MODELING DAY-HIKING IN THE SENSITIVE RESOURCE ZONE OF MOUNT RAINIER NATIONAL PARK: A BASIS FOR RECOMMENDING INDICATORS AND STANDARDS

MARK E. VANDE KAMP

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1. INTRODUCTION

The University of Washington Protected Area Social Research Unit administered this project. It was proposed and funded by Mount Rainier National Park (MORA). The general purpose of the project was to simulate the movement of day hikers in Paradise Meadows – a network of trails in the Sensitive Resource Zone of Mount Rainier National Park. The computer simulation provides detailed estimates of visitor distribution in space and time that would be extremely difficult or impossible to collect directly. Such information is critical for effective planning of visitor management. More specifically, the information will be used in the Visitor Experience and Resource Protection (VERP) planning framework.

1.1 The Visitor Experience and Resource Protection (VERP) Framework

The VERP framework is a tool developed by the National Park Service to address user capacities and thus protect both park resources and visitor experience from impacts associated with visitor use. VERP was used in developing the Mount Rainier National Park General Management Plan, and the park has made a commitment to implement VERP throughout MORA. The VERP framework is an ongoing, iterative process of determining desired conditions (including desired cultural resource conditions, desired natural resource conditions, and desired visitor experiences), selecting and monitoring indicators and standards that reflect these desired conditions, and taking management action when the desired conditions are not being realized. VERP is a decision-making framework, but does not diminish management's role in decision-making.

Information about visitor use is essential because VERP is, at its core, a means of managing the impacts associated with visitor use. It is difficult to imagine how decisions intended to limit the impact of visitation could be made in the absence of information describing current levels and patterns of visitor use.

1.1.1 The Sensitive Resource Zone in the VERP Framework and in This Document

MORA is a large park with diverse environments and recreation opportunities. Within the VERP framework, managers deal with such diversity by designating a variety of management zones for a given park. At MORA, the General Management Plan describes ten recreation zones. This document describes computer simulation of visitor use on trails in only one of them – the Sensitive Resource Zone.

The General Management Plan describes the Sensitive Resource Zone as an environment in which, "…visitors would be able to move relatively freely along trails." and visitors would "…not be impeded by other visitors." These descriptions of the desired conditions for the Sensitive Resource Zone allow higher levels of interaction with other visitors than in wilderness zones. Thus, commonly-used indicators of wilderness social conditions, such as the number of other parties encountered, are difficult to measure in this zone, in part because hiker recall of encounters is inconsistent when there are more than about seven encounters per day (Manning, Lime, Freimund, and Pitt 1996;

Vande Kamp, Johnson, and Swanson 1998). Encounters may also be weakly related to the negative conditions that arise due to high levels of visitor use in the Sensitive Resource Zone. For example, the number of encounters per hour or hiking day may be less important than relatively limited instances (short in time and/or limited in space) in which large numbers of visitors create congestion that limits visitors' freedom of movement.

Computer simulation of visitor use can provide a variety of estimates describing visitor use on trails. These estimates will be used to help managers select indicators and set standards that will protect the desired social and physical conditions in the Sensitive Resource Zone.

1.2 Computer Simulation Models of Visitor Use

VERP planning benefits when managers have access to a wide range of information describing visitor use. For example, summary statistics of the kind reported in the report titled *Visitor Use in the Management Zones of Mount Rainier National Park* (Vande Kamp 2009c) are essential. In addition, computer simulation models based on descriptive information can provide more sophisticated estimates of visitation that can help managers gain insight into, a) existing conditions, and b) the relationships between visitation and various impacts on visitor experiences and physical resources.

Computer simulation models provide a range of information that can be of great use to managers. For example, a computer simulation can provide estimates of potential indicators that are difficult and/or expensive to measure directly. One such description of social conditions that is of particular interest in the Sensitive Resource Zone is the area of trail available for each hiker. Research in walkway design has established that freedom of movement is closely related to the walkway surface available to each pedestrian (Federal Highway Administration 1999). Accordingly, detailed information about the trail surface per hiker (hereafter, hiker density) in Paradise Meadow at different use levels could help managers answer questions such as, how often do current use patterns produce negative impacts on experiences and resources? Is there a consistent relationship between use patterns and resource impacts that can be measured? And what actions might alter use patterns to mitigate negative impacts?

Similarly, the simulation can be used to estimate cumulative passages across trail segments. The most extensive visitor impact on the biological resources of Paradise Meadow occurs when off-trail hikers trample vegetation. The amount of damage depends on a variety of factors (cf. Cole and Spildie 1998) but is always related to the number of visitors passing an impacted area and the proportion of those visitors who leave the official trail. Without detailed information about cumulative visitor passages, it is virtually impossible to understand the relationship between visitation and vegetation impact sufficiently to select indicators and set standards that will protect both visitor experiences and physical resources.

Computer simulations can provide both descriptive and predictive estimates of visitor use. Descriptive information is focused on existing levels and patterns of visitation. Such information can help managers answer questions such as, "How does visitation on Trail A compare to visitation on Trail B?" It can also identify "bottlenecks" or "choke points" where visitation is most dense and thus most likely to have impacts on experiences or physical resources. Finally, descriptive information can make routine monitoring feasible by estimating the relationship between an easy-to-collect measure (e.g., the number of vehicles in the parking area), and a difficult-to-collect measure (e.g., the hiker density on the trail segments closest to Myrtle Falls). Based on the modeled relationship, routine monitoring can focus on the easy-to-collect measure.

Predictive information is provided by simulation models when they are used to estimate visitation for possible future conditions (i.e., conditions different from those that were present when the source data for the models were collected). For example, a simulation could be used to estimate measures of visitation that might arise if: a) a change in management policy altered the types of hikers using a trail, b) use of some trails was constrained by construction or closure, or c) visitation rose to levels not yet experienced. Of course, the predictive information would be based on a variety of assumptions that might or might not hold true in that hypothetical future, but the same limitation applies to any predictive technique.

1.2.1 Stochastic, Itinerary-Based Simulation Using the RBSim Computer Program

Computer simulation has become a routinely-used tool in many industries and applications. A full review of the many types of simulation models and their uses is beyond the scope of this document. However, it is important to discuss some of the basic characteristics of the simulation models used here so that readers gain some understanding of the strengths and weaknesses of the approach used.

Attempts to model the distribution of park visitors can employ a range of techniques. At Mount Rainier, one attempt used a relatively simple mathematical model to estimate use in Paradise Meadow (Vande Kamp and Zwiebel 2004). That model, like many other simple models, was deterministic – that is, it contained no random factors and always produced the same outputs when given the same inputs. In contrast, the simulation models reported in this document are stochastic – that is, they include random factors that create variability in the model outputs from one run to the next. Stochastic models have a number of advantages. For example, they not only provide descriptions of visitor use, but also estimate the variability that might be expected in those descriptions. Because there is variability in their outputs, stochastic models must be run multiple times, and their outputs must be aggregated as averages or other summary statistics. This document will report the number of model runs used to estimate the reported descriptions of visitor use.

Among stochastic models, there are two very different approaches to building simulations– these might be labeled the itinerary-based approach, and the agent-based approach. The simulation models reported in this document are itinerary-based. In itinerary-based models, each hiking party is assigned a set itinerary as it enters the simulation. That itinerary will be carried out no matter what conditions are present in the model. In an agent-based approach, each hiking party is assigned a set of decision rules to follow. The party's itinerary is not determined until it moves through the simulation and "decides" how to proceed at a number of points along the way. Each approach has different strengths and weaknesses. Itinerary-based approaches tend to be easier to construct, to be well suited to describing conditions that currently exist, and to be poorly suited to predicting visitor use in situations where structural changes might be made to the trails or other facilities in the simulation. In contrast, agent-based approaches are more difficult to construct (determining decision rules that reproduce existing use patterns can be a complex and difficult process), but they can be used to predict visitor use in situations with major changes to the trails or other facilities. Given that the priorities of this project were to first, accurately describe current conditions, and second, estimate future conditions in the absence of significant changes to the trail system, itinerary-based models were thought to be the superior option.

Many computer programs are available for building simulation models. They range from very general programs suitable for simulations of many situations, to very specific programs designed to simulate specific situations such as manufacturing processes or vehicle traffic. They also range in cost, from free programs available for download to as much as $50,000 (Vande Kamp 2003). There have been relatively few attempts to create simulation models of recreational visitor movements. After an attempt to build a simulation of wilderness recreation in the 1970s (van Wagtendonk and Cole 2005), there was a hiatus before more recent simulation modeling efforts (see Cole 2005). Two computer programs have been used in the majority of recent efforts to build simulation models of recreational visitor use: 1) Extend, developed by Imagine That, Inc., is a general purpose software package suitable for use in business, industry, and government applications, and 2) RBSim, developed by GeoDimensions Pty Ltd., a special-purpose simulator designed for use in modeling recreational visitor use on linear networks such as trails or roads. RBSim was selected for use in this project largely because its focus on recreational systems made it easier to use, and because it made extensive use of GIS data in both the input and output of the simulations it produced.

One aspect of RBSim that also made it attractive was the intent of GeoDimensions Pty Ltd. to develop the program with a user-friendly interface such that working with the program would require relatively little training. This aspect of the program has not been developed in the manner envisioned at the time of its adoption for this project.

In summary, the computer simulation models reported in this document are stochastic, itinerary-based, and developed using the RBSim simulator program.

1.3 The Structure of this Document

Much of this document describes computer simulation of day-hiking on trails in Paradise Meadows at Mount Rainier National Park. These trails connect with the larger wilderness trail system of MORA, but this simulation focuses on trails in the area that is north of the Paradise Valley Road and no further east than the Skyline Trail near Sluiskin Falls.

The ultimate goal of the computer simulation is to provide results that estimate a variety of useful information about visitation in Paradise Meadow. However, this document also a) reports the basic information that forms the foundation of the simulation, and b) describes the characteristics of the simulation. Brief and general descriptions of the different information are included, in order, below. The next chapter describes the specific information relevant to the Paradise Meadow simulation.

1.3.1 Description of Visitor Use

Two closely-related forms of descriptive information are necessary to simulate day-hiking on trails. The first type of information describes the number of visitors entering the trails and the times when they enter. The second type of information describes where visitors hiked and when they passed specific points along the trails. These two types of information were generally provided by the two methods of data collection reported in the report titled *Visitor Use in the Management Zones of Mount Rainier National Park* (Vande Kamp 2009c). The first, and simplest, method involves the use of electronic trail counters to collect counts of hikers, as well as information about the times when they passed the counter. The second method, called the waypoint survey, was developed specifically to collect itinerary information. Waypoint surveys provide detailed information about the movement of hiking parties on trails, as well as information about the amount of time they spend in specific areas. The simulation model described in this document is built based on the descriptive information collected by trail counters and waypoint surveys, and presented in the *Visitor Use...* report.

1.3.2 Entry Distributions

The data collected using electronic trail counters are routinely presented in the form of frequency distributions showing the number of hiker passages during specified time periods (usually one-hour intervals). Trail counters record hikers passing in both directions, but simulation models require frequency distributions describing the number of hikers *entering* the trail. This section will describe the entry distributions of visitors to the trails being simulated, as well as the methods and data used to estimate those distributions.

1.3.3 Pauses/Stops

Most day-hiking trips feature stops during which hikers might eat lunch, rest, or simply observe the scenery. These stops can significantly alter the relationships between visitation and its impacts on physical resources and the quality of visitor experiences. This section will describe the pauses and stops that will be built into the simulation, as well as the methods and data used to estimate those stops.

1.3.4 Assumptions and Simplifications

Computer simulations are models of visitor movement and distribution. As such, they are simplifications of reality. Simplification is a strength because it makes it feasible to build the simulation and use it to estimate important measures of visitation. Nonetheless, it is important to describe the various assumptions and simplifications used in the construction of the model because some of them may invalidate certain types of use estimates. For example, the different hiking speeds assigned to different parties may be due, in part, to the tendency of slower parties to pause more often. However, without information about the specific location of the locations and durations of those pauses, the simulation may have all parties hike continuously at different speeds. Such a simplification would be unlikely to affect the total number of encounters between parties while hiking, but would affect the number of encounters that occur when one party is stationary. This section will describe assumptions and simplifications, and discuss some of their implications.

1.3.5 Validation

The ideal method of validating estimates of visitation based on simulation models is to collect data that are fully independent of the data used in developing the model and to compare those independent observations to the model predictions. Studies designed specifically to collect validation data have not been conducted for the model reported in this document. However, some independent data are available for the trails (e.g., total hiking times recorded in all the waypoint surveys and the counts recorded by a trail counter on the Skyline Trail). Thus some assessment of simulation validity can be made for the trails. This section will describe the methods used to assess simulation validity, the results of those assessments, and any alteration of the simulation made to address shortcomings identified by the validity assessment.

1.3.6 Simulation Results

This document is not intended to report all the potentially useful estimates of visitor use that might be generated using the simulation model. Instead, a limited set of estimates closely related to discussions of social indicators and standards (see the report titled *Visitor-Experience Indicators and Standards for the Sensitive Resource Zone of Mount Rainier National Park* [Vande Kamp 2009b]) will be presented. Such estimates include measures describing trail surface area per hiker and total hiker passages in August. Additional estimates of visitor use might be generated in the future. The computer files and RBSim computer program that make up each simulation will be archived and transferred to Mount Rainier along with this document.

1.3.7 Recommending Indicators and Standards for the Sensitive Resource Zone

The final section of this report discusses and recommends several indicators and standards for use in the Sensitive Resource zone. This section generally addresses several aspects of the indicators, but it is not intended to be a complete presentation of all issues related to indicator and standard selection, and is not an implementation plan providing detailed instruction for deploying the recommended indicators.

2. SIMULATING DAY-HIKING IN PARADISE MEADOW

On clear summer days when the avalanche lilies are in bloom and blue ice is visible in the glacial crevasses high above it is easy to understand why Paradise is the most heavily used area in Mount Rainier National Park. In 2003 an estimated 370,000 people drove, rode, or hiked to the lodge, visitor center, and climbing facilities at 5,400 feet on the south flank of the mountain (NPS 2004). Of those, about 70 percent took walks or hikes on the system of paved and gravel trails (see Figure 1) located in the sub-alpine meadow north of the visitor center and lodge (Vande Kamp 2001). Those walks and hikes are an important aspect of many visitors' experiences of Mount Rainier (Johnson, Foster, and Kerr 1991). At the same time, the level of visitation in the meadow has created negative impacts on the physical resources and the quality of visitor experiences found there. Off-trail hiking has damaged vegetation in many areas of the meadow (Rochefort and Swinney 2000) and at peak times, visitor movement on popular trails is impeded by high visitor density (Vande Kamp and Zweibel 2004).

In order to set policies that protect the physical resources and the quality of visitor experiences, managers of Mount Rainier seek to understand the relationships between manageable aspects of visitation (where visitors go, what visitors do, how many visitors are present) and important resources or experiences directly threatened by visitation. Toward this end, a computer simulation model of visitation patterns in Paradise Meadow will be used:

- To estimate potentially informative measures of visitation that are difficult to observe directly (such as the square feet of trail per hiker) and to relate those estimates to more easily measured and managed measures of visitation (such as the number of vehicles entering park gates).
- To identify "bottlenecks" in the trail system where hiker density is highest and changes in trails or hike routing information might be most effective.
- To explore the impacts of hypothetical changes in management policy, trail construction, or visitation yet to occur in the real world (while acknowledging the assumptions and limitations inherent in such prediction).

