

# ARCHES NATIONAL PARK VISITOR USE, ACCESS, AND EXPERIENCE STUDY – FINAL REPORT



November 2020

Prepared for  
Arches National Park

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the science of insight

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# CONTENTS

<b>EXECUTIVE SUMMARY .....</b>	<b>1</b>
<b>1.0 INTRODUCTION .....</b>	<b>8</b>
<b>2.0 METHODS .....</b>	<b>10</b>
2.1 STUDY AREA .....	10
MAIN TRAVEL CORRIDOR.....	10
THE WINDOWS.....	12
DELICATE ARCH .....	14
DEVILS GARDEN .....	16
2.2 DATA COLLECTION.....	18
ENTRANCE STATION QUEUE COUNTS .....	22
ENTRANCE STATION TRAFFIC COUNTS.....	23
SECONDARY ROAD TRAFFIC CALIBRATION COUNTS .....	23
GPS ROUTE TRACKING .....	23
PARKING LOT ACCUMULATION AND TURNOVER.....	26
VISITOR USE COUNTS .....	29
PEOPLE-AT-ONE-TIME (PAOT) AND PEOPLE-PER- VIEWSCAPE (PPV) COUNTS .....	30
VEHICLES-AT-ONE-TIME (VAOT) CALCULATION.....	31
DELAY CARD ADMINISTRATION .....	31
<b>3.0 RESULTS .....</b>	<b>34</b>
3.1 ENTRANCE STATION QUEUE COUNTS .....	34
MEAN AND MAXIMUM DAILY ENTRANCE STATION QUEUE LENGTH .....	34
MEAN HOURLY ENTRANCE STATION QUEUE LENGTHS.....	35
3.2 ENTRANCE STATION TRAFFIC COUNTS.....	36
VEHICLE ARRIVAL VOLUMES.....	36

DESIGN DAY ANALYSIS .....	40
3.3 SECONDARY ROAD TRAFFIC COUNTS .....	43
CALIBRATION .....	43
VEHICLE ARRIVALS AND DEPARTURES .....	44
3.4 GPS ROUTE TRACKING.....	52
TRAVEL ROUTES .....	52
TOTAL TRIP TIMES .....	56
SITE DWELL TIMES.....	59
3.5 PARKING LOT ACCUMULATION AND TURNOVER ANALYSIS AND RESULTS .....	61
PARKING ACCUMULATION .....	61
PARKING DURATION .....	65
3.6 VISITOR USE COUNTS .....	67
CALIBRATION.....	67
VISITOR ARRIVALS AND DEPARTURES .....	68
DAILY VISITOR ARRIVALS.....	68
HOURLY VISITOR USE VOLUMES.....	71
MEAN HOURLY VISITOR ARRIVALS AND DEPARTURES.....	75
3.7 PEOPLE-PER-VIEWSCAPE (PPV) AND PEOPLE AND VEHICLE-AT-ONE-TIME (PAOT AND VAOT) COUNTS.....	77
THE WINDOWS.....	77
DELICATE ARCH .....	81
DEVILS GARDEN .....	85
3.8 STUDY SITE DWELL TIMES.....	89
THE WINDOWS.....	89
DELICATE ARCH .....	90
DELICATE ARCH VIEWSCAPE .....	92
DEVILS GARDEN .....	93
<b>4.0 STATISTICAL MODELING OF STUDY DATA.....</b>	<b>94</b>
4.1 HOURLY ENTRANCE STATION VEHICLE ARRIVALS AND HOURLY SITE-LEVEL PARKING ACCUMULATION (VAOT), BY STUDY SITE .....	95
4.2 HOURLY SITE-LEVEL VEHICLE ARRIVALS AND HOURLY SITE-LEVEL PARKING ACCUMULATION (VAOT), BY STUDY SITE .....	96
4.3 HOURLY SITE-LEVEL VEHICLE ARRIVALS AND HOURLY SITE-LEVEL TRAIL USE ARRIVALS, BY STUDY SITE.....	97
4.4 HOURLY SITE-LEVEL PARKING ACCUMULATION (VAOT) AND HOURLY SITE-LEVEL TRAIL USE ARRIVALS, BY STUDY SITE.....	98
4.5 HOURLY SITE-LEVEL TRAIL USE ARRIVALS AND HOURLY SITE-LEVEL MEAN PAOT/PPV IN THE VIEWSCAPE, BY STUDY SITE.....	99
4.6 HOURLY SITE-LEVEL TRAIL USE ARRIVALS AND HOURLY SITE-LEVEL MAXIMUM PAOT/PPV IN THE VIEWSCAPE, BY STUDY SITE.....	100

