	<0.001

These results indicate that group encounters along the trail segment between the Half Dome trail junction and the base of the subdome is related to the number of daily Half Dome hikers. The same caution needs to be taken regarding predicted values beyond the range of values observed in the study. Similar to group encounters on the Nevada Falls to Half Dome trail junction group encounters increase with higher amounts of daily Half Dome hikers (Figure 15). In addition, the relationship between group encounters on the Half Dome trail junction to the subdome and the daily number of Half Dome hikers is not linear (i.e., wilderness encounters tend to increase at a higher rate with more visitors along the Half Dome trail).

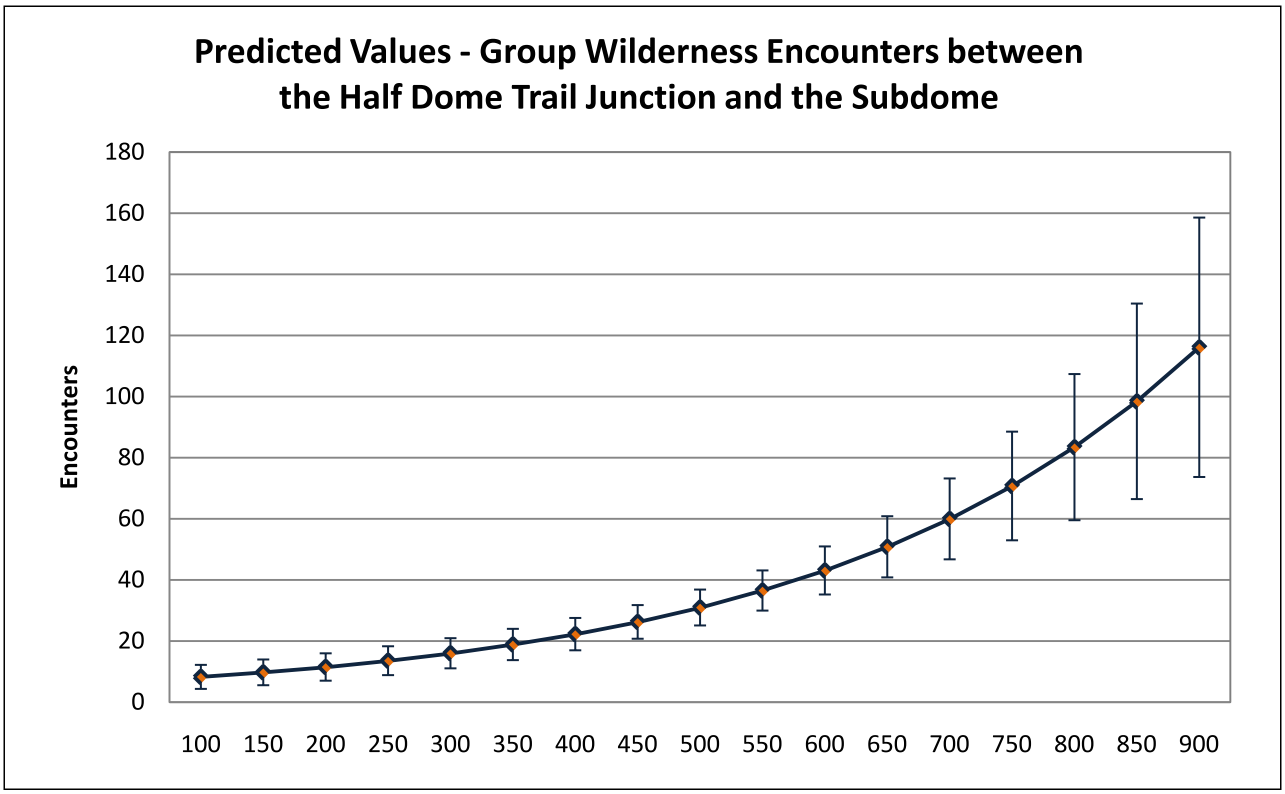

Figure 15. Predicted values for hourly group wilderness encounters on trail segment between the Half Dome trail junction and the subdome.

Table 27. Predicted values for hourly wilderness encounters on the trail segment from Nevada Falls to the Half Dome trail junction.