2.1 Description of Visitor Use: Paradise Meadow

Recent studies of visitor use of Paradise Meadow include counts collected using electronic trail counters and itinerary information collected using waypoint surveys. The results of these studies are reported in the report titled *Visitor Use in the Management Zones of Mount Rainier National Park* (Vande Kamp 2009c). Results vary considerably from the early to late summer hiking season, as the snow covering the trails melts. The results reported here describe use during the later portion of the summer hiking season when trails were largely free of snow. Thus, the reported summary statistics such as averages apply only to the late summer hiking season when trails have only small stretches of snow cover that do not deter significant numbers of hikers from using available trails and do not allow hikers to establish random routes across the snow. This seasonal limitation applies both to the studies of visitor use and the simulation model developed based on those studies.

For the purposes of modeling, the descriptive information of primary interest concerns the daily number of hikers to be modeled, and the times at which they begin their hikes (i.e., the entry distribution). This section focuses on the number of visitors using the trails; the distribution of entry times is discussed in the next section.

At least four different types of information can be used to estimate the number of Paradise Meadow hikers. The estimation procedures and the resulting estimates based on 1) electronic trail counts, 2) waypoint survey participation, 3) vehicle counts, and 4) counts collected during the 1995 Visitor Distribution Survey (Vande Kamp, Johnson, Kucera, and Young 1997) are discussed below.

2.1.1 Total Hikers on a 95th Percentile Day: Estimates Based on Electronic Trail Counts

Trail counters have been installed at a number of locations in Paradise Meadow during different seasons. In 2006, trail counts and vehicle counts were collected to determine whether, and how, construction activity was affecting Paradise visitation. One conclusion in the report titled *Altered Visitor Use in the Paradise Area in Response to Construction Activity* (Vande Kamp 2008) was that total visitation levels were roughly comparable to prior years. Thus, the trail counts collected in 2006 provide the most recent information that can be used to estimate the total number of hikers on a 95th percentile day. Specifically, electronic trail counts collected on the Nisqually Vista Trail, the Skyline Trail (north of the lower junction with the Alta Vista Trail), and the East Skyline Trail (NE of Lakes Trail junction) were used to make three separate estimates.

Estimates were calculated by extrapolating from the passages recorded on the 95th percentile day. The extrapolation was based on data from the 2004 waypoint survey (see the report titled *Visitor Use in the Management Zones of Mount Rainier National Park*; Vande Kamp 2009c). For example, the 95th percentile day count for the Nisqually Vista Trail counter was 439 passages. The waypoint survey indicated that 12.2% of all Paradise Meadow hikers pass that location. Thus, the estimate of total visitation is 439/0.122 = **2811 hikers**. Similarly, the 95th percentile day count for the East Skyline Trail counter was 369 passages. The waypoint survey indicated that 14.5% of all Paradise Meadow hikers pass that location. Thus, the estimate of total visitation is 369/0.145 = **2545 hikers**.

The estimate based on the Skyline Trail counter is slightly more complex because the trail counter recorded passages by climbers (who are not classified as “hikers” in this estimate) and multiple passages by a substantial number of “up-and-back” hikers. The 95th percentile day count was 1689 passages. Of these, 300 were estimated to be climbers (based on estimates of peak climbing use provided by MORA staff), and 259 were estimated to be “second passes” by “up-and-back” hikers (based on waypoint survey data: cf. Visitor Use in the Management Zones of Mount Rainier National Park (Vande Kamp 2009c)). The waypoint survey indicated that 29.5% of all Paradise Meadow hikers pass that location. Thus, the estimate of total visitation is 1130/0.295 = **3831 hikers**.

2.1.2 Total Hikers on a 95th Percentile Day: Estimate Based on Waypoint Survey Counts

The 2004 waypoint survey provides some limited information that can also be used to directly estimate the total number of Paradise Meadow hikers. On one sunny weekend day, survey workers attempted to contact one of every three hiking parties that entered the Meadow. Records indicate that they contacted 143 parties on that day. If we multiply this party count by three (to account for the sampling interval) and multiply by the average party size (3.26 persons, according to the waypoint survey data) we can estimate the number of hikers entering the meadow during the sampled period of the observed day: 143 * 3 * 3.26 = 1399.

This number must then be adjusted in two ways, first we must account for the number of hikers who entered the meadow at times or locations that were not surveyed during the waypoint study. Based on hourly traffic counts of vehicles entering the Nisqually entrance and observation of hikers during the waypoint study, it is estimated that the waypoint survey did not contact 30 percent of all hikers. Thus, the estimated number of total hikers on the observed day was 1999.

In order to produce an estimate of total hikers on a 95th percentile day, this estimate must also be adjusted to account for the differences between visitation on the counted day and visitation on a 95th percentile day. Based on daily traffic counts in 2004, 1987 vehicles entered on a 95th percentile day and 1619 vehicles entered on the observed day. Thus, after adjusting for the differences in vehicle entries, the estimate of total visitation is 1999/(1619/1987) = **2452 hikers**.

2.1.3 Total Hikers on a 95th Percentile Day: Estimate Based on Vehicle Counts

A third method of estimating total hikers is based on vehicle counts collected in 2006 rather than on direct counts of hikers. Using information from the report *Altered Visitor Use in the Paradise Area in Response to Construction Activity* (Vande Kamp 2008) and hourly traffic counts from 2004 and 2005, we can estimate that 2007 vehicles park in the Paradise area on an average weekend day in July or August. If we multiply this vehicle count by the proportion of parties visiting Paradise that take walks or hikes, then multiply by the average party size (0.391 and 3.06, respectively; see Vande Kamp, Swanson, and Johnson 2002) we can estimate the number of hikers entering the meadow during an average weekend day: 2007 * 0.391 * 3.06 = 2401.

This number must then be adjusted to account for the differences between visitation on an average weekend and visitation on a 95th percentile day. Based on daily traffic counts in 2004 and 2005, 2157 vehicles entered on a 95th percentile day and 1745 vehicles entered on average weekend days. Thus, after adjusting for the differences in vehicle entries, the estimate of total visitation is 2401/(1745/2157) = **2968 hikers**.

2.1.4 Total Hikers on a 95th Percentile Day: Estimates Based on 1995 Visitor Distribution Survey Counts

A final method of estimating total hikers is based on hiker counts collected in 1995. The document reporting results of this survey (see Vande Kamp, Johnson, Kucera, and Young 1997) estimated that 1968 hikers enter Paradise Meadow between the hours of 10:00 and 4:00 on a sunny summer weekends in July and August. One problem with this estimate arises because some visitors who hiked on the Nisqually Vista Trail and also passed other observed points were counted twice. If we do not count any hikers that might have been counted twice, survey results suggest that no fewer than 1603 hikers entered the meadow.

These numbers must then be adjusted in two ways, first we must account for the number of hikers who entered the meadow at times that were not observed during the visitor distribution survey. Based on hourly traffic counts of vehicles entering the Nisqually entrance, it is estimated that 65 percent of all hikers enter between 10:00 and 4:00. Thus, the estimated numbers of total hikers on an entire sunny summer weekend day fell between 2470 and 3032.

In order to produce an estimate of total hikers on a 95th percentile day, this estimate must also be adjusted to account for the differences between visitation on sunny summer weekend days and visitation on a 95th percentile day. Based on daily traffic counts in 1995, 3291 vehicles were estimated to enter the Nisqually and Stevens Canyon gates on a sunny summer weekend day, and 3506 vehicles entered on a 95th percentile day. Thus, after adjusting for the differences in vehicle entries, we estimate that total visitation was between 2470/(3291/3506) = **2631 hikers** and 3032/(3291/3506) = **3230 hikers**.

2.1.5 Total Hikers on a 95th Percentile Day: Summary

Based on four different sources of information, we calculated seven estimates of the total number of hikers entering Paradise Meadow on a 95th percentile day. The table below shows those estimates, which range from 2452 to 3831 hikers. The average estimate is 2924 hikers (the median estimate is similar, at 2811 hikers). Based on this average estimate, the model of the 95th percentile day should simulate the entry of 897 parties (2924 hikers / 3.26 average party size).

Primary Information Type	**Specific Source**	**Estimated Hikers**
2006 Electronic Trail Count	Nisqually Vista Trail Counter	2811
	East Skyline Trail Counter	2545
	Main Skyline Trail Counter	3831
2004 Waypoint Survey	Parties Contacted	2452
2006 Vehicle Counts	Vehicles Counted in Paradise Area	2968
1995 Manual Trail Counts	Counts Including Nisqually Vista Trail	3230
	Counts Excluding Nisqually Vista Trail	2631

Table 1. Estimates of total hikers entering Paradise Meadow on a 95th percentile day.

2.1.6 Total Hikers on 95th Percentile Days, Average Weekend Days, Average Weekdays, and Average August Days

The number of hikers in Paradise Meadow is strongly correlated with the number of vehicles entering the Nisqually Entrance of MORA (Vande Kamp, Johnson, Kucera, and Young 1997). Based on that finding and the availability of hourly vehicle counts for

2004 and 2005, the estimated number of hikers using Paradise Meadow in conditions other than a 95th percentile day were calculated by adjusting the 95th percentile day estimate. For example, analyses of the traffic data showed that average vehicle entries on August weekend days were 81.8 percent of entries on the 95th percentile day. Accordingly, the model of the average August weekend day simulated the entry of 734 parties (897 parties * 0.818). The table below shows the number of hiking parties that were calculated based on this method and used in the simulation models used to estimate conditions under four different levels of visitation.

Visitation Level	Number of Parties Simulated
95th Percentile Day	897
Average August Weekend Day	734
Average August Weekday	420
Average August Day	506

Table 2. Number of hiking parties simulated in order to estimate four different use levels.

2.1.7 Total Climbing Parties and Climber Entry Distribution

In addition to the number of hiking parties in each simulation, parties of climbers were also included. A total of 49 climbing parties were simulated, regardless of the hiking visitation level. This number was based on the higher levels of climbing use reported by Husbands (2006). It is likely that the average number of climbing parties was actually smaller on weekdays and average days than on 95th percentile days and weekends. However, with no empirical basis for estimating those lower levels of climbing use, a simplifying assumption was made to simulate high levels of climbing use in all conditions.

The entry distribution of climbers and times when descending climbers left Pebble Creek were based on professional judgment and iterative examination of model outputs. Climbers entered the Meadow between 8:00 and 12:00, with 6, 17, 16, and 10 parties entering during each of those hours. To estimate the return times of other climbing parties descending the trails on the same day, each simulated party spent between four and six hours above Pebble Creek before returning. All climbing parties hiked down the most direct route between Waypoint C and Waypoint Q at Pebble Creek.

2.2 Entry Distribution: Paradise Meadow

The second type of descriptive information essential for building simulation models is the frequency distribution of hikers entering trails across the time of day. Because there are four points at which hikers enter the trail network in Paradise Meadow[1], it was thought that more than one entry distribution might be necessary to describe visitation in the simulation. The figure below shows the different entry points, labeled “A” through “D”.

[1] A fifth entry trail near point D is used by a small percentage of hikers. These hikers were not represented in the simulation model.

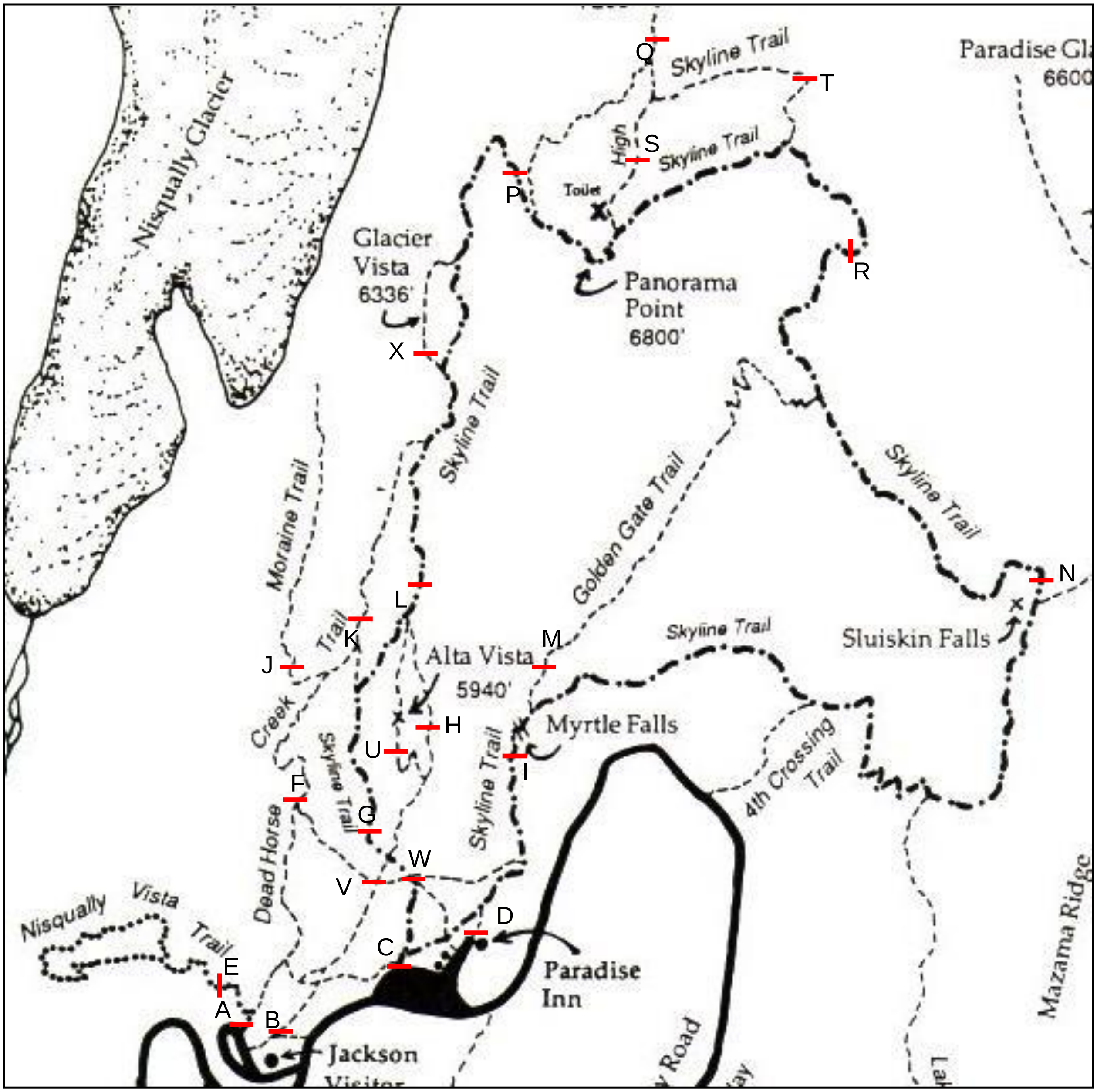


Figure 1. Locations of waypoint signs -- 2004 Paradise Meadow Survey.

Entry points A and B were close together and were primarily served by the parking lot at the Jackson Visitor Center. Similarly, entry points C and D were primarily served by the upper parking lot. Thus, a distribution for combined entries at points A and B was compared to the distribution for combined entries at points C and D. The chart below shows those entry distributions for the time period during which the waypoint survey was conducted (i.e., 9:00 to 17:00). The distributions were very similar, with the largest difference (4.6 percent) falling between 13:00 and 14:00. This similarity suggests that a single entry distribution could be used in simulating hiker entries at all four entry points.