4.7 HOURLY ENTRANCE STATION VEHICLE ARRIVALS AND HOURLY SITE-LEVEL VEHICLE ARRIVALS, BY STUDY SITE .....	101
4.8 DAILY ENTRANCE STATION VEHICLE ARRIVALS AND DAILY SITE-LEVEL VEHICLE ARRIVALS, BY STUDY SITE .....	102
<b>5.0 SIMULATION MODELING .....</b>	<b>103</b>
5.1 METHODS .....	103
MODEL OVERVIEW .....	103
MODEL INPUT ANALYSIS .....	104
MODEL ALGORITHM AND PROGRAMMING .....	109
5.2 SIMULATION ANALYSIS OF VISITOR USE AND CAPACITIES .....	111
SIMULATION RESULTS: CURRENT VISITOR USE CONDITIONS .....	112
5.3 MODEL VALIDATION .....	118
VAOT .....	118
PAOT/PPV .....	118
ENTRANCE STATION VEHICLE QUEUE COUNTS .....	119

## LIST OF FIGURES

FIGURE 1. SCHEMATIC DIAGRAM OF STUDY AREA .....	11
FIGURE 2. THE WINDOWS STUDY SITE AND VIEWSCAPE .....	13
FIGURE 3. THE WINDOWS VIEWSCAPE BOUNDARY .....	13
FIGURE 4. DELICATE ARCH STUDY SITE AND VIEWSCAPE .....	15
FIGURE 5. DELICATE ARCH VIEWSCAPE BOUNDARY .....	15
FIGURE 6. DEVILS GARDEN STUDY SITE AND VIEWSCAPE .....	17
FIGURE 7. DEVILS GARDEN VIEWSCAPE BOUNDARY .....	17
FIGURE 8. DATA COLLECTION DEPLOYMENT LOCATIONS FOR PARKWIDE MEASURES .....	19
FIGURE 9. DATA COLLECTION DEPLOYMENT LOCATIONS: THE WINDOWS .....	20
FIGURE 10. DATA COLLECTION DEPLOYMENT LOCATIONS: DELICATE ARCH .....	20
FIGURE 11. DATA COLLECTION DEPLOYMENT LOCATIONS: DEVILS GARDEN .....	21
FIGURE 12. SCHEMATIC DIAGRAM OF ENTRANCE STATION QUEUE COUNT AREA .....	22
FIGURE 13. ROADWAY INTERCEPT FOR GPS ADMINISTRATION .....	25
FIGURE 14. PARKING LOT ACCUMULATION AND TURNOVER DATA COLLECTION PROCEDURE: THE WINDOWS .....	27
FIGURE 15. PARKING LOT ACCUMULATION AND TURNOVER DATA COLLECTION PROCEDURE: DELICATE ARCH .....	28
FIGURE 16. PARKING ACCUMULATION AND TURNOVER DATA COLLECTION PROCEDURE: DEVILS GARDEN .....	29
FIGURE 17. MEAN HOURLY ENTRANCE STATION QUEUE LENGTH .....	35
FIGURE 18. DAILY TOTAL ENTRANCE STATION VEHICLE ARRIVALS (GRAY SHADING INDICATES WEEKENDS/HOLIDAYS) .....	36
FIGURE 19. HOURLY ENTRANCE STATION VEHICLE ARRIVALS (GRAY SHADING INDICATES WEEKENDS/HOLIDAYS) .....	37
FIGURE 20. HOURLY ENTRANCE STATION VEHICLE ARRIVAL, BY SAMPLING DAY AND DAY OF WEEK CATEGORY .....	38
FIGURE 21. MEAN HOURLY ENTRANCE STATION VEHICLE ARRIVALS, BY DAY OF WEEK CATEGORY .....	39
FIGURE 22. DAILY ENTRANCE STATION VEHICLE ARRIVALS, BY DATE, JANUARY-DECEMBER 2019 .....	41
FIGURE 23. DAILY ENTRANCE STATION VEHICLE ARRIVALS AND DESIGN DAY, IN DESCENDING ORDER, 2019 PEAK SEASON .....	42
FIGURE 24. DAILY ENTRANCE STATION VEHICLE ARRIVALS AND DESIGN DAY, BY DATE, 2019 PEAK SEASON .....	42
FIGURE 25. DAILY TOTAL VEHICLE ARRIVALS, BY TRAFFIC COUNTER LOCATION AND DATE (GRAY SHADING INDICATES WEEKENDS/HOLIDAYS) .....	45