Daily Visitor Arrivals	Group Trail Encounters	Error of Estimation
100	8.25	3.93
150	9.74	4.21
200	11.49	4.48
250	13.55	4.72
300	15.98	4.94
350	18.86	5.12
400	22.24	5.29
450	26.24	5.51
500	30.96	5.87
550	36.52	6.57
600	43.08	7.87
650	50.82	10.01
700	59.95	13.24
750	70.73	17.78
800	83.44	23.92
850	98.43	31.99
900	116.12	42.45

4. Discussion

The results from this study show that visitor use on Half Dome is lower on permit days than on non-permit days. All but one of the various measures used to estimate visitor use conditions resulted in statistically significant differences in use levels between permit and non-permit days. Moreover, daily visitor use levels were found to be strongly related to PAOT on both the cable route and the summit. These results are likely a reflection of the “closed” system of visitor access to Half Dome. In other words, the vast majority of visitors access Half Dome via the Half Dome trail to the subdome and subsequently to the summit. Thus, the “simplicity” of the travel system lends itself well to predictability and potentially the application of limits on visitor use levels to achieve management objectives. Similar results have been found in other closed travel systems including Glacier Point, Bridalveil Fall, and Yosemite Falls in YNP (Pettebone, 2009; Lawson et al. 2009) and Devils Postpile NM (Pettebone et al. 2010).

Levels of Visitor Use on Half Dome

Both the 2008 and 2010 studies describe the variability of visitor use on Half Dome throughout the course of a day and show that the temporal characteristics of visitor use are similar between the two study seasons. Perhaps the most important finding from the 2010 study was that a large amount of temporal displacement occurred as a result of the three-day permit system. Specifically, average daily visitor use in 2010 on permit days (i.e., 301 visitors/day) is similar to average daily visitor use on weekdays in 2008 (i.e., 416 visitors/day). Likewise, average daily visitor use in 2010 on non-permit days (i.e., 635 visitors/day) is similar to average daily visitor use on Saturdays and holidays in 2008 (i.e., 692 visitors/day). Thus, it appears that a consequence of the 2010 permit system was the interchange of use levels from weekend to weekdays. However, the highest daily level of use recorded during 2010 (872 visitors) was substantially lower than the highest level of daily use recorded in 2008 (1,200 visitors). Thus, while visitor use during 2010 on non-permit days reflects typical Saturday and holiday use from 2008, there were no anomalously high levels of visitor use like those recorded in 2008.

Estimates of PAOT on the cable route and on the summit follow the same pattern described in the previous paragraph where weekday use (i.e., non-permit days) levels are substantially higher than weekend use (i.e., permit days) levels. PAOT estimates on the cable route are particularly important because evaluative data related to safety and visitor experience on the Half Dome cable route were collected in 2008. This evaluative data provides a clear and concise measure from which to consider the implications of various levels of visitor use. Specifically, the 2008 study identifies thresholds of: 1) 30 PAOT to provide for unimpeded visitor travel on the cable route, and 2) 70 PAOT when visitors perceive safety issues and unacceptable experiential conditions on the cable route. On permit days in 2010 the 30 PAOT threshold was exceeded only 15% of the time and the 70 PAOT threshold was not exceeded on any sample days. Thus, on permit days visitor travel was unimpeded 85% of the time preserving conditions where visitors did not perceive safety issues or negative impacts to their experience. In contrast, the threshold of 30 PAOT was exceeded 65% of the time during non-permit days and the 70 PAOT was exceeded 23% of the time. In other words, on non-permit days visitor travel on the cable route was impeded regularly and conditions on the cables were sometimes perceived as unacceptable.

These results suggest that the objectives of visitor safety and acceptable experiential conditions on the cable route cannot be provided with a daily visitor use permit system implemented only on some, but not all, days of the week. This assertion appears to be substantiated by the regression analyses developed in this study that show PAOT conditions on the cables to be strongly related to the number of daily visitors to Half Dome. The 2010 Half Dome permit system allowed up to 400 visitors per day to access the subdome and the summit of Half Dome, however, average daily use on Half Dome was about 300 visitors/day. The regression model developed in this study predicts an average of about 24 PAOT at 400 visitors/day and 15 PAOT at 300 visitors/day, both well below the PAOT thresholds of 30 and 70. However, predicted values for maximum PAOT at 400 visitors/day is about 51 and for 300 visitors/day is predicted to be about 36. Thus, YNP managers should expect visitor travel on the cables to be impeded to some degree during the day even with a permit system that limits use to the current interim permit system's daily levels.