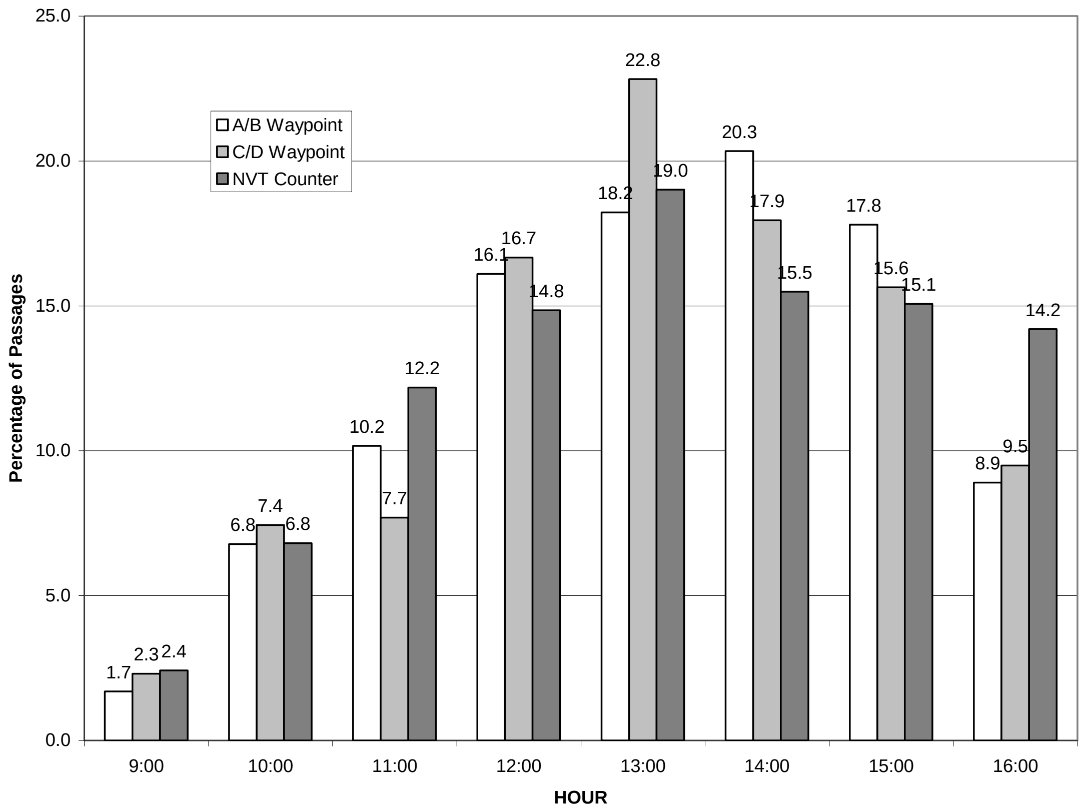


Figure 2. Hourly hiker entries at observed locations in lower Paradise Meadow.

In order to simulate all entries into Paradise Meadow, hiker entries prior to 9:00 and after 17:00 must also be estimated. The electronic trail counter located on the Nisqually Vista Trail in 2006 (see the report titled *Altered Visitor Use in the Paradise Area in Response to Construction Activity*; Vande Kamp 2008) provides a basis for such estimation. The fact that trail counters do not differentiate between hikers moving in different directions on the trail usually complicates the use of electronic trail counts for estimating the entry rates of hikers. However, the Nisqually Vista Trail is a short loop located near the trail entry point, and the counter was placed in a location where hikers were unlikely to pass more than once. Thus, it is not surprising that the recorded counts correspond quite strongly with the entry counts recorded during the waypoint survey.

The figure below shows the entry distribution used in constructing the simulation model of visitor use on Paradise Meadow trails. The distribution is represented in terms of the percentage of visitors entering during each hour because the simulation might be run with different total numbers of hiking parties entering. Based on the Nisqually Vista Trail counter, the number of entries before 8:00 and after 21:00 was so small that it could safely be assumed to be zero. Along with the entry distribution to be used in the simulation model, the hourly distribution of hiker passages recorded by the Nisqually Vista Trail counter during 2006 is also included in the figure for comparison purposes. Note that the distributions are identical before 9:00 and after 17:00.

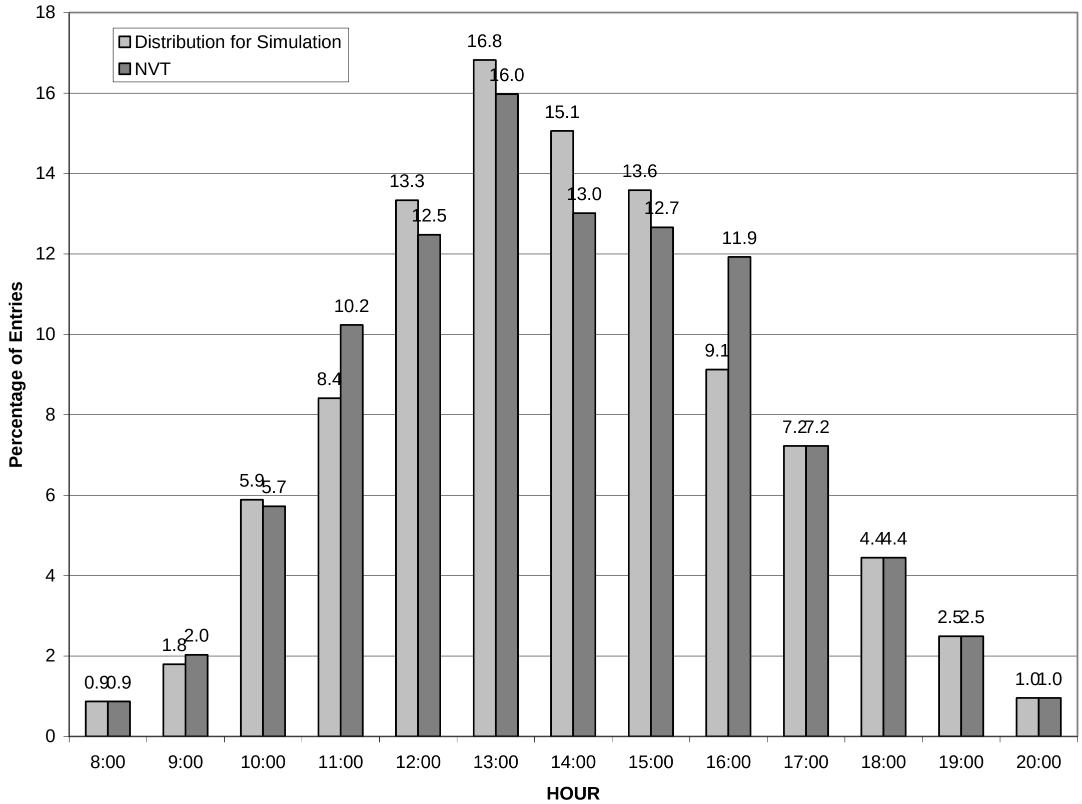


Figure 3. Hourly distribution of hiker entries used in computer simulation model. (Nisqually Vista Trail counter distribution included for comparison.)

2.3 Pauses/Stops: Paradise Meadow

One aspect of visitor itineraries that was not described by the data collected in the waypoint studies was the amount of time that visitors were not actually hiking along the trails. Informal observation (and common sense) demonstrates that most visitors do not hike constantly, but stop to rest, eat or drink, or simply view the scenery. If the model is to provide useful information, it can not completely disregard those pauses or stops.

Because of the limited information available to estimate where and for how long visitors stopped, a number of simplifying assumptions were made in the representation of pauses and stops in this simulation model. The most important of these is that in the model, stops only occur at 4 locations: 1) Alta Vista, 2) Myrtle Falls, 3) Panorama Point, and 4) Nisqually Vista Trail. Even casual observation of visitors' behavior in Paradise Meadow shows that this assumption is commonly violated. However, the implications of this assumption are only critical if they substantially alter the density of visitors on the trails and/or the level of trail congestion and ability of visitors to move freely. Observation suggests that the short pauses made by visitors probably have little effect on trail congestion. In some cases, hikers may step off the trail tread, decreasing their impact on trail congestion. However, in other cases, visitors who pause on the trail will increase congestion. Hikers making longer stops are most likely to stop off the trail tread, but are also unlikely to invalidate the model. Recall that the model is intended to describe hiker density on trails, not at stopping points. Having all parties pause at the same location (for varying durations) will inflate visitor density while the parties are bunched up in that location. However, it will have probably have little effect on visitor density on the trails because the analysis of the density in the model only counts parties that are hiking on the trails.[2]

One factor that will affect the number of hiking encounters is the amount of time that simulated hiking parties spend stopped at the various locations. Although we did not ask hikers how many minutes they were not hiking during their visit, we have other means of estimating stops at specific sites. For three locations (those other than the Nisqually Vista Trail), unobtrusive observation of pauses was conducted. The table below provides the mean and standard deviation of the pauses that were observed at those locations (see the report titled *Visitor Use in the Management Zones of Mount Rainier National Park*; Vande Kamp 2009c).

Site	Mean Duration of Pause/Stop (Minutes)	Standard Deviation
Alta Vista	3	5
Myrtle Falls	7	6
Panorama Point	16	15

Table 3. Mean and standard deviation of hiking pauses observed at three sites in Paradise Meadow.

Pauses on the Nisqually Vista Trail were estimated based on hiking speeds. The waypoint survey provides information about the amount of time that hikers spent hiking the loop trail (i.e., the time recorded between the first and second time they passed waypoint E). In order to estimate the time that simulated visitors should spend stopped at overlooks on the Nisqually Vista Trail, we subtracted the estimated amount of time necessary to hike the loop from the time that they reported actually spending on the loop. This estimation procedure required an assumption about the actual hiking speeds of visitors. Waypoint studies of day-hikers on wilderness trails at MORA (see the report titled *Modeling Day-hiking in the Transition Trail Zone of Mount Rainier National Park*; Vande Kamp 2009a), were used to estimate hiking speeds of 2.11, 2.54, and 3.27 k. p. h. These estimates are in line with a previously-published estimate of 3.2 k. p. h. for flat-ground hiking (van Wagtendonk and Benedict 1980). On the Nisqually Vista Trail, it is likely that many hikers are tourists rather than the more dedicated day hikers observed on wilderness trails. Accordingly, a hiking speed of 2.5 k. p. h. was assumed, and thus, the mean duration of pauses or stops was estimated to be 14 minutes. Based on the observation data recorded at the other three stopping points, the standard deviation was estimated to be equal to the mean duration, 14 minutes.

The area in which hiker movement is simulated ends at Pebble Creek (i.e.,

[2] The total amount of time spent hiking is expected to have a greater effect on hiking encounters than the places where pauses occur. However, if the four places where pauses occur in the model create a situation in which simulated hikers spend more time on trail segments that are more (or less) busy than the “average” trail, the simplifying assumption will bias estimates of hiker density.

waypoint Q). However, the model must include some provision for accurately representing the time some parties spent hiking beyond that point. This is done by representing that hiking time as a stop at point Q. The duration of this stop is estimated based on the time difference parties recorded between their first and second time passing the waypoint. These durations averaged 121 minutes with a standard deviation of 87 minutes. This procedure constitutes a limitation of the model, because no encounters are simulated or recorded for parties hiking beyond Pebble Creek. However, this is of little concern for this model because the primary estimate of concern is visitor density rather than total encounters. Even if encounters with other visitors were examined, this limitation would be of minimal concern because fewer than 5 percent of all hiking parties reported hiking beyond that point, and encounters in that area are unlikely to have a large influence on summary statistics. Finally, encounters beyond Pebble Creek are qualitatively different than encounters in the lower meadow because fewer hikers are present and they are primarily traveling on the Muir Snowfield rather than on maintained trails.

2.4 Hiking Speeds: Paradise Meadow

One factor that has a large effect on the spatial distribution of hiking parties in the simulation is the speed (and range of speeds) at which hiking parties move along the simulated trail. This effect is obvious when one considers that if all parties hike at the same speed, those that were close together at the beginning of a trail segment would remain grouped as they moved up the trail. Such grouping would mean that random variation in the entry of parties could continue to have effects on hiker density much farther along the trails than would occur in actuality.

Actual hiking speeds can be calculated from the waypoint study data and used in building the simulation model. In order to minimize the effects of stops, pauses, and steep terrain, a relatively flat trail segment with few attractions or other reasons to stop was needed to estimate hiking speeds. The trail segment between waypoint D and I fit this description and was used in the speed calculations. For each party that hiked this trail segment, the total time that they spent between the waypoints in either direction was divided by the distance between those points in order to calculate a hiking speed. Using this procedure, the average hiking speed between waypoint D and I was 3.22 kilometers per hour with a standard deviation of 1.15. This speed was generally consistent with studies of hiking speeds across varied terrain (van Wagtendonk and Benedict 1980). However, the trail segment used in the calculations was one of the smoothest and flattest in Paradise Meadow. Thus, the average speed for all hiking was estimated to be 2.75 kilometers per hour.

The RBSim software does not currently allow random assignment of hiking speeds to parties. However, different types of hikers can be defined – each with a different hiking speed. For this simulation, four types of hiking parties were defined. The hiking speeds of each party type, and the number of parties assigned to each type were designed to produce a distribution of hiking speeds that approximated the distribution described by the waypoint survey.

The range of speeds found in the sample distribution were divided into four, roughly-equal intervals and the proportion of hiking parties within each interval was determined by examining the frequency table of hiking speeds. Based on this analysis, the simulation model assigned the following four hiking speeds to the indicated proportion of hiking parties:

Speed (kph)	Proportion of Hiking Parties
2.07	0.22
2.57	0.359
3.07	0.255
3.57	0.166

Table 4. Proportion of simulated hiking parties assigned to four hiking speeds in the Paradise Meadow computer simulation model.

Because not every party hiked the segment of trail used in the hiking speed calculations, estimated hiking speeds could not be linked to specific parties in the waypoint survey and were randomly assigned. In actuality, however, hiking speeds were probably not randomly distributed across all hiking parties. For example, hikers who reached Panorama Point may have hiked at higher speeds than hikers who reached only Myrtle Falls. Nonetheless, because there was no way to compare actual hiking speeds for all parties, the four hiking speeds listed above were randomly assigned across all simulated parties in the proportions described in the table above.

2.5 Assumptions, Simplifications, and Limitations: Paradise Meadow

The characteristics of the simulation described in this section have all been discussed in the earlier descriptions of the simulation model, its parameters, and how it was developed. These characteristics are summarized here (in approximate order of their importance) to ensure that readers are aware of them (particularly the limitations) before reading and interpreting the simulation results.

The first limitation of the simulation is that its results describe only use that occurs during the peak summer (i.e., all or mostly snow-free) hiking season. Waypoint data collected earlier in the summer of 2004 when trails were partially snow covered could be used to build a model and estimate use patterns earlier in the hiking season.

A second limitation is that the simulation measures hiker density on trail segments of arbitrary and varying lengths. This limitation is of potential importance for the identification of bottlenecks in the trail system where hiker density may impinge upon visitors' ability to move freely. For example, the trail area per hiker on the Skyline trail between waypoints L and X might be calculated as a single average, but there could be a shorter segment of trail within that length, such as a set of stairs or narrowing of the trail tread, where hiker density was much higher.

A third limitation of the simulation is that the number of climbing parties entering the simulation, and their behavior is relatively simple and based on both professional judgment and empirical data. The degree to which climbers' hiking is modeled correctly could have a small effect on the accuracy of hiker density estimates for the busiest days, and a potentially greater effect on the estimates of all August passages on the trail route used by hikers. It may also be important that the model makes no attempt to differentiate between interactions between climbers and day-hikers, and considers them to be equivalent in estimates of hiker density.

A final limitation of the simulation is that the entry distribution is based on weekend data. Some of the results below summarize simulation runs representing average weekday use and it is possible that those results would differ slightly if an entry distribution for weekdays had been estimated and incorporated into the simulation.