FIGURE 26. HOURLY VEHICLE ARRIVALS, BY TRAFFIC COUNTER LOCATION AND DATE (GRAY SHADING INDICATES WEEKENDS/HOLIDAYS) .....	47
FIGURE 27. HOURLY VEHICLE ARRIVALS, BY COUNTER LOCATION, SAMPLING DAY, AND DAY OF WEEK CATEGORY.....	49
FIGURE 28. MEAN HOURLY VEHICLE ARRIVALS AND DEPARTURES, BY COUNTER LOCATION AND DAY OF WEEK CATEGORY .....	51
FIGURE 29. FREQUENCY DISTRIBUTION OF ROUTE PROFILES: PRIVATE VEHICLES .....	53
FIGURE 30. FREQUENCY DISTRIBUTION OF ROUTE PROFILES: COMMERCIAL VEHICLES .....	53
FIGURE 31. TYPOLOGY OF ROUTE PROFILES: PRIVATE AND COMMERCIAL VEHICLES (NUMBERS CORRESPOND TO DESCRIPTIONS IN TABLE 7 AND TABLE 8).....	55
FIGURE 32. MEAN TOTAL TRAVEL TIME, BY ROUTE PROFILE AND OVERALL: PRIVATE VEHICLES .....	57
FIGURE 33. MEAN TOTAL TRAVEL TIME, BY ROUTE PROFILE AND OVERALL, COMMERCIAL VEHICLES .....	57
FIGURE 34. FREQUENCY DISTRIBUTION OF GPS-BASED DWELL TIMES, BY STUDY SITE AND VEHICLE TYPE .....	60
FIGURE 35. HOURLY PARKING ACCUMULATION, BY LOCATION, SAMPLING DAY, AND DAY OF WEEK CATEGORY .....	62
FIGURE 36. HOURLY AVERAGE PARKING ACCUMULATION, BY LOCATION AND DAY OF WEEK CATEGORY.....	64
FIGURE 37. AVERAGE AND FREQUENCY DISTRIBUTION OF PARKING DURATION, BY LOCATION AND DAY OF WEEK CATEGORY .....	66
FIGURE 38. DAILY VISITOR ARRIVALS, BY TRAIL COUNTER LOCATION AND DATE (GRAY SHADING INDICATES WEEKENDS/HOLIDAYS).....	70
FIGURE 39. HOURLY VISITOR USE VOLUME (ARRIVALS AND DEPARTURES), BY TRAIL COUNTER LOCATION AND DATE (GRAY SHADING INDICATES WEEKENDS/HOLIDAYS) .....	72
FIGURE 40. HOURLY VISITOR ARRIVALS, BY TRAIL COUNTER LOCATION, SAMPLING DAY, AND DAY OF WEEK CATEGORY.....	74
FIGURE 41. HOURLY MEAN ARRIVALS AND DEPARTURES, BY TRAIL COUNTER LOCATION AND DAY OF WEEK CATEGORY .....	76