PAOT on the summit of Half Dome was a variable that had not been collected previously and very little was known about PAOT conditions on the summit. The results from this study suggest that PAOT on the summit is similar to PAOT on the cables. In other words, if there are 50 PAOT on the cable route there will be about 50 PAOT on the summit for a total of about 100 PAOT on Half Dome from the base of the cable route and up. However, PAOT on the cables increases at a slightly higher rate than PAOT on the summit. The relationship between PAOT on the cable route and PAOT on the summit has 2 important implications related to visitor evacuation in the event of a weather event: 1) during high levels of use on the cable route (>100 PAOT) a total of about 200 visitors may need to be evacuated from Half Dome, and 2) visitor travel times on the cable will likely be slow for long periods of time during an evacuation based on the high volumes of people descending from the summit. No evaluative data has been collected or developed regarding safety or visitor acceptability on the summit of Half Dome. However, as noted, the Half Dome Visitor Use Model will be used to simulate the implications of various PAOT levels on the summit, with respect to visitors' travel times to descend the cables. Thus, simulation results and data from the 2010 monitoring provide an understanding about visitor use on the summit that was previously unavailable and can be used to develop common sense approaches to provide for visitor safety and quality visitor experiences.

Wilderness Encounters

Like PAOT on Half Dome, group encounters along trail segments in wilderness were found to be related to the daily number of people hiking to Half Dome. Individual people were the metric used by observers when collecting data and groups were derived based on results from a companion study. The differences in the number of people per hour on the trail segment from the Half dome trail junction to the base of the subdome was statistically significant, but the segment between

Nevada Falls and the Half Dome was not statistically significant at the 95% confident interval. The small sample size of this dataset, a result of trail encounter data being prioritized lower than the other data collected in 2010, does not provide a particularly robust estimation of encounter rates along trails in the Half Dome area and should be interpreted with caution.

Despite the small sample size, the trail encounter data display similar relationships between permit and non-permit days as the other data collected on Half Dome (i.e., visitor use conditions are lower on permit days than on non-permit days and strong statistical relationships exist with daily levels of visitor use). Of particular interest are the results from the Nevada Falls to the Half Dome trail junction segment. Although statistical tests did not confirm significant differences at the 95% confidence level the descriptive results for this trail segment suggest substantial differences in the number of people encountered along this trail segment per hour (68 people/hour on permit days and 117 people/hour on non-permit days). Moreover, group encounter rates were found to be significantly different at the 95% confidence level along this trail segment and both measures of encounters (people and groups) along the trail segment between the Half Dome trail junction and the subdome were found to be significantly different between permit and non-permit days at the 95% confidence level. Collectively, these results indicate that the 2010 permit system influenced overall visitor use beyond the immediate Half Dome area. There are two important implications from these analyses: 1) Half Dome is the main destination/attraction site for visitors in this area, and 2) encounter rates along these trail segments can be managed using a daily permit system for Half Dome.

To put these levels of group encounters into a wilderness context we offer a comparison of encounter rates reported in previous research in other high-use wilderness areas (Table 28). Estimates of hourly group encounters on the two trail segments in the Half Dome study show that on non-permit days encounter rates are substantially higher than encounter rates in other high-use wilderness areas. However, encounter rates on permit days are similar to encounter rates found in other high-use wilderness areas. For example, the average group encounter rate on the trail from the Half Dome Junction to the subdome is 13.21 groups/hour which is comparable to the average group encounter rate on the Dog Lake trail (12.79/hour) and Cathedral Peak trail (11.17/hour). The group encounter rate from Nevada Falls to the Half Dome junction is 16.91 groups/hour and compares to a weekend day at Snow Lake in eastern Washington (18.27 groups/hour).

Table 28. Comparison of group encounter rates on trails in wilderness areas.