A number of simplifying assumptions were made in the course of designing the simulation. The extent to which these assumptions limit the generality of the simulation results is probably small. The assumptions include: a) all hiking parties entered between 8:00 A.M and 9:00 P.M., b) a single entry distribution was used to represent the similar, but slightly different rates of hiker entry at four Paradise Meadow entry points, c) the only stops by hiking parties that were represented in the simulation were those occurring at Alta Vista, Nisqually Vista, Myrtle Falls, and Panorama Point, d) the distribution of stop durations at each of those points was the same for parties making short hikes and those making longer hikes, e) the continuous range of actual hiking speeds were represented by a set of four discrete speeds, f) the distribution of hiking speeds was the same for parties making short hikes and those making longer hikes, g) because it crosses a steep snow field that rarely melts out, the trail from Panorama Point directly East to the East Skyline Trail is not included in the model, and h) hiking above Pebble Creek was not simulated, but represented by a stop at waypoint Q.

2.6 Validation: Paradise Meadow

The primary reason for simulating day-hiking on the Wonderland Trail to Summerland was to estimate measures describing trail surface area per hiker, or hiker density. Thus, the best test of simulation validity would be to systematically record hiker density and compare those measures to the simulation estimates for days when a comparable number of hiking parties enter the trail. However, systematic measures of hiker density are difficult to collect and have not been collected at this point in time. In their absence, two other types of comparisons were used to assess the validity of the simulation.

2.6.1 Simulated and Actual Trip Durations

In the first, and simplest, assessment of validity we compared the average duration of the trips made by the simulated hiking parties to the duration of trips recorded during the waypoint study of Paradise Meadow hikers. This is not an ideal test because the recorded trip durations are not completely independent of the information used to construct the simulation – simulated hiking parties were assigned itineraries collected during the waypoint study. However, the duration of simulated hikes was based on hiking speed and duration of stop calculations that did not make use of the total hike durations from the waypoint survey. The table below includes the averages and standard deviations for simulated and observed hike durations.[3]

[3] Simulated climbing parties (see Section 2.1.7) are not included in these figures.

	Average Duration	Standard Deviation
Simulation	115	82
2004 Waypoint Study	119	88

Table 5. Duration of simulated and observed hikes (in minutes).

The average simulated duration was very similar to the hiking durations observed in 2004, as was the standard deviation. Thus, the simulation corresponded closely with data that were recorded on at least a semi-independent basis during the waypoint study, suggesting that the hiking speeds and durations of stops used in the simulation produce trips that closely approximate the trips of actual hikers.

2.6.1 Hourly Distributions of Simulated and Actual Trips past Two Locations

The second assessment of validity compared the temporal distribution of the counts actually registered by two electronic trail counters (the Main Skyline Trail counter just north of the Alta Vista Junction and the East Skyline Trail counter near Sluiskin Falls) to the temporal distribution of simulated parties passing those same locations. The distributions of these electronic trail counts are more nearly independent of the simulation construction than were the hike durations used in the first validity assessment.[4] The total daily counts from the trail counters were only two of seven information sources used in estimating the total number of hikers entering the simulation, and the hourly distribution of those counts were not used at all. Thus, the counted distributions provided a largely independent test of the degree to which the hiking behavior of the simulated day-hiking parties corresponded to hikers' measured behavior.

The figures below represent simulated and observed distributions of hikers passing the Main Skyline Trail counter. Each chart includes bars showing two temporal distributions, 1) the distribution of simulated day-hiking parties, averaged across 50 simulated 95th percentile days (897 entering parties), and 2) the distribution of hiker passages observed in 2006. The first chart shows the absolute correspondence between simulated and observed distributions by representing the frequency counts of hiker passages. The second chart shows the relative correspondence across hours by representing the proportion of daily hiker passages that occurred during each hourly period.

[4] The hourly distribution of counts from a third trail counter on the Nisqually Vista Trail is not used because those data were one of the primary sources of information used in estimating the simulated entry distribution of hikers.

FIGURE 4. HOURLY AVERAGE OF SIMULATED AND ACTUAL VISITORS PASSING THE MAIN SKYLINE TRAIL COUNTER (PASSAGES)

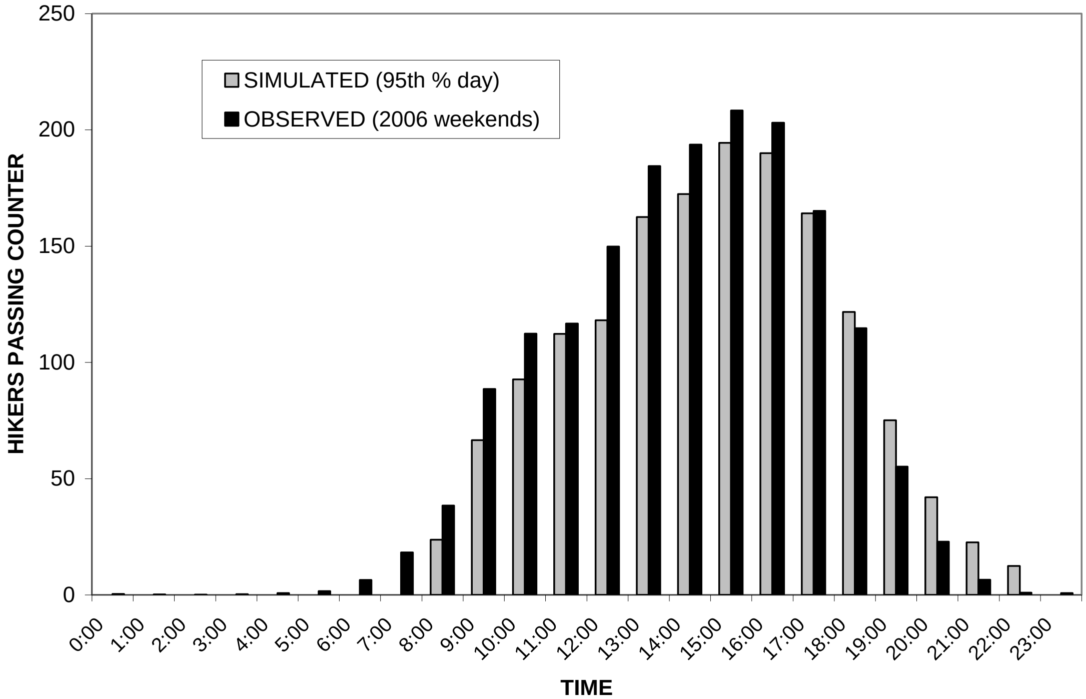
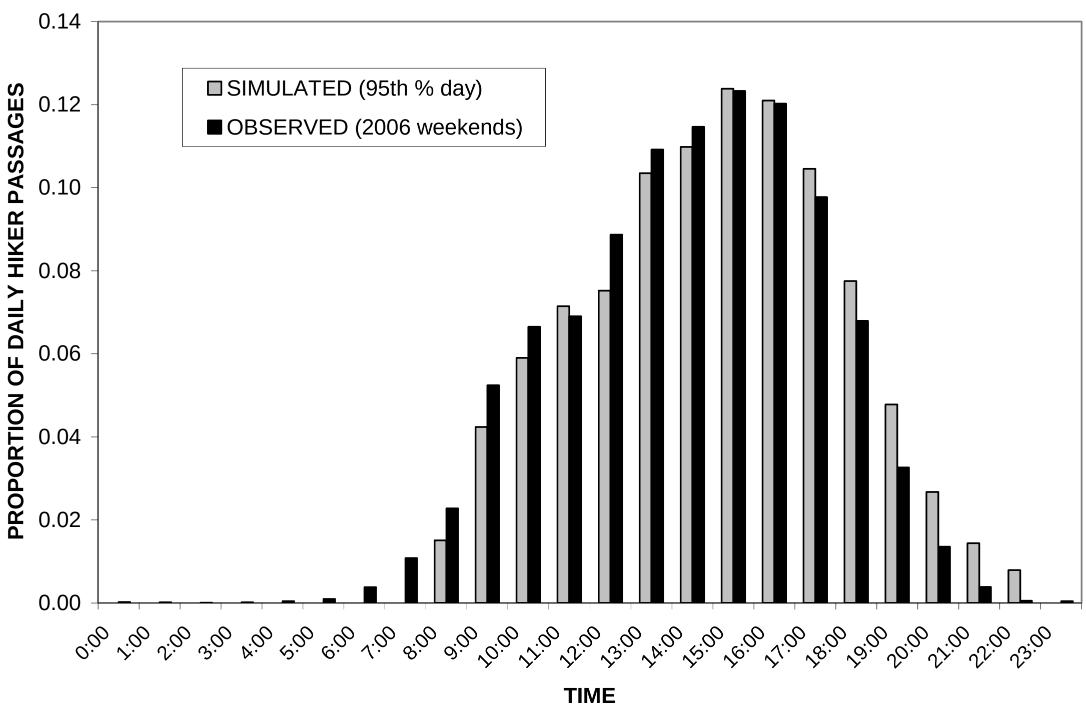


FIGURE 5. HOURLY AVERAGE OF SIMULATED AND ACTUAL VISITORS PASSING THE MAIN SKYLINE TRAIL COUNTER (PROPORTIONS)



Visual inspection of the temporal distributions showed that they were very similar. The first chart shows that the number of observed hiker passages during the peak period from 13:00 to 17:00 was slightly higher than simulated passages (because the number of passages recorded by the Main Skyline Trail counter produced the highest estimate of general visitation [see Section 2.1.1 and 2.1.5]). However, the second chart shows that proportion of simulated and observed hikers was very consistent. The discrepancies between the simulated and observed percentages for each hour ranged from 0.1 to 1.5 percent. In general, the simulation corresponded closely with the independent data recorded by the Main Skyline Trail counter.

The second set of figures below represents simulated and observed distributions of hikers passing the East Skyline Trail counter. The charts and temporal distributions correspond to those above describing the Main Skyline Trail.

FIGURE 6. HOURLY AVERAGE OF SIMULATED AND ACTUAL VISITORS PASSING THE EAST SKYLINE TRAIL COUNTER (PASSAGES)

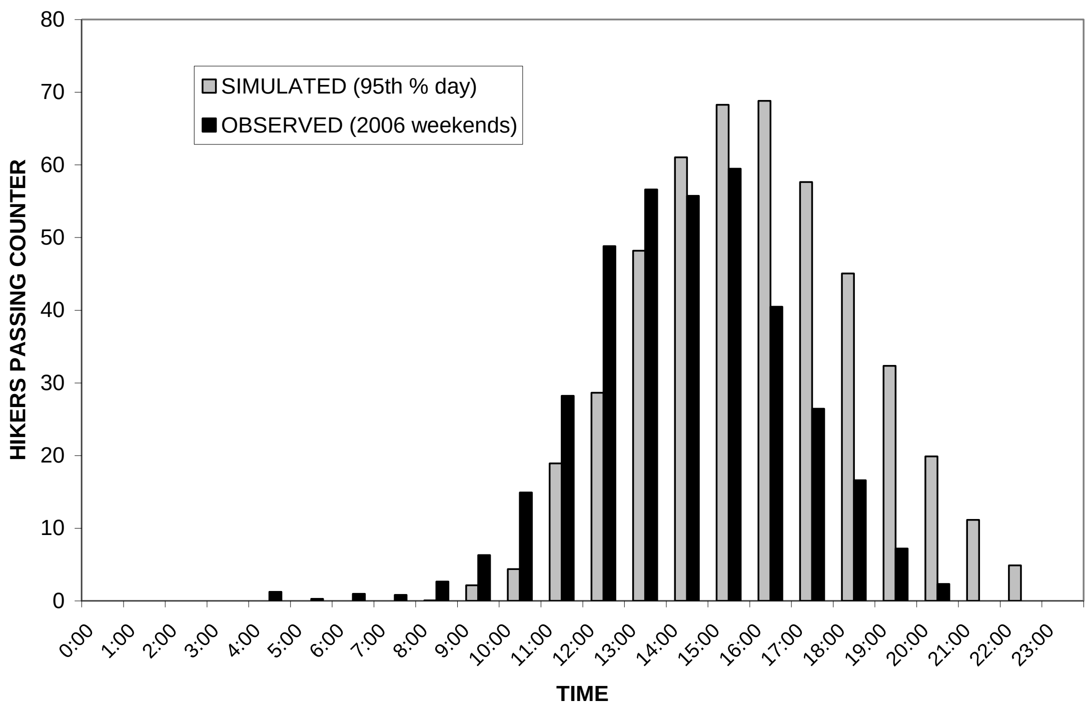
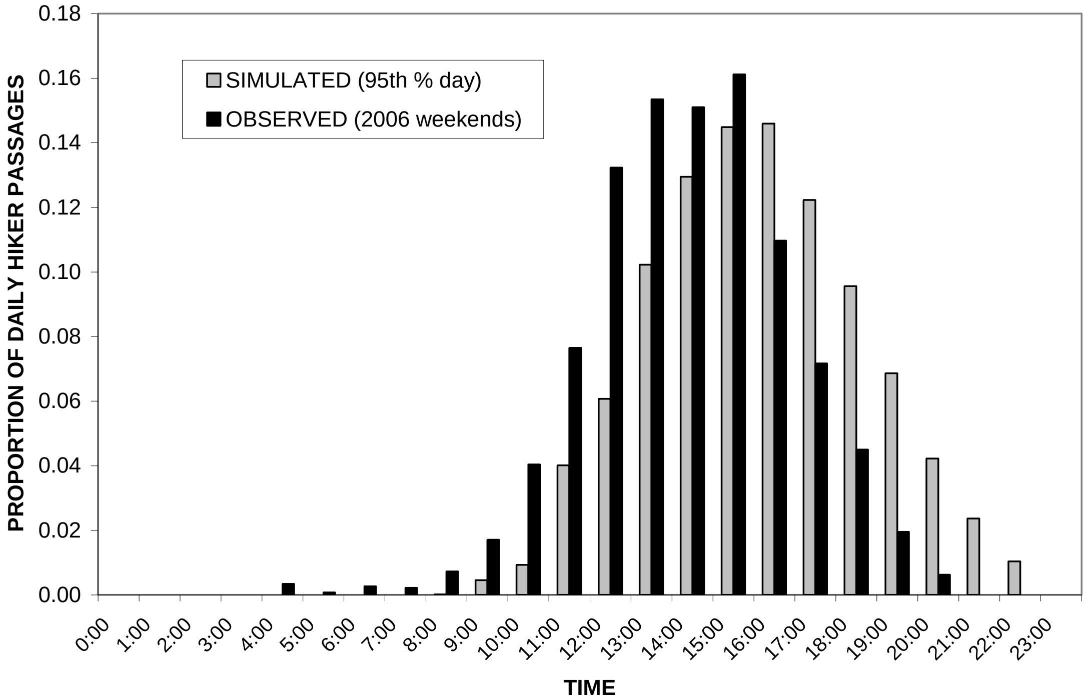


FIGURE 7. HOURLY AVERAGE OF SIMULATED AND ACTUAL VISITORS PASSING THE EAST SKYLINE TRAIL COUNTER (PROPORTIONS)



Visual inspection of the temporal distributions showed that they were similar, but had greater discrepancies than those seen on the Main Skyline Trail. The first chart shows that the number of simulated observed hiker passages during the peak period from 14:00 to 19:00 was higher than observed passages and that the peak occurred later. The second chart repeats the finding of a later peak in simulated passages. The discrepancies between the simulated and observed percentages for each hour ranged from 0.1 to 7.2 percent. In general, the simulation corresponded with the independent data recorded by the East Skyline Trail counter, but there were some consistent discrepancies. The later peak in simulated passages most likely arose because the simulation used one general entry distribution for trips of all lengths (see Sections 2.2 and 2.5). In actuality, hikers who used the East Skyline Trail apparently made earlier starts than other hikers.[5] The higher number of passages recorded in the simulation reflects the fact that the average trail counts recorded in 2006 represent use levels lower than a 95th percentile day. Whether that discrepancy reflects natural variation or bias in one or the other measurement is not clear.