FIGURE 42. HOURLY AVERAGE, MINIMUM, AND MAXIMUM NUMBER OF PEOPLE-AT-ONE-TIME (PAOT): THE WINDOWS VIEWSCAPE .....	79
FIGURE 43. SCATTERPLOT AND REGRESSION EQUATION: VAOT AT THE WINDOWS AND PAOT IN THE WINDOWS VIEWSCAPE .....	80
FIGURE 44. HOURLY AVERAGE, MINIMUM, AND MAXIMUM NUMBER OF PEOPLE-AT-ONE-TIME (PAOT): DELICATE ARCH VIEWSCAPE .....	83
FIGURE 45. SCATTERPLOT AND REGRESSION EQUATIONS: VAOT AT DELICATE ARCH AND PAOT IN THE DELICATE ARCH VIEWSCAPE.....	84
FIGURE 46. HOURLY AVERAGE, MINIMUM, AND MAXIMUM NUMBER OF PEOPLE-PER-VIEWSCAPE (PPV): DEVILS GARDEN .....	87
FIGURE 47. SCATTERPLOT AND REGRESSION EQUATION: VAOT AT DEVILS GARDEN AND PPV IN THE DEVILS GARDEN VIEWSCAPE .....	88
FIGURE 48. FREQUENCY DISTRIBUTION OF DELAY CARD-BASED DWELL TIMES: THE WINDOWS .....	90
FIGURE 49. FREQUENCY DISTRIBUTION OF DELAY CARD-BASED DWELL TIMES: DELICATE ARCH .....	91
FIGURE 50. FREQUENCY DISTRIBUTION OF DELAY CARD-BASED DWELL TIMES: DELICATE ARCH VIEWSCAPE .....	92
FIGURE 51. FREQUENCY DISTRIBUTION OF DELAY CARD-BASED DWELL TIMES: DEVILS GARDEN .....	93
FIGURE 52. HOURLY ENTRANCE STATION VEHICLE ARRIVALS AND HOURLY SITE-LEVEL PARKING ACCUMULATION (VAOT), BY STUDY SITE.....	95
FIGURE 53. HOURLY SITE-LEVEL VEHICLE ARRIVALS AND HOURLY SITE-LEVEL PARKING ACCUMULATION (VAOT), BY STUDY SITE .....	96
FIGURE 54. HOURLY SITE-LEVEL VEHICLE ARRIVALS AND HOURLY SITE-LEVEL TRAIL USE ARRIVALS, BY STUDY SITE .....	97
FIGURE 55. HOURLY SITE-LEVEL PARKING ACCUMULATION (VAOT) AND HOURLY SITE-LEVEL TRAIL USE ARRIVALS, BY STUDY SITE.....	98
FIGURE 56. HOURLY SITE-LEVEL TRAIL USE ARRIVALS AND HOURLY SITE-LEVEL MEAN PAOT/PPV IN THE VIEWSCAPE, BY STUDY SITE .....	99
FIGURE 57. HOURLY SITE-LEVEL TRAIL USE ARRIVALS AND HOURLY SITE-LEVEL MAXIMUM PAOT/PPV IN THE VIEWSCAPE, BY STUDY SITE.....	100