Location	Groups/hour	People/hour
USFS-Washington and Oregon (Cole et al.1997)		
Snow Lake-weekend	18.27	68.96
Snow Lake-weekday	6.67	N/A
Rachel/Rampart Lakes	7.50	N/A
Green Lakes	4.00	N/A
NPS-Yosemite-Tuolumne Meadows (Broom and Hall, 2010)		
Cathedral Lakes	11.17	27.89
Lyell Canyon	7.89	18.89
Rafferty Creek	6.15	15.50
Dog Lake	12.79	43.74
Young Lakes-West	2.96	9.00
Young Lakes-East	2.56	5.97
Mono Pass	3.58	8.16
NPS-Half Dome		
Nevada Falls to Half Dome Trail Junction		
Non-Permit Days	39.98	117.13
Permit Days	16.91	67.64
Half Dome Trail Junciton to Subdome		
Non-Permit Days	51.37	150.51
Permit Days	13.21	52.82

Similar to PAOT on Half Dome, wilderness encounters were found to be related to the daily number of people hiking to Half Dome. A negative binomial model produced the best fit for these data and suggests a curvilinear relationship between the daily number of people and wilderness encounters along the trail segments from Nevada Falls to the base of the subdome. However, caution is advised for interpreting predicted values beyond the limits of the available data used to estimate these models. In particular, the nature of the relationship between daily visitor use to Half Dome and trail encounter rates may or may not be curvilinear as suggested in the model. In other words, encounter rates may decrease more quickly at lower levels of use than is suggested by the model.

It is important to note that wilderness encounter data will be collected again in 2011. The data collected in 2010 provides information about encounter rates in the Half Dome area that was previously unavailable and is a good base from which to further study this important proxy for wilderness character. In 2010, wilderness encounter data were not a primary topic of inquiry and one limitation of this study was that trail encounter data were collected as scheduling around other variables of interest allowed. However, the strong statistical relationships found between trail encounters and daily use on Half Dome from the 2010 data provides an important base of knowledge from which to develop more robust studies in the future and data from 2011 will improve understanding of this important facet of wilderness management on Half Dome.

Comprehensive Daily Use Level Comparison

Lastly, a comprehensive comparison of PAOT and group encounter rates along trails at various daily use levels are presented in Table 29. These estimates of PAOT and encounter rates are based on the regression models for each relative measure of visitor use condition (i.e., PAOT or encounter rate). The information in this table is reflective of conditions found in 2010 under the three-day permit system. Thus, any changes to the visitor management system on Half Dome in the future *may* change the specific statistical relationships found in this study, therefore, it is imperative that monitoring accompany any changes in visitor management on Half Dome to determine the net changes in visitor use in order to ensure that visitor use conditions meet YNP management objectives for visitor safety and experience.

Table 29. Estimated visitor use levels on Half Dome and trails near Half Dome.

Daily Visitor Use	Average Cable PAOT	Maximum Cable PAOT	Average Summit PAOT	Maximum Summit PAOT	Group Trail Encounters-Nevada Falls to the Half Dome trail junction	Group TrailEncounters-Half Dome Trail Junction to the Subdome
100	N/A[1]	N/A[1]	N/A[1]	N/A[1]	10.96	8.25
150	N/A[1]	N/A[1]	N/A[1]	N/A[1]	12.26	9.74
200	6.80	20.44	11.51	29.96	13.71	11.49
250	11.06	28.05	15.09	35.41	15.33	13.55
300	15.32	**35.67**	18.68	40.87	17.15	15.98
350	19.58	**43.29**	22.27	46.32	19.18	18.86
400	23.83	**50.91**	25.85	51.78	21.45	22.24
450	28.09	**58.53**	29.44	57.23	23.99	26.24
500	**32.35**	**66.15**	33.03	62.69	26.83	30.96
550	**36.61**	**73.77**	36.62	68.14	30.01	36.52
600	**40.87**	**81.38**	40.20	73.60	33.56	43.08
650	**45.12**	**89.00**	43.79	79.05	37.54	50.82
700	**49.38**	**96.62**	47.38	84.50	41.99	59.95
750	**53.64**	**104.24**	50.96	89.96	46.96	70.73
800	**57.90**	**111.86**	54.55	95.41	52.52	83.44
850	**62.16**	**119.48**	58.14	100.87	58.74	98.43
900	**66.41**	**127.09**	61.72	106.32	65.70	116.12

[1] Predicted values are beyond the practical limits of these data and produce negative values
Values in orange indicate PAOT values that exceed 30 that impede visitor travel times on the cable route. Values in red indicate PAOT values of 70 that exceed visitor perceptions of safe and acceptable experiential conditions on the cable route.

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