2.7 Simulation Results: Paradise Meadow

This section describes four sets of results corresponding to simulation of: 1) a 95th percentile day, 2) an average weekend day, 3) an average weekday, and 4) all August use.

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[5] Use of the East Skyline Trail was not so highly associated with a particular trail entry point that differences in the entry distributions reliably correspond to the later peak in simulated passages noted on that trail.

Some caution is advised regarding the results for the average weekday and for August use because the entry distribution used in constructing those simulation models was based only on weekends (see Section 2.5 above).

Each set of results is based on 50 iterations of the simulation model. This number of iterations was selected based on a method described by Itami, Zell, Grigel, and Gimblett (2005). In this method, a "short run" of the simulation is used to estimate the variability in one or more outcome measures, and that variability is used in calculations that determine the number of iterations necessary to reach a desired level of precision in the simulation results. In this case, the desired level of precision in estimating the average number of minutes that visitor density was likely to impede movement (i.e., minutes on the busiest trail segment that there were fewer than 100 $ft.^2$ per hiker) was a 95-percent confidence interval of plus-or-minus 1.5 minutes for the "95^{th} percentile day" simulation. A "short run" of 15 iterations found that the variance in minutes was 38, and that 50 iterations of the simulation would yield the desired precision. For the "average weekend", "average weekday", and "average August day" simulations, 50 iterations produced even narrower confidence intervals.

2.7.1 Potentially Impeded Movement on a 95^th^ Percentile Day

The 95^{th} percentile day is one measure of what might be called "peak use". In most use distributions, a few extraordinary days lie far outside the normal range of use. Although managers may be concerned about the impact of such days, they generally fall outside the realm of general planning. For the purposes of the MORA VERP team, it was thought appropriate that simulation of peak use should focus on the use level higher than 95 percent of days, and lower than the 5 percent of busiest days. For Paradise Meadow, use on this 95^{th} percentile day was 897 hiking parties (see Section 2.1).

Minutes of potentially impeded movement per day. As stated in the MORA General Management Plan, the desired conditions for Paradise Meadow and other areas in the Sensitive Resource Zone include the ability for visitors to move freely (see Section 3). Because the density of visitors has the potential to impede visitor movement, one potential indicator of acceptable conditions measures the amount of time that visitor density is sufficient to alter visitor movement – specifically, the number of minutes during a 95th percentile day that each trail segment has fewer than 100 ft.2 of trail surface for each hiker on that trail.[6] As described above, the simulation model was run 50 times in order to estimate this potential indicator (labeled minutes of potentially impeded movement per day) with a 95-percent confidence interval of plus-or-minus 1.5 minutes.

On most trail segments, hiker density had the potential to impede movement for only a few minutes, even on the 95^{th} percentile day. The figure below shows the trail segments longer than 50 meters[7] that averaged more than 10 minutes of potentially impeded movement across the 50 simulated days.

[6] See Section 3.3.2 for a discussion of the research relating visitor density to walkway congestion.

[7] Trail segments shorter than 50 meters in length had highly variable estimates of surface area per hiker due to random variation in the size and proximity of hiking parties. On this basis, they were excluded from analyses and are not represented in the figures presented in this section.

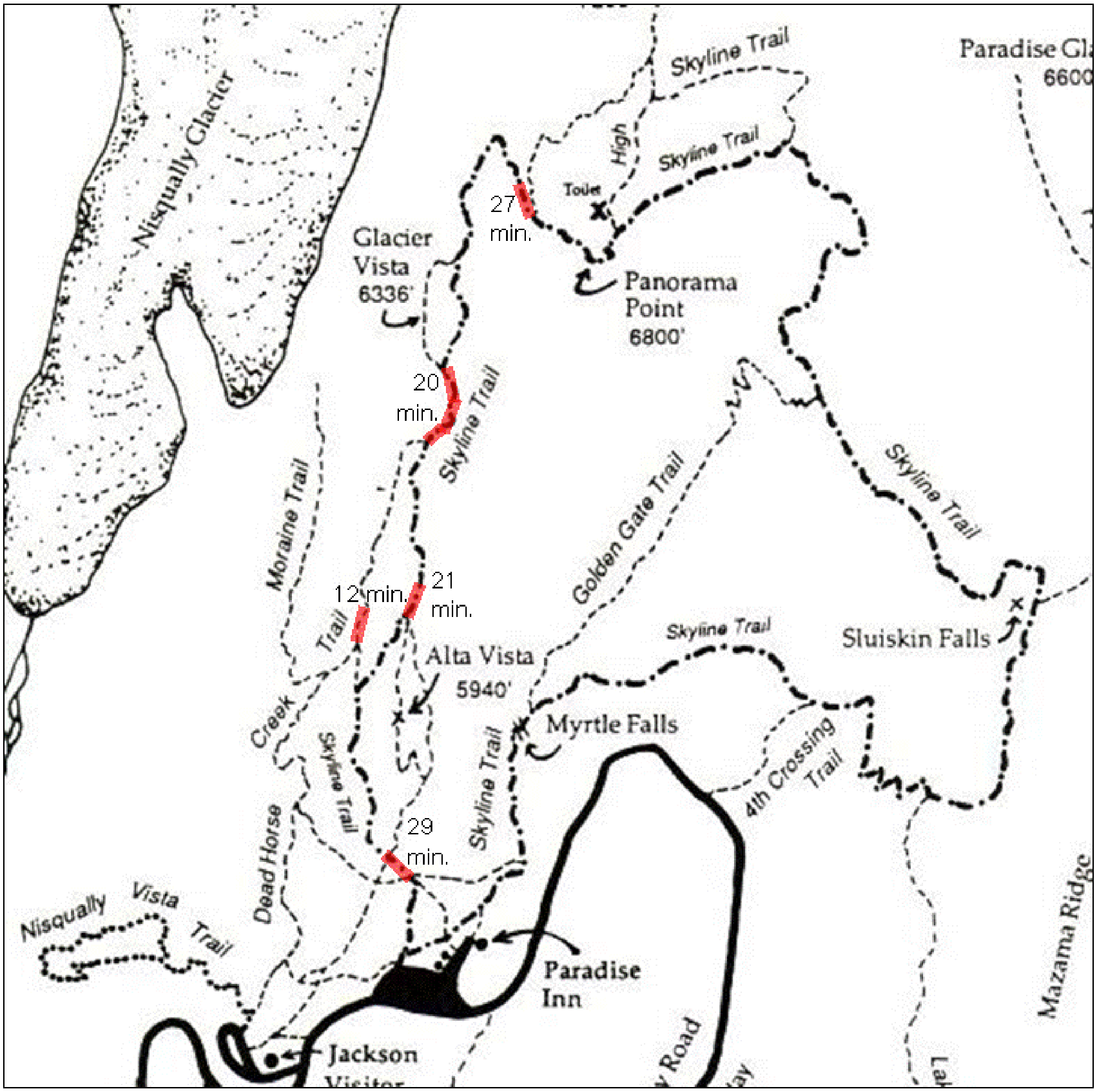

Figure 8. Trail segments estimated to have more than 10 minutes of potentially impeded movement per day based on 50 runs simulating a 95th percentile day.

One important consideration when interpreting this information is that the minutes of potentially impeded movement represented in this chart are not necessarily contiguous. For example, due to random variation in hiker distribution, the 29 minutes of high density on the lower segment of the Skyline Trail were spread across several hours of each simulated day. This consideration makes it important to also consider an additional measure of hiker density, the average trail surface area per hiker during the peak hour of visitor use.

Average trail surface per hiker (ft.^{2}) during the peak hour. The degree to which the minutes of potentially impeded movement are concentrated during peak times varies from trail segment to trail segment. The figure below shows all trail segments that averaged less then 300 ft.^{2} of surface area per hiker[8] during the peak hour of visitor use (from 15:00 to 16:00) on a 95th percentile day.

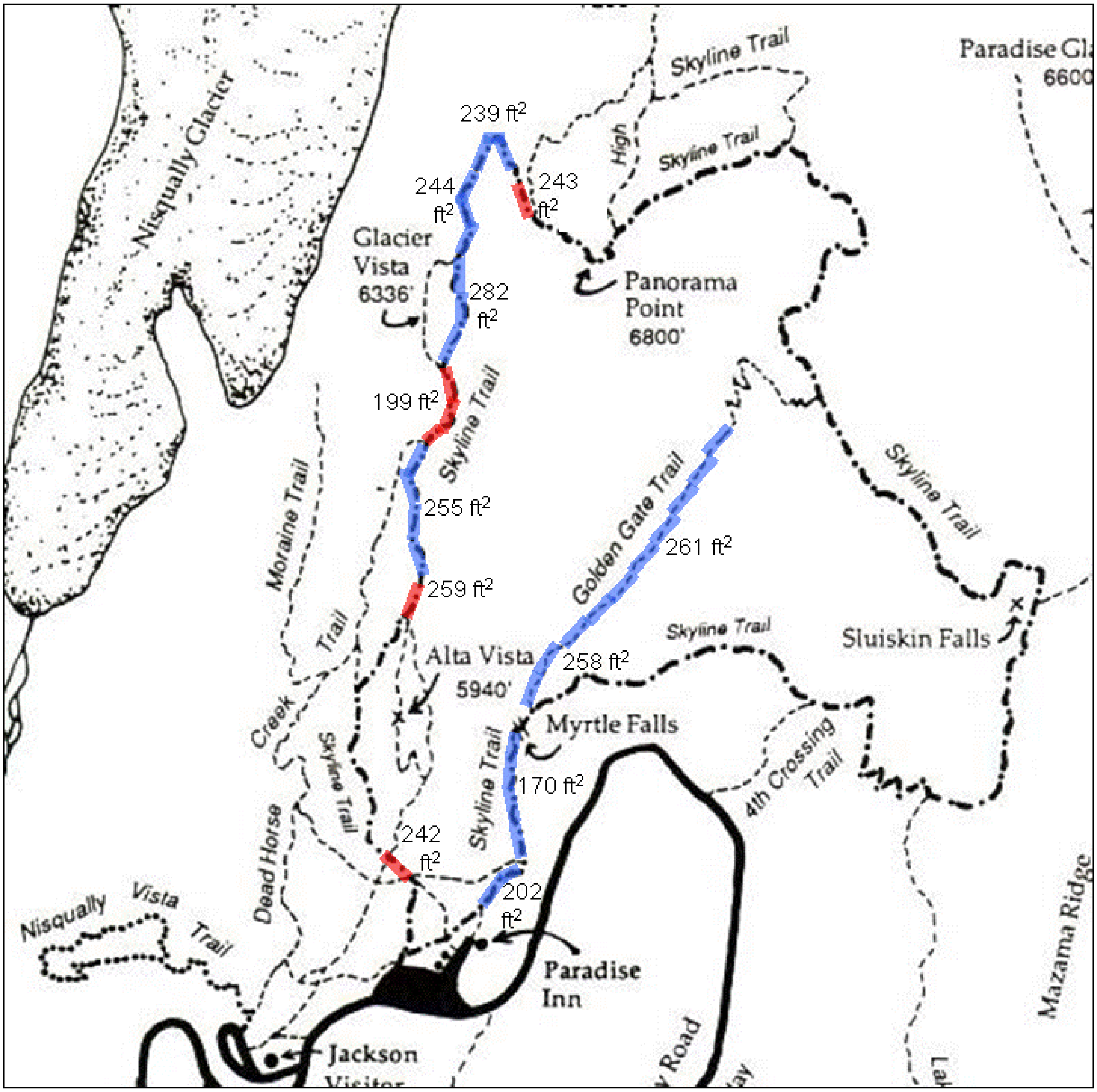

Figure 9. Trail segments estimated to have less than 300 ft.^{2} of surface area per hiker during the peak hour (15:00 to 16:00) of a 95th percentile day. Colors show segments that did and did not have more than 10 minutes/day with less than 100 ft.^{2} of surface area per hiker.

Readers should note that on 95th percentile days, there were no trail segments with

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[8] Note that the hourly average was calculated based on an observation taken every minute for the full 60 minutes, and that the 300 ft.2 threshold for highlighting in the figure was an arbitrary cutoff intended to illustrate the average density levels found on the busiest trail segments identified in earlier charts/analyses.

average peak-hour density levels that were estimated to impede visitor movement (i.e., no segments averaged less than 100 $ft.^2$ of surface area per hiker across the 50 simulated days).

It is also interesting that the segments with the highest and third-highest peak hour densities (the trail segments leading from the Paradise Inn to Myrtle Falls) were not among the trail segments averaging more than 10 minutes of potentially impeded movement. Apparently, use of the trail to Myrtle Falls was high, but did not have the variability and bunching of hiking parties that created the potential for impeded movement on the western segments of the Skyline Trail. Clearly, the two different measures of visitor density, 1) minutes of potentially impeded movement, and 2) average peak-hour surface area per hiker, are related to each other, but are not identical.

These results show considerably lower hiker density than the estimates produced by an earlier regression-based model of visitor use at Paradise Meadow (Vande Kamp and Zwiebel 2004). There are a number of potential explanations for the discrepancy (e.g., differing patterns of visitor movement during construction of the Paradise water supply, the inherent limitations of the regression-based model). The more extensive research data underlying the computer simulation and greater sophistication of the modeling process suggest that the estimates produced by the computer simulation model should be more accurate. However, validation research will ultimately show which model is more reliable.

Peak hour minutes of potentially impeded movement (PHMPIM). In order to further explore the relationship between peak-hour surface area and minutes of potentially impeded movement, the minutes of potentially impeded movement occurring only within the peak hour (15:00 to 16:00) were calculated. On most trail segments, hiker density during the peak hour had the potential to impede movement for only a few minutes, even on the 95^{th} percentile day. The figure below shows the trail segments longer than 50 meters[9] that averaged more than 2 minutes of potentially impeded movement during the peak hour across the 50 simulated days.

[9] Trail segments shorter than 50 meters in length had highly variable estimates of surface area per hiker due to random variation in the size and proximity of hiking parties. On this basis, they were excluded from analyses and are not represented in the figures presented in this section.