FIGURE 58. HOURLY ENTRANCE STATION VEHICLE ARRIVALS AND HOURLY SITE-LEVEL VEHICLE ARRIVALS, BY STUDY SITE .....	101
FIGURE 59. DAILY ENTRANCE STATION VEHICLE ARRIVALS AND DAILY SITE-LEVEL VEHICLE ARRIVALS, BY STUDY SITE .....	102
FIGURE 60. BASELINE SIMULATION RESULTS: THE WINDOWS.....	113
FIGURE 61. BASELINE SIMULATION RESULTS: DELICATE ARCH.....	115
FIGURE 62. BASELINE SIMULATION RESULTS: DEVILS GARDEN.....	117

**LIST OF TABLES**

TABLE 1. ARCHES GPS ROUTE TRACKING SAMPLING EFFORT.....	24
TABLE 2. SUMMARY OF PEOPLE-AT-ONE-TIME (PAOT) AND PEOPLE-PER-VIEWSCAPE (PPV) COUNTING EFFORT .....	30
TABLE 3. DELAY CARD SAMPLING EFFORT: THE WINDOWS.....	33
TABLE 4. DELAY CARD SAMPLING EFFORT: DELICATE ARCH.....	33
TABLE 5. DELAY CARD SAMPLING EFFORT: DEVILS GARDEN.....	33
TABLE 6. AVERAGE AND MAXIMUM DAILY ENTRANCE STATION QUEUE LENGTH .....	34
TABLE 7. FREQUENCY DISTRIBUTION OF TRAVEL ROUTES, BY ROUTE PROFILE: PRIVATE VEHICLES.....	56
TABLE 8. FREQUENCY DISTRIBUTION OF TRAVEL ROUTES, BY ROUTE PROFILE: COMMERCIAL VEHICLES.....	56
TABLE 9. FREQUENCY DISTRIBUTION OF TOTAL TRIP TIMES: PRIVATE VEHICLES .....	58
TABLE 10. FREQUENCY DISTRIBUTION OF TOTAL TRIP TIMES: COMMERCIAL VEHICLES .....	58
TABLE 11. AVERAGE, STANDARD DEVIATION, AND MAXIMUM NUMBER OF PEOPLE-AT-ONE-TIME AND VEHICLES-AT-ONE-TIME (PAOT AND VAOT): THE WINDOWS .....	77
TABLE 12. PERCENTAGE OF PAOT COUNTS EXCEEDING ANALYSIS THRESHOLD: THE WINDOWS .....	78
TABLE 13. AVERAGE, STANDARD DEVIATION, AND MAXIMUM NUMBER OF PEOPLE-AT-ONE-TIME AND VEHICLES-AT-ONE-TIME (PAOT AND VAOT): DELICATE ARCH .....	81
TABLE 14. PERCENTAGE OF PAOT COUNTS EXCEEDING ANALYSIS THRESHOLD: DELICATE ARCH .....	82
TABLE 15. AVERAGE, STANDARD DEVIATION, AND MAXIMUM NUMBER OF PEOPLE-PER-VIEWSCAPE AND VEHICLES-AT-ONE-TIME (PPV AND VAOT): DEVILS GARDEN .....	85
TABLE 16. PERCENTAGE OF PPV COUNTS EXCEEDING ANALYSIS THRESHOLD: DEVILS GARDEN.....	86
TABLE 17. AVERAGE HOURLY AND DAILY PRIVATE VEHICLE ARRIVALS, BY POINT OF ACCESS TO ARCHES NATIONAL PARK (WEEKEND DAYS AND HOLIDAYS) .....	104
TABLE 18. HOURLY AND DAILY ENTRANCE STATION COMMERCIAL VEHICLE ARRIVALS, BY TYPE.....	105
TABLE 19. FREQUENCY DISTRIBUTION OF VISITOR GROUP SIZES: PRIVATE VEHICLES .....	106
TABLE 20. FREQUENCY DISTRIBUTION OF VISITOR GROUP SIZES: COMMERCIAL MINIBUSES .....	107
TABLE 21. FREQUENCY DISTRIBUTION OF VISITOR GROUP SIZES: COMMERCIAL COACH BUSES.....	107
TABLE 22. FREQUENCY DISTRIBUTION OF PRIVATE VEHICLE ROUTE PROFILES FOR VEHICLES ARRIVING BEFORE NOON .....	108
TABLE 23. FREQUENCY DISTRIBUTION OF PRIVATE VEHICLE ROUTE PROFILES FOR VEHICLES ARRIVING AT NOON OR LATER.....	108
TABLE 24. FREQUENCY DISTRIBUTION OF COMMERCIAL VEHICLE ROUTE PROFILES.....	108