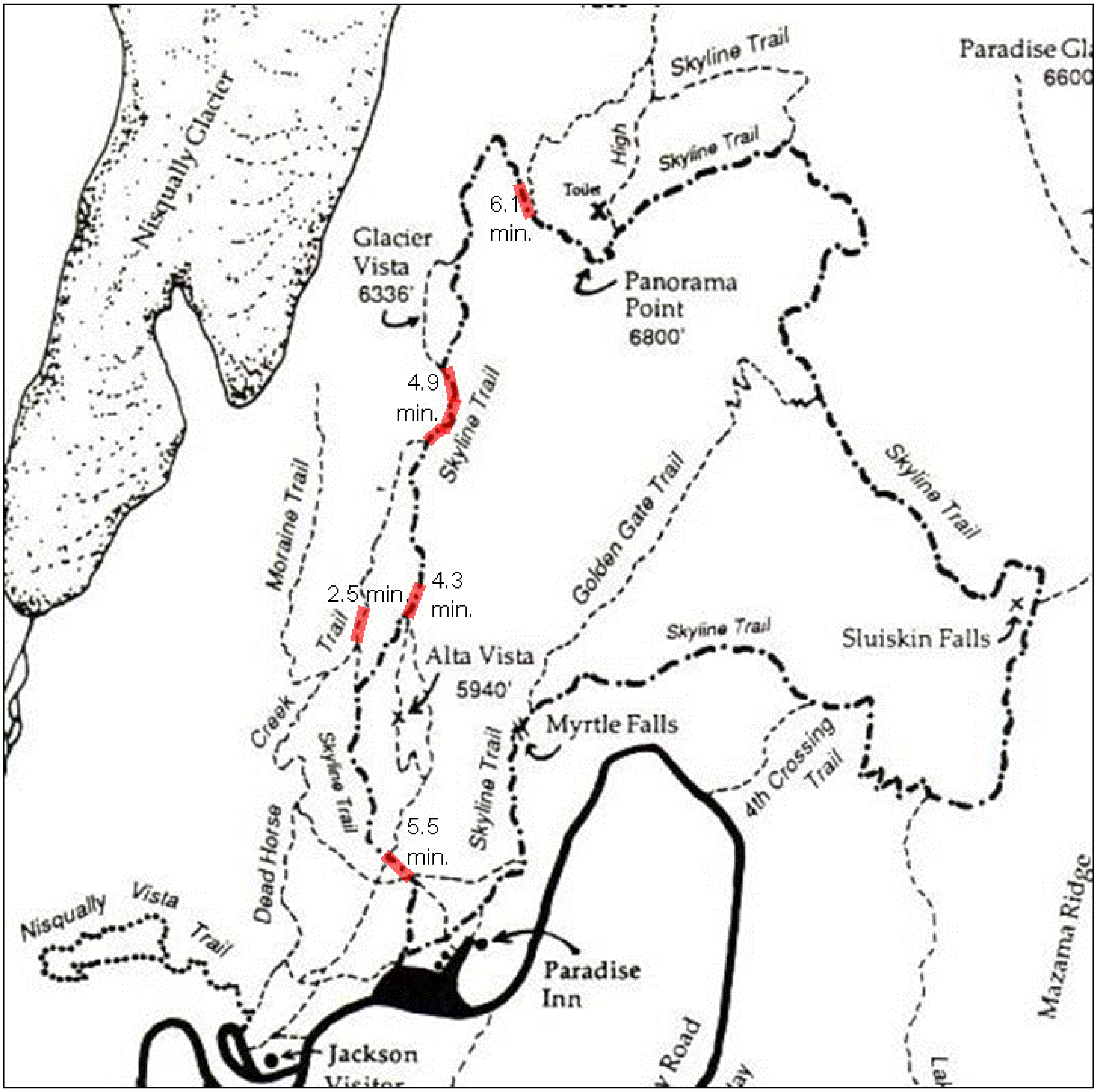


Figure 10. Trail segments estimated to have more than 2 minutes of potentially impeded movement during the peak hour (15:00 to 16:00) based on 50 runs simulating a 95th percentile day.

The PHMPIM measure was very strongly correlated with the minutes of potentially impeded movement per day. Across all 3250 observations (65 trail segments and 50 simulated days) the correlation was 0.877. Across the 65 trail segments (averaged across the 50 simulated days) the correlation was 0.992. A linear regression predicting minutes of potentially impeded movement per day based on PHMPIM produced the following equation:

Minutes of potentially impeded movement per day = PHMPIM * 3.58 + 0.42

Like the daily measure, PHMPIM is only weakly correlated to hiker density during the peak hour, (r = -0.116), in part because all but the heavily-used trails were generally estimated to have 0 PHMPIM. When the analysis was limited to the trails with less than 1000 $ft.^2$ of surface area per hiker, the correlation was moderate (r = -0.403).

2.7.2 Potentially Impeded Movement on an Average August Weekend Day

The 95^{th} percentile day provides a useful description of peak use, but the difference between peak use and more routine use levels can also be informative. In this section we estimate visitor density in Paradise Meadow during an average weekend day. Use on such an average weekend day was 734 hiking parties (see Section 2.1).

Minutes of potentially impeded movement per day. The model simulating use on an average weekend day was run 50 times in order to estimate the potential indicator measuring (for each trail segment greater than 50 meters in length) the minutes per day during which there was less than 100 $ft.^2$ of trail surface per hiker. The figure below shows the trail segments that averaged more than 10 minutes of potentially impeded movement across the 50 simulated weekend days.

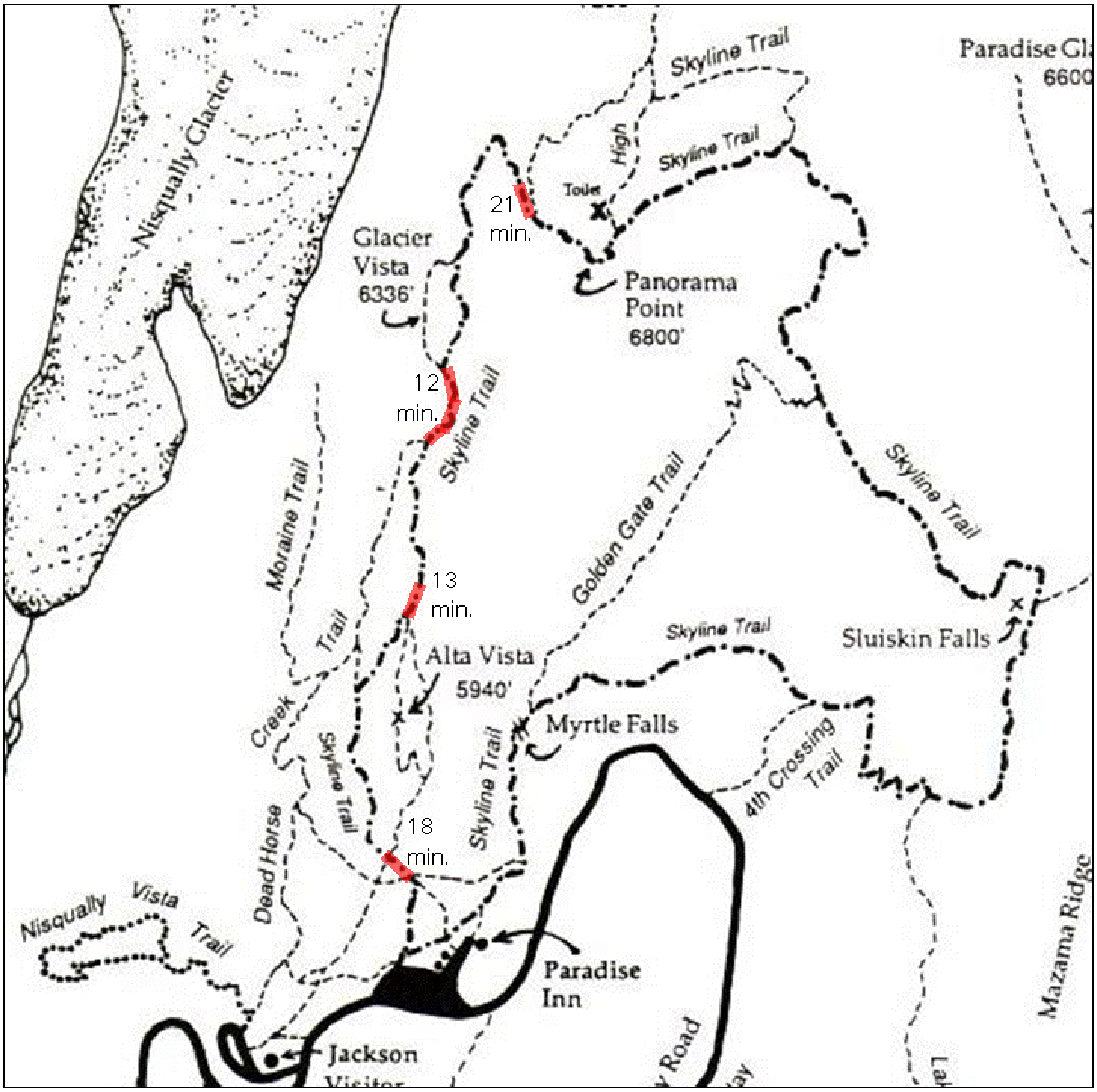


Figure 11. Trail segments estimated to have more than 10 minutes of potentially impeded movement per day based on 50 runs simulating an average August weekend day.

As explained above in reference to the chart representing 95th percentile days, the minutes of potentially impeded movement represented in this chart are not necessarily contiguous.

Average trail surface per hiker ($^{ft.2}$) during the peak hour. The degree to which the minutes of potentially impeded movement are concentrated during peak times again varied from trail segment to trail segment. The figure below shows all trail segments that averaged less then 300 ft.^{2} of surface area per hiker during the peak hour of visitor use (from 15:00 to 16:00) on an average August weekend day.

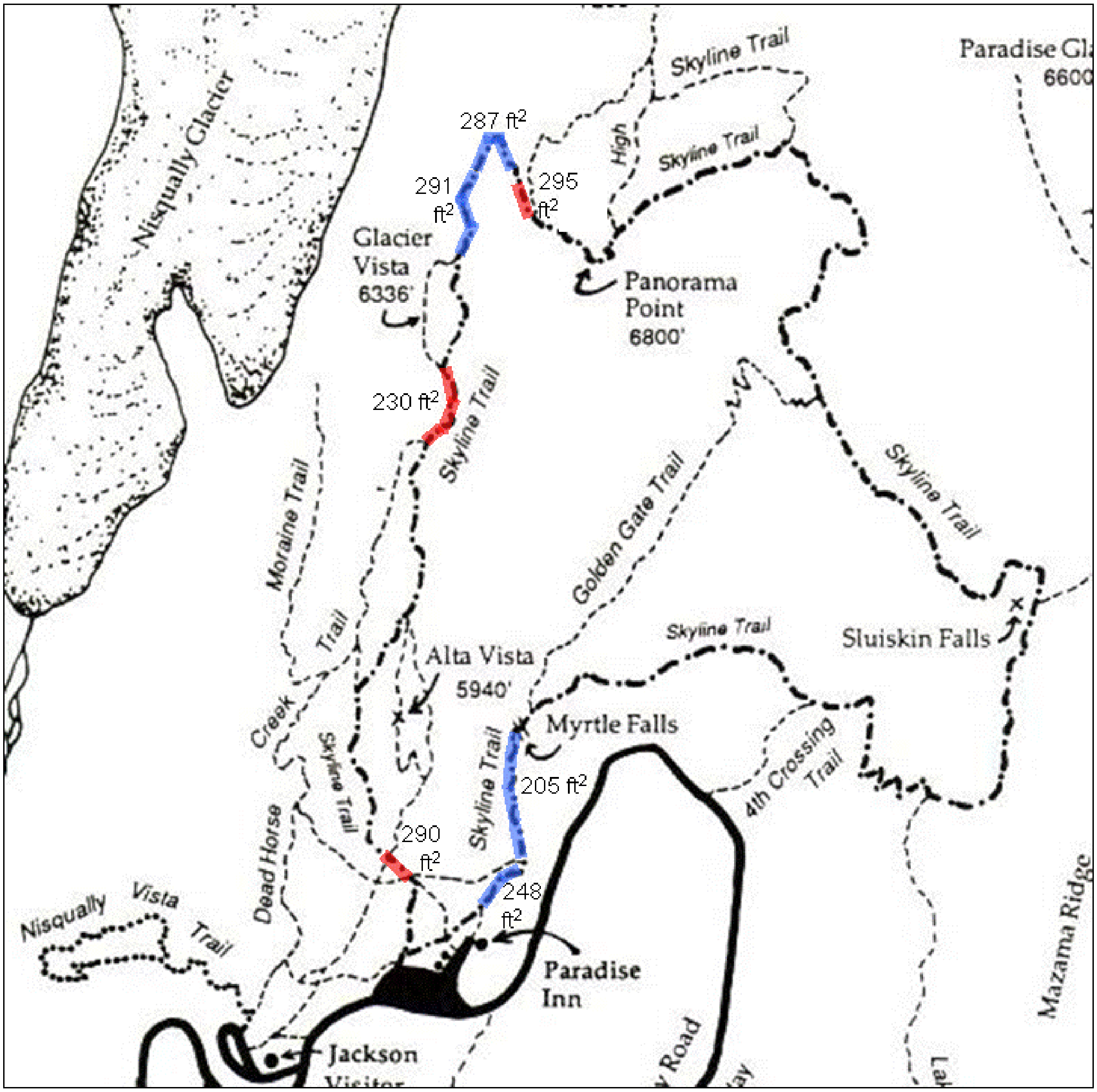


Figure 12. Trail segments estimated to have less than 300 ft.² of surface area per hiker during the peak hour (15:00 to 16:00) of an average August weekend day. Colors show segments that did and did not have more than 10 minutes/day with less than 100 ft.² of surface area per hiker.

Comparing the two charts representing average weekend days to the earlier charts representing 95th percentile days shows that visitor density on the trail to Myrtle Falls fell at nearly the same proportion as the overall reduction in hiking parties. However, density on the western Skyline Trail segments changed at a slower rate because the number of climbing parties was the same in both simulations. Although this distinction is exacerbated in the simulation because the number of simulated hiking parties is identical, it is probably not entirely an artifact of the simulation design. The difference in hiking use between average August weekend days and 95th percentile days is probably considerably greater than the same difference in climbing use.

2.7.3 Potentially Impeded Movement on an Average August Weekday

The model simulating use on an average weekday (420 hiking parties, see Section 2.1) was run 50 times in order to estimate the potential indicators measuring (for each trail segment greater than 50 meters in length) the minutes per day during which there was less than 100 $ft.^2$ of trail surface per hiker, and the average trail surface per hiker during the peak hour (15:00 to 16:00). No trail segments averaged more than ten minutes of potentially impeded movement on average August weekdays or less than 300 $ft.^2$ of surface area per hiker during the peak hour of visitor use (from 15:00 to 16:00) on those days.

2.7.4 Total August Trail Passages

Another estimate of visitor use is of interest to members of the MORA VERP team, or any other readers concerned with the relationship between visitor use and the biological impacts associated with off-trail hiking and trampling of vegetation. Estimates of the total number of visitor passages can be used to test hypotheses about the relationship between the intensity and breadth of vegetation damage and the number of visitors passing impacted sites. The strength of each relationship has important implications for managers seeking interventions that will limit vegetation damage while maximizing visitor access.

In order to estimate the total number of visitor passages over each trail segment in Paradise Meadow, visitor use on an average August day was simulated. Use on this average August day was 506 hiking parties (see Section 2.1). the simulation model was run 50 times in order to estimate daily visitor passages with a 95-percent confidence interval of plus-or-minus 17 passages for the busiest trail segment. This daily confidence interval translates to a 95-percent confidence interval of plus-or-minus 527 passages for the estimate of monthly passages on the busiest trail segment (i.e., 47,925 plus-or-minus 527 = plus-or-minus 1.1 percent). The confidence intervals for the less heavily-used segments should be roughly comparable in terms of percentages.

The figure below shows the estimated August passages for all trail segments in Paradise Meadow. Readers should note that many of the large differences in passages for contiguous trail segments are due to simplifying assumptions concerning the turnaround points used by hiking parties in the current simulation model. Specifically, because simulated hikers reversed course only at segment junctions, the model assumes that all hikers who enter a trail segment hike the entire segment. In reality, some hikers turn back at points along each trail segment and the true number of hiker passages at each point on the trail decreases (or increases) in a relatively continuous manner rather than incremental pattern shown in the figure.