## LIST OF ABBREVIATIONS

ARCH	Arches National Park
GPS	Global Positioning System
NPS	National Park Service
PAOT	People-at-One-Time
PPV	People-Per-Viewscope
VAOT	Vehicles-at-One-Time

## EXECUTIVE SUMMARY

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This report describes the results of the Arches National Park Visitor Use, Access, and Experience Study conducted from August 31 through October 31, 2019. This study was commissioned by the National Park Service (NPS) to help inform transportation planning and visitor use management at Arches National Park (ARCH). The specific purposes of the study are to: 1) collect descriptive information about vehicle traffic volumes, parking demand, trail use levels, and visitor densities at popular attraction sites; 2) estimate statistical relationships among transportation conditions, visitor use levels, and crowding at popular attraction sites; and 3) to conduct computer simulation modeling-based analyses of transportation and visitor use/access-related scenarios.

The research conducted to achieve these study purposes and presented in this report involves several interrelated components, including: 1) automated and observation-based vehicle traffic volume and queue length counts; 2) GPS- and delay card-based tracking of parkwide and site-level visitor use patterns; 3) observation-based parking data collection; 4) automated trail use counts; 5) observation-based counts of the number of people-at-one-time (PAOT) and people-per-viewscape (PPV) at popular visitor attractions; and 6) statistical and simulation modeling of study data.

During the 2019 data collection period, a total of 1,040 person-hours of field data collection was conducted in ARCH, resulting in 2,051 visitor contacts, 1,379 observation-based PAOT/PPV counts, 319 additional observation-based counts, and 12,074 hours of road and trail counter data.

This Executive Summary provides an overview of key findings from the data collection, analysis, and modeling conducted in this study. The Executive Summary, however, does not represent all findings that are likely to be of interest to any single reader. Moreover, the Executive Summary does not present detailed information about the study methods, limitations, and assumptions. Therefore, readers wishing to make full use of this report should carefully read sections that are relevant to their particular interests.

The remainder of the Executive Summary is organized into separate subsections that provide a summary of the key findings for each of the data collection, analysis, and modeling tasks conducted in this study.

### **Entrance Station Queue Counts**

*On average, daily entrance station queue lengths were slightly but not significantly higher on weekend days and holidays than on weekdays during the sampling period. Hourly entrance station queue lengths varied throughout the day and were significantly longer in the morning hours than the afternoon hours. Overall, entrance station queues did not backup up onto Route 191 in either direction at any point during the study period.*

- The daily mean entrance station queue length ranged from 6 to 27 vehicles at one time.
- Peak queue lengths ranged from approximately 27-75 vehicles on weekend days and holidays and from approximately 13-81 vehicles on weekdays.
- On weekend days and holidays, the average entrance station queue length peaked at 39 vehicles at 9:00 a.m., compared to the average entrance station queue length on weekdays which peaked at 34 vehicles at 10:00 a.m.
- Hourly entrance station queue lengths were significantly higher in the morning hours, with approximately 21 vehicles on average, than in the afternoon hours with approximately 9 vehicles on average across all sampling days.

### Entrance Station Traffic Counts

*During the counting period, vehicle arrivals were highest on weekend days and holidays, particularly on Saturdays. On average during the sampling period, vehicle arrivals began as early as 4:00 a.m., peaked between 8:00 a.m. and 10:00 a.m. depending on the day of week category, declined somewhat during the late morning hours, remained steady through the afternoon hours, and then dropped off steeply at 6:00 p.m.*

- Daily vehicle arrivals ranged from approximately 750 to 3000 vehicles per day during the counting period. About 10% of days during the counting period had more than 2,700 vehicle arrivals per day.
- Peak hourly vehicle arrivals ranged from just over 100 vehicles to roughly 300 vehicles on the majority of days during the counting period. Peak hourly vehicle arrivals exceeded 350 vehicles on two days during the counting period.
- Average hourly vehicle arrivals were slightly higher on weekend days and holidays than on weekdays. Holiday and weekend mean vehicle arrivals peaked at approximately 250 vehicles in the 8:00 a.m. hour, while weekday mean vehicle arrivals peaked at approximately 230 vehicles in the 9:00 a.m. hour.

### Secondary Road Traffic Counts

*During the counting period, total daily vehicle arrivals on both Salt Valley Road and Willow Springs Road were relatively low, but Salt Valley Road receives roughly twice as much traffic as Willow Springs Road regardless of the day of week category. On average during the sampling period, vehicle arrivals began as early as 7:00 a.m. and fluctuated at low levels throughout the day at both locations.*

- Daily vehicle arrivals on Salt Valley Road ranged from 15 to 51 vehicles, while daily vehicle arrivals at Willow Springs Road ranged from 3 to 28 vehicles during the counting period.
- Peak hourly vehicle arrivals on Salt Valley Road ranged from 3 to 11 vehicles, while peak hourly vehicle arrivals on Willow Springs Road ranged from 1 to 9 vehicles.

## GPS Route Tracking

*The vast majority of visitors to Arches National Park visited one or more of the three study sites during their visits to the park. Private vehicle-based groups were much more likely than commercial tour groups to visit all three study sites. Study site dwell times varied by visitor group type (private vehicle versus commercial tour) and by site. Overall, private vehicle visitor groups stayed in the park approximately 30 minutes longer than commercial vehicle visitor groups.*

- Virtually all private vehicle groups (96%) and commercial vehicle groups (97%) visited one or more of the study sites.
- Slightly more than one-third (36%) of private vehicle visitor groups traveled to all three study sites. In contrast, a small proportion (8%) of commercial vehicle visitor groups traveled to all three sites.
- The most popular site for private vehicle visitor groups that traveled to only one study site was the Windows (42%), followed by Delicate Arch (31%), and Devils Garden (27%). In contrast, the most popular site for commercial vehicle visitor groups that traveled to only one study site was, by far, the Windows (81%).
- Private vehicle visitor groups who traveled to the Windows spent an average of 40.5 minutes at the site. In comparison, commercial vehicle visitor groups who traveled to the Windows spent an average of 59.4 minutes at the site (roughly 47% more time).
- Private vehicle visitor groups who traveled to Delicate Arch spent an average of 71.5 minutes at the site. In comparison, commercial vehicle visitor groups who traveled to Delicate Arch spent an average of 31.4 minutes at the site (roughly 56% less time).
- Private vehicle visitor groups who traveled to Devils Garden spent an average of 65.5 minutes at the site. In comparison, commercial vehicle visitor groups who traveled to Devils Garden spent an average of 86.5 minutes at the site (roughly 32% more time).
- Overall, private vehicle visitor groups spent on average 3.3 hours in the park, while commercial vehicle visitor groups spent slightly less time, spending on average 2.7 hours in the park.

## Parking Lot Accumulation and Turnover

*Parking areas at all three study sites were at least partially full on all days when parking accumulation data collection began at 9:00 a.m. Hourly parking accumulation in the Windows parking lot consistently exceeded designated capacities during peak hours. Parking accumulation in the Devils Garden, and Delicate Arch parking lots exceeded designated capacities on several occasions during the sampling period, but not as consistently as in the Windows parking lot. Average vehicle turnover ranged from one hour or less to approximately two hours depending on the site.*

- Hourly parking accumulation at the Windows was generally at or above designated capacity on weekend days and holidays from about 10:00 a.m. 2:00 p.m. On weekdays, hourly parking accumulation was near or above capacity for multiple hours on two of the three sampling days.
- Hourly parking accumulation at Delicate Arch was near or above the designated capacity of the main and overflow lots at the start of each sampling day on weekend days and holidays. It generally stayed near or above capacity through 11:00 a.m. on weekend days and holidays, and then declined through the afternoon hours. Hourly parking accumulation did not exceed the designated capacity on weekdays.
- Hourly parking accumulation at Devils Garden reached or exceeded the designated capacity parking during the morning hours of each sampling day on weekend days and holidays. Hourly parking accumulation generally did not exceed designated capacity at Devils Garden during afternoon hours or on weekdays.
- On average, vehicles were parked in the Windows parking lot for just over one hour, vehicles were parked at the Delicate Arch parking lot for approximately two hours, vehicles were parked at the Delicate Arch Viewpoint parking lot for approximately one hour or less, and vehicles were parked in the Devils Garden parking lot for approximately two hours.