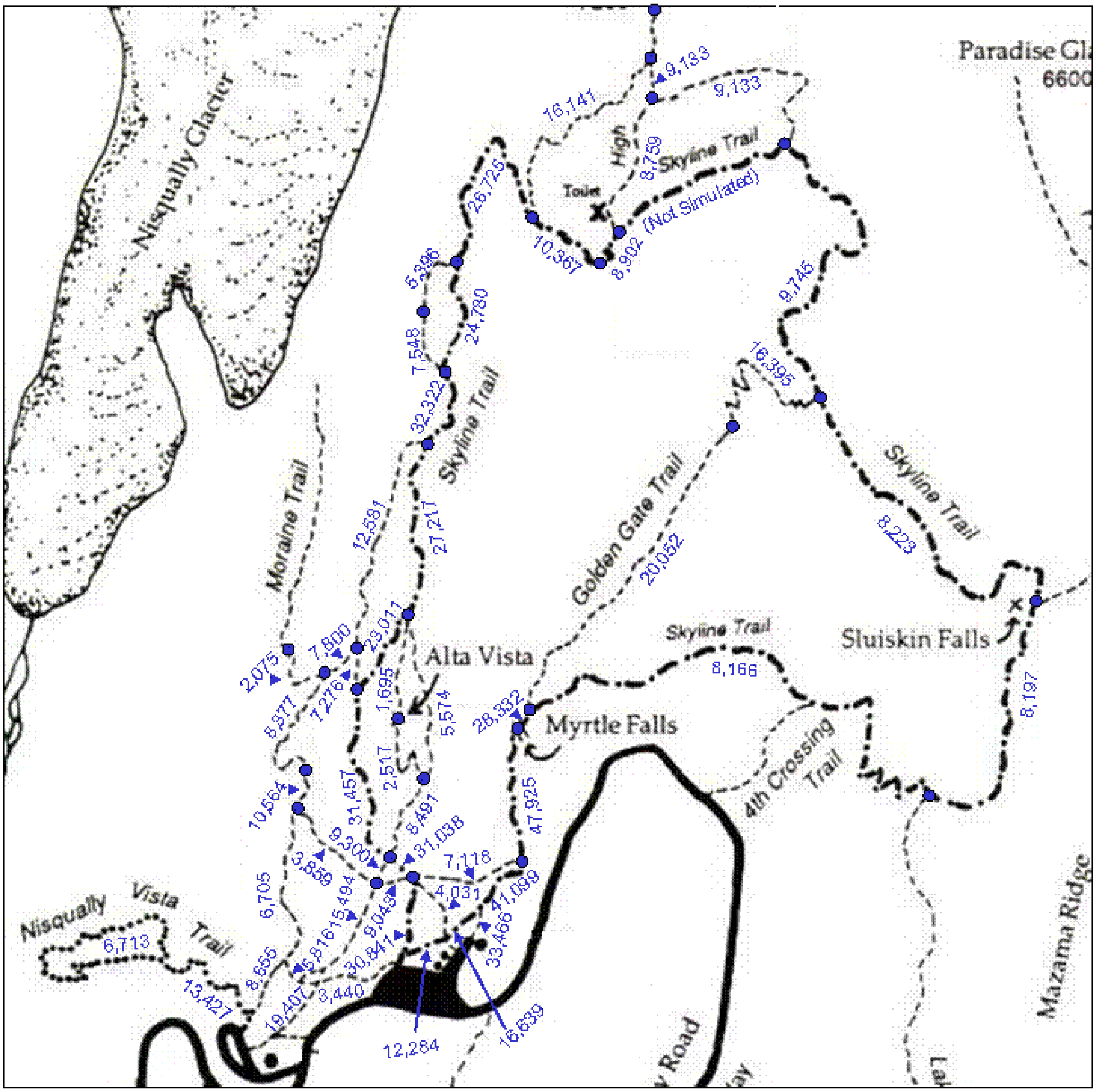


Figure 13. Estimated hiker passages over Paradise Meadow trail segments in August.

One of the most striking results is the concentration of use along the western segments of the Skyline trail. This concentration would be substantially reduced if climbing parties were excluded. Climbing parties were always modeled as hiking the Skyline Trail until the junction where they headed to Pebble Creek rather than Panorama Point. For each trail segment on that route, climbers were responsible for approximately 9,900 passages. Of course, climbing parties are a real portion of Paradise Meadow users, and excluding them altogether would present a distorted picture of use. However, the 49 hiking parties included in every day of this simulation are almost certainly an overestimate of climbing use across the entire month, and the total number of passages along the route used by climbers may also be overestimated by as much 3,000 to 4,000 passages.

Perhaps even more striking is the level of use on the Skyline Trail to Myrtle Falls. The busiest trail segment in Paradise Meadow ends at Myrtle Falls. The analyses of visitor density and potentially impeded movement (see Section 2.7.1 and 2.7.2) suggest that the trail can accommodate the current level of use, but the absolute numbers are impressive, and the levels of use on the nearby Golden Gate Trail are also high.

Finally, the number of hiker passages on the Nisqually Vista Trail is relatively small because visitors are assumed to hike the loop trail in only one direction. This observation may suggest an opportunity for more visitors to use that trail, particularly if encounters between groups are minimized by encouraging visitors to hike the loop in a particular direction.

3. RECOMMENDING INDICATORS AND STANDARDS FOR THE SENSITIVE RESOURCE ZONE

3.1 Desired Visitor Experience

> **Opportunities would be provided for visitors to see and enjoy natural and cultural resource attractions while remaining close to developed facilities. Visitors could pursue a variety of nonmotorized and nonmechanized activities and use wheelchairs on designated trails; however, to protect sensitive resources no cross-country travel would be permitted in the summer. No stock use also would be permitted. Many people may be present and there would be few opportunities for solitude. Although a high degree of social interaction may occur, visitors would be able to move relatively freely along trails. People would be able to experience park resources close to developed facilities and not be impeded by other visitors. Camping may be permitted, but only in designated trailside camps and shelters in the summer. (In the winter cross-country camping would be permitted near developed areas.) Overnight party sizes would be limited. No special skills or knowledge would be needed to use these areas, although visitors would be informed about minimum impact practices. Interpretation would be commonly provided through bulletin boards, wayside exhibits all types of signs, and formal/informal interpretive programs. In the winter, access would not be facilitated by mechanized or motorized means (e.g., grooming equipment).**

3.2 Focal Experiential Outcome

Two experiential outcomes are singled out in the desired visitor experience for clear emphasis or de-emphasis:

- Managers specify that "…visitors would be able to move relatively freely along trails." and visitors would "…not be impeded by other visitors." thus placing a high priority on freedom of movement.
- Managers also specify that there would be, "…few opportunities for solitude…" and "…a high degree of social interaction may occur." thus indicating that solitude was not a priority.

Based on the desired visitor experience, the focal experiential outcome of freedom of movement was selected for attention.

3.3 Recommended Indicator: Hiker Density

3.3.1 The Indicator and the Way in Which Visitation Leads to Impact

Hiker density is very strongly linked with freedom of movement. Research describing pedestrian flows on sidewalks and walkways has investigated the relationship between pedestrian density and the rate and character of movement they exhibit (Transportation Research Board 2000). Such research clearly establishes a relationship between pedestrian density and freedom of movement. There may be some argument whether the details of that relationship are identical for urban walkways and hiking trails, but even if such details differ, the existence of such a relationship forms a strong justification for using hiker density as an indicator in the sensitive resource/recreation zone.

3.3.2 Specifying a Standard for Hiker Density: Peak Hour Minutes of Potentially Impeded Movement

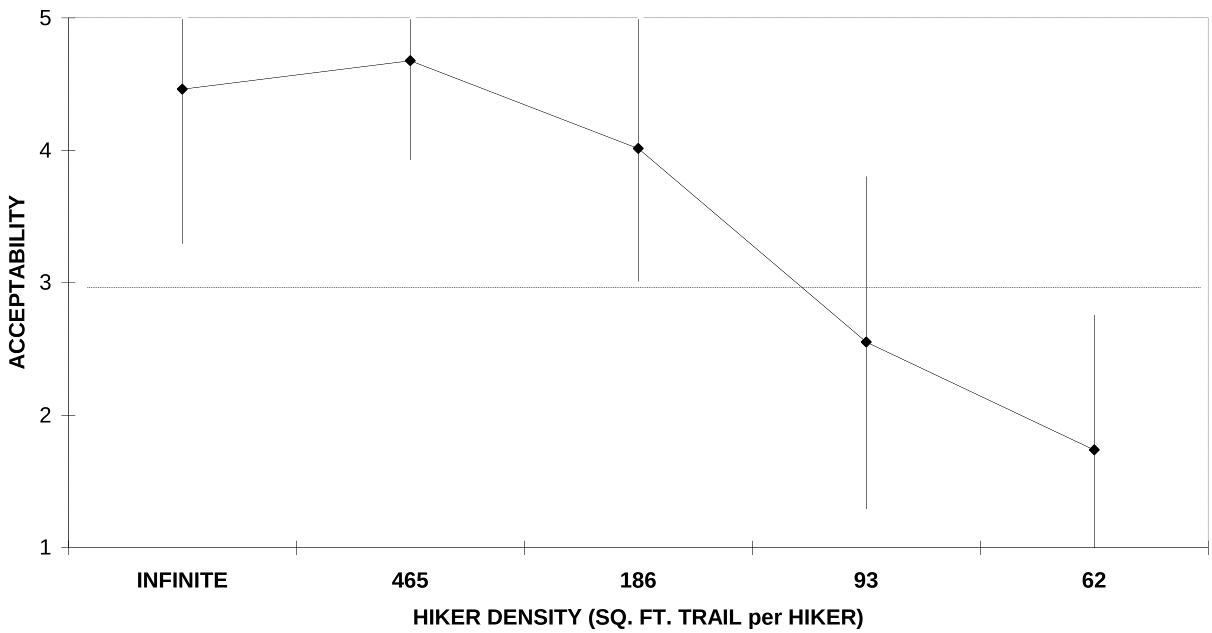
There are many different ways to measure hiker density, one of which must be selected in order to specify a standard. Density can be measured as "snapshots" or can be averaged across various time periods. It can be measured in terms of average trail area per hiker, or in terms of the amount of time that the trail area per hiker falls below a particular threshold. In this case, we recommend a standard measured in what we call *peak hour minutes of potentially impeded movement*, or PHMPIM ("Pim-Pim").

In order to specify this standard, two judgments must be made. The first judgment concerns the conditions that are considered to have the potential to impede visitor movement, and the second judgment concerns the acceptable number of minutes during the peak hour of a busy day that such conditions can be present.

The first judgment: when do conditions have the potential to impede movement? The Transportation Research Board (2000) has published a description of walkers' ability to move freely along a walkway. There are six levels of service in this description that are usually designated by the letters A to F. Rather than letters, Pushkarev and Zupan (1975) use "Open"- "Unimpeded"- "Impeded"-"Constrained"- "Crowded"- "Congested"- "Jammed". According to the TRB description, the transition from A to B (i.e., "Open" to "Unimpeded") occurs at approximately 130 $ft.^2$ per person, and the transition from B to C (i.e., "Unimpeded" to "Impeded") occurs at approximately 40 $ft.^2$ per person. The report goes on to describe results of photographic studies suggesting, "…that up to 100 $ft.^2$/ped. are required before completely free movement occurs without conflicts, and that at 130 $ft.^2$/ped, individual pedestrians are no longer influenced by others. Bunching or "platooning" does not completely disappear until space is about 500 $ft.^2$/ped or higher." In light of the published levels of service and the more detailed descriptions of the photographic study results, we recommend that when there are less than 100 $ft.^2$/hiker conditions should be considered to have the potential to impede hiker movement.

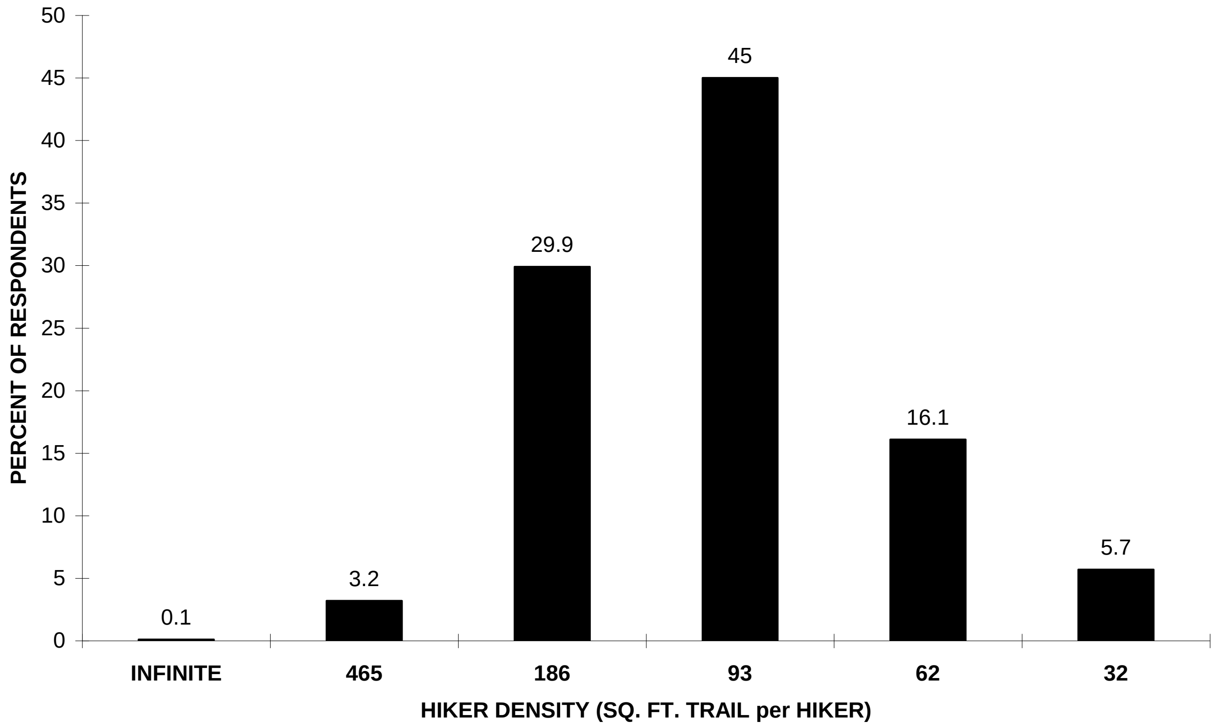
A second argument for placing emphasis on 100 $ft.^2$/ped. as a threshold between acceptable and unacceptable conditions can be made based on data collected from Paradise Meadow hikers. In a 1995 survey, hikers were shown six pictures showing different numbers of hikers on a trail with a surface area of 930 $ft.^2$. They were then asked to rate the acceptability of the conditions shown, and to select the photo that showed the maximum number of hikers that should be present on trails. The figures below represent their responses. Note that average acceptability ratings dropped below the neutral point between the pictures showing 186 and 93 ft.^{2}/ped., and that almost half of respondents selected the picture showing 93 ft.^{2}/ped. as the maximum number of hikers that should be present.

FIGURE 14. MEAN ACCEPTABILITY OF HIKERS ON TRAILS



NOTE: Bars around means represents 1 SD

FIGURE 15. MAXIMUM NUMBER OF HIKERS THAT SHOULD BE PRESENT ON TRAILS



The second judgment: how many minutes is it acceptable for visitors to be potentially impeded? Before discussing our recommendation for the second judgment it is important to further describe how PHMPIM could be measured. We recommend that for each minute during the busiest hour of peak use days, the number of hikers on the busiest trail segment(s) in the sensitive resource zone be measured (or estimated using simulation models). Those hiker counts would then be translated into hiker density measurements by dividing the trail surface area of the observed trail segment by the number of hikers. Observations indicating less than 100 ft.^{2} of trail surface area per hiker would be counted as minutes of potentially impeded movement (PHMPIM).

Although freedom of movement is an important aspect of the visitor experience to be provided in the sensitive resource zone, neither the desired visitor experience nor its underlying documentation specify the maximum number of minutes during which visitor movement should have the potential to impede visitors. In the absence of such language, the VERP planning team could consider estimates of current PHMPIM as a primary source of numeric information to be used in selecting standards. Currently, the best source of such estimates is the simulation model of visitor use Paradise Meadow. The numeric description of visitor use on Paradise Meadow trails provided by the simulation model, combined with direct experience of current use levels and professional judgment concerning the appropriateness of those conditions, provide a reasonable comparison point for managers to set standards for PHMPIM in the sensitive resource zone.

Estimated PHMPIM for Paradise Meadow trail segments were presented above in section 2.7.1. For the peak hour of 15:00 to 16:00, only five trail segments averaged more than 2 PHMPIM. The busiest trail segment (the northern segment of the Skyline Trail before the junction with the spur trail to Pebble Creek) averaged 6.1 PHMPIM. If MORA managers feel that conditions on 95th percentile days currently represent an approximate upper boundary of appropriate conditions, then a standard of 5 PHMPIM might be recommended. In the absence of specific discussion with the VERP planning team regarding an appropriate standard, a specific recommendation cannot be made.

3.3.3 Implementing a Monitoring Program for Hiker Density

In designing a monitoring program for hiker density, an important question arises concerning the direct or indirect measurement of the indicator. Indirect measurement of hiker density can be accomplished by building computer simulation models describing visitor use of the trail systems in the sensitive resource/recreation zone. For example, with further validation the Paradise Meadow simulation model could be used as the primary basis for estimating PHMPIM in that area. In that situation, the monitoring program could simply entail electronic or manual counting of the visitors entering the trail system (or even more indirectly, the number of vehicles in the Paradise area) on peak days. The simulation model would then be used to estimate PHMPIM on any or all trail segments.[10]

One unaddressed issue for the use of computer simulation models for monitoring concerns the way snow alters the way visitors use the trail systems and the way the altered use patterns change as the snow melts. It is possible (perhaps even likely) that on some days when much of the trail system is snow covered, hiker density will be higher than on busier peak days later in the year when the trail system is clear of snow. To fully protect the desired visitor experience across the entire visitation system, models must accurately estimate hiker density across a broad range of snow conditions. However, building such models is hampered by the difficulty of collecting itinerary data and modeling hiking patterns for times, a) when visitors hike in random directions across the snow, and b) during the very short period when trails are partially snow-covered. It is not clear whether the effort necessary to construct models estimating visitor density across all such conditions would be justified by their contribution to visitor experience and resource protection. Efforts might be better spent in support of trail-marking and other visitor control techniques during the critical period of snowmelt.

Another issue with computer simulation is the cost of collecting the necessary itinerary data, constructing simulation models, and validating their predictions for all areas in a given management zone. It is likely that few parks, particularly parks such as MORA with diverse visitor use in a variety of environments, could allocate the resources necessary to implement a monitoring program that was entirely based on computer simulation.

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[10] The use of computer simulation models also offers a number of other advantages for the ongoing management of the sensitive resource zone. Given certain caveats, it could be used to explore possible implications of future changes in the level or pattern of use. For example, the model could be used to simulate use of Paradise trails if a transit system were put in place and visitors were delivered by buses of various sizes on various schedules. A full discussion of the use of simulation models falls outside the range of this document.

In the absence of indirect monitoring, direct measurement of hiker density might be monitored. Direct measurement of hiker density for all trail segments in a particular area (e.g., Sunrise or Tipsoo Lake) is probably not feasible. However, it is likely that the busiest trail segments in a particular area could be identified based on professional judgment or a short period of direct observation. Subsequently, direct monitoring could focus on those busiest segments.

Several methods might be used to count the number of visitors on the busiest trail segments. For areas in which long continuous stretches (> 100 meters) of trail are visible, digital photographs could be taken at every minute of the peak hour of use and the number of visitors in those photos could counted. For other trail segments, observation points at either end of the observed segment could be defined. Two observers could start from the middle of the segment, counting the number of visitors passing in the opposite direction (in order to count the number of visitors initially present on the trail segment), then stop at the observation point and maintain a time-stamped count of the visitors entering and leaving the trail segment during the peak use hour. By combining the counts of both observers, the number of visitors on the trail at each minute during the peak use hour could be estimated. The hiker counts collected using either method could be readily translated into hiker density measurements by dividing the trail surface area of the observed trail segment by the number of hikers. Observations indicating less than 100 ft.^{2} of trail surface area per hiker would be counted as minutes of potentially impeded movement (PHMPIM).

For both indirect and direct monitoring of hiker density it is critical that the monitored trail segments be at least 100 meters long. PHMPIM measurements for shorter trail segments are strongly affected by normal levels of variability in party size and visitor movement. For example, a 1.5 meter-wide trail segment measuring 49 meters in length would provide fewer than 100 ft.^{2}/ped every time a party of 8 or more hikers passed over it. PHMPIM measurements for longer trail segments are more likely to reflect conditions that have the potential to impair visitor movement.

3.3.4 Information Needs

Through much of the GMP process, hiker density has been a top candidate for use as a social indicator in the sensitive resource/recreation zone. Thus, considerable work has been conducted to support its use. Currently, the primary information needs involve validation of the simulation model of Paradise Meadow trails. In addition, incorporating snow into the simulation model is a high priority.

There is little need for information regarding the significance of hiker density for visitor experiences. The case for freedom of movement and its relationship with hiker density forms a strong argument for hiker density as an effective indicator.

Readers should note that information regarding the relationship between hiker density and off-trail hiking is also important in relation to protecting the natural biological environment (as a step in protecting both ecosystem resources and visitor experiences). Further attempts to relate the number of hiker passages (aggregated over days or weeks) to biological impacts should be a high priority.

3.3.5 Possible Management Actions Necessary to Maintain Standard

A variety of management actions might serve to limit PHMPIM. The least obtrusive would be to provide information to hikers that would seek to persuade them to avoid the busiest trails during peak times. Care would be necessary to design effective messages. It is conceivable that if information drawing attention to specific trails was widely disseminated, it could actually increase hiker density in those areas.

A more obtrusive action would be to alter trail construction to increase hiker capacity of the busiest trail segments. Although such action would decrease the probability of impeded movement it would be necessary to consider whether the larger trail and large number of visitors might create negative physical and experiential impacts other than impeded movement (e.g., vegetation trampling or noise).

Finally, managers could directly regulate use of specific trails or trail networks in the sensitive resources zone. Currently, the only means to implement such regulation would be to decrease the parking available to visitors near those trails. However, such an action will obviously be much less effective in areas served by a visitor transportation system because total visitation will no longer be directly tied to private vehicle parking. Thus, it is likely that altering use levels sufficiently to effectively regulate hiker density in the sensitive resource zone would require a program to directly manage total hiking use of trails in the sensitive resource zone.

3.4 Recommended Indicator: Audible Sounds of Visitors

3.4.1 The Indicator and the Way in Which Visitation Leads to Impact

Some sounds detract strongly from visitor experiences. For example, when surveys asked about incidents in which other visitors detracted from experience, hikers on a number of trails in the transition trail zone reported that inappropriate noise from rowdy visitors was the most common detracting behavior (Vande Kamp, Johnson, and Swanson 1998; Vande Kamp, Swanson, and Johnson 1999). Comparable questions have not been asked of visitors in the sensitive resource zone, but an indicator measuring the audible sounds of visitors could be useful to monitor and protect experience quality. Natural soundscapes have recently gained prominence as a resource worthy of protection in their own right (National Park Service 2000), and sounds are one way in which visitors may have negative impacts on wildlife (Bowles 1995). All these factors support the adoption of an indicator measuring audible sounds of visitors and suggest that direct measures of visitor opinions about soundscapes are not required to support such adoption.

Obviously, the number of times that the sounds of visitors are audible is determined as much by visitor behavior as by the number of visitors. Thus, the indicator may appear conceptually inconsistent with the idea of establishing a user capacity. However, the VERP handbook (NPS, 1997) defines user capacity as, "...the types and levels of visitor and other public use that can be accommodated while sustaining the desired resource and social conditions that complement the purpose of the park." Note that this definition, a) emphasizes the goal of sustaining desired conditions, and b) addresses both the level and type of public use. Natural soundscapes are an important aspect of desired conditions, and types of visitors might be defined based on their sound levels. Accordingly, a VERP indicator measuring the audible sounds of visitors is appropriate.

3.4.2 Specifying a Standard for Audible Sounds of Visitors

Current information concerning the impacts of sounds on visitor experience is not sufficient to recommend a numeric standard for audible sounds of visitors.[11] Such a standard might eventually be stated in a form such as, "During at least 95 percent of peak use hours, observers will hear no more than X sounds per hour from visitor parties." Several sources will be useful in selecting such a standard, including: a) research describing the impacts of visitor sounds on other visitors' experiences, b) monitoring of existing sound levels in the sensitive resource zone at MORA, and c) the professional judgment of managers concerning appropriate sound levels in relation to the desired conditions for the sensitive resource zone. Research at MORA has established that the sounds of other visitors are commonly reported to negatively affect day-hikers' experiences (Vande Kamp, Johnson and Swanson 1998, Vande Kamp, Swanson, and Johnson 1999), but the relationship between the number and intensity of audible sounds and the level of impact on experiences has not been investigated.

3.4.3 Implementing a Monitoring Program for Audible sounds of visitors

Monitoring sound can be a complex undertaking. The simplest and most appropriate method of monitoring the audible sounds of visitors in the sensitive resource zone is probably attended listening. In attended listening, a trained observer sits quietly with a data sheet or other means of recording information. When they hear a sound, they record the time at which they first heard it, the amount of time it was audible, and a description of the sound. In quiet environments, attended listening can be used to record all audible sounds, but for the purposes of monitoring this indicator, it might be necessary to focus on recording only the sounds of visitors. Monitoring can also be conducted using microphones and recording equipment. However, such efforts introduce technical issues related to the equipment, and generally require that observers listen to recorded sounds in order to identify them, thus providing only a limited advantage over attended listening in the hours of labor necessary to produce useable information.

A monitoring program must include descriptions of both how to record sounds and when to record them. One problem would be to schedule listening sessions during peak use. If standards are stated in terms of 95th percentile conditions, then only a very small number of hours every season provide an opportunity to directly measure whether conditions are within standard. One means of addressing this problem is discussed in the next section.

3.4.4 Information Needs

The primary form of information useful to managers would be a study designed to: a) provide a baseline inventory of the sounds of visitors at different sites in the

[11] Although a standard for the audible sounds of visitors can be based on their impacts on natural soundscapes or wildlife, this section focuses only on protecting visitor experiences from the impact of sound.

sensitive resource zone, and b) describe the relationship between sounds and use levels (i.e., direct or electronic counts of the number of visitors) at those sites. Such a study would help managers specify a standard for visitor sounds by providing numeric descriptions of conditions they have experienced. For example, the study might establish that on summer weekends, observers hear 15 sounds per hour on the Skyline Trail just past the junction with the Alta Vista Trail, but that observers on the Myrtle Falls Trail hear 25 sounds per hour. By comparing such numbers with professional judgment about the appropriateness of the conditions at those sites, a numeric standard might be selected.

Such a study might also greatly simplify the task of future monitoring. If sound events are related to use levels, then attended listening during busy, but not peak use, time periods could be used to estimate sound conditions during the busiest times. It would be much easier to design monitoring programs to simultaneously measure sound events and use levels than to arrange monitoring of sound events on enough 95th percentile days to provide reliable direct evidence of whether conditions meet standards.

3.4.5 Possible Management Actions Necessary to Maintain Standard

A variety of management actions might serve to limit the sounds made by visitors. The least obtrusive would be to provide information to hikers that would seek to persuade them to hike quietly, particularly in high, open, rocky areas where sounds travel most readily. Slightly more intrusive would be messages encouraging hikers to alter their trips in some way (either in scheduling or the routes they hike) so as to minimize the density of hikers, particularly in sensitive areas. Care would be necessary to design effective messages. The content might vary from persuasive appeals ("please hike quietly to help everyone enjoy this special place") to more coercive messages ("visitors who yell or otherwise make excessive noise may be subject to fines"). Selecting the appropriate content would depend on the degree that conditions exceed the standard, or evidence showing that the less coercive messages were not sufficient to meet the standard.

If sound events are related to use levels, managers could also directly regulate use of specific trails or trail networks in the sensitive resource zone. Currently, the only means to implement such regulation would be to decrease the parking available to visitors near those trails. However, such an action will obviously be much less effective in areas served by a visitor transportation system because total visitation will no longer be directly tied to private vehicle parking. Thus, it is likely that altering use levels sufficiently to effectively regulate the sounds of visitors hiker density in the sensitive resource zone would require a program to directly manage total use of trails in the sensitive resource zone.

3.5 Unpicked Potential Indicator: Direct Measures of Impeded Movement

3.5.1 Measures of Delay or Deviation in Course

Other possible indicators that are strongly related to freedom of movement include measures of the results of congestion such as: a) delays due to slowed hiking or stopping when encountering other visitors, or b) the number of times parties were forced to alter their path or even step off the trail to let other parties past. One primary advantage of hiker density over such indicators is the existing research relating hiker density to the rate and characteristics of visitor movement. The results of congestion are also likely to be difficult to monitor accurately. Direct measurement would require trained observers to systematically observe visitor movement at specifically selected sites, and surveys asking for visitor self-report of slowing or changing course would most likely have issues similar to surveys asking about large numbers of encounters with other visitors – finding that such instances are remembered inaccurately and attempts to measure them yield indicators with poor measurement characteristics.

4. ADDITIONAL ANALYSES AND FUTURE RESEARCH

Currently, the primary information need to support the selection of indicators and standards in the Sensitive Resource Zone is further validation of the simulation model of Paradise Meadow trails. Although existing analyses have supported the validity of the model (see Section 2.6), direct measurement of the predicted hiker density and other measures such as PHMPIM would be the most relevant validation method.

A second information need is to produce validated estimates of visitor density for early-season periods when snow is present on Paradise Meadow trails. Snow alters the way visitors use the trail systems in ways that are currently not well documented. It is possible (perhaps even likely) that on some days when much of the trail system is snow covered, hiker density will be higher than on busier peak days later in the year when the trail system is clear of snow. To fully protect the desired visitor experience across the entire visitation system, a model based on the early-season itinerary data collected in 2004 (see Vande Kamp 2009c) should be developed and validated.

There is little need for information regarding the significance of hiker density for visitor experiences. The case for freedom of movement and its relationship with hiker density forms a strong argument for hiker density as an effective indicator.

Because Paradise Meadow is the most commonly visited site in MORA, the relationship between total vehicle entries and counts of hikers has been very strong in past studies (see Vande Kamp, Johnson, Kucera, and Young, 1997). The possibility of simply using vehicle entries to monitor trail conditions should be explored. It would be relatively simple to collect traffic count data (either at the park entrances or using a counter located at Paradise) during validation of the simulation model in order to assess the feasibility of this potentially efficient method of monitoring.

The current model assumes that nearly all visitors will arrive in private vehicles. However, beginning in the 2006 season, a shuttle system has been implemented that carries visitors from Cougar Rock Campground to the Paradise area. It is unclear whether the current shuttles, or future shuttles, do or will alter the way that parties enter Paradise Meadow and thus affect hiker density on the trails. Data collection examining whether and how tightly parties remain clustered together after exiting shuttle buses would be necessary to determine whether the entry distribution used in the current simulation model should be modified to reflect shuttle bus delivery of visitors, and if so, how.Readers should note that information regarding the relationship between hiker density and off-trail hiking is also important in relation to protecting the natural biological environment (as a step in protecting both ecosystem resources and visitor experiences). Further attempts to relate the number of hiker passages (aggregated over days or weeks) to biological impacts should be a high priority.

Finally, it is important to attempt monitoring of hiker density in parts of the Sensitive Resource Zone outside Paradise Meadow. By assessing the feasibility of monitoring at Sunrise and Tipsoo Lake, managers can determine the long term viability of the proposed hiker density indicator. They can also assess the priority that should be placed on the development of simulation models to describe total use in those areas. If direct monitoring is effective, and total use is far below levels at which visitor movement is impeded, then simulation modeling would be given a low priority. However, other outcomes would suggest that simulation models of those areas would be useful and should be developed.

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