### Visitor Use Counts

*Daily visitor arrivals at the Windows, Delicate Arch, and Devils Garden were variable during the counting period, ranging from less than 500 to over 3,000 visitors per day per site. Daily visitor arrivals tended to be higher on weekend days and holidays than weekdays. Average hourly visitor arrival patterns varied by site.*

- Daily visitor arrivals at the Windows trail counter location was fairly consistently between 1,000 and 2,000 visitors per day, regardless of the day of week, through most of the counting period. Hourly visitor arrivals at the Windows generally peaked around 11:00 a.m. and declined slightly or stayed flat through the afternoon hours.
- There were 1,000 visitor arrivals or more per day at the Delicate Arch trail counter location on the majority of days during the counting period. Hourly visitor arrivals at Delicate Arch were generally highest early in the morning and late in the afternoon and relatively low during the midday hours.
- Daily visitor arrivals at the Devils Garden trail counter location generally ranged between 1,000 and 1,500 visitors during the counting period. Hourly visitor arrivals at Devils Garden were generally somewhat higher in the morning and had a slight downward trend through the late morning and afternoon hours.

### People-at-One-Time (PAOT) and People-Per-Viewscape (PPV) Counts

*Overall, the range of PAOT/PPV counts varied by site and throughout the hours of the sampling day. However, the maximum PAOT/PPV counts at each study site exceeded the site-specific analysis threshold on every day that counts were conducted.*

- On weekend days and holidays, about half (51%) of all PAOT counts recorded in the Windows viewscape exceeded the analysis threshold of 20 PAOT. On weekdays, nearly one-third (30%) of the PAOT counts in the Windows viewscape exceeded the analysis threshold.
- On weekend days and holidays, nearly half (48%) of all PAOT counts recorded in the Delicate Arch viewscape exceeded the analysis threshold of 30 PAOT. On weekdays, more than one-third (35%) of the PAOT counts in the Delicate Arch viewscape exceeded the analysis threshold.
- On weekend days and holidays, 16% of all PPV counts recorded in the Devils Garden viewscape exceeded the analysis threshold of 20 PPV. On weekdays, 10% of the PPV counts in the Devils Garden viewscape exceeded the analysis threshold.

### **Study Site Dwell Times**

*Visitors generally spend shorter lengths of time at the Windows than at either of Delicate Arch or Devils Garden.*

- On average, visitor who were administered a delay card at the Windows spent about 40 minutes there. Duration of stay at the Windows ranged from two minutes to just over two hours, with the majority (58%) of visitors spending less than 40 minutes at the site.
- On average, visitor who were administered a delay card at Delicate Arch spent just under two hours there. Duration of stay at Delicate Arch ranged from five minutes to just over five hours, with more than two-thirds (69%) of visitors spending 1.5 to 2.5 hours at the site.
- On average, visitors who were administered a delay card at Devils Garden spent about an hour and a half there. Duration of stay at Devils Garden ranged from six minutes to nearly seven hours, with under half (45%) of visitors spending less than one hour at the site.

### **Statistical Modeling of Study Data**

*Regression analyses conducted to model site-level relationships among transportation and visitor-use-related measures produced strong statistical relationships with each independent variable explaining 70% or more of the variance in each dependent variable. The statistical modeling results suggest the following:*

- For every 100 hourly vehicle arrivals at the entrance station, there are approximately 38 cars parked at one time at the Windows, approximately 44 cars parked at one time at Delicate Arch, and approximately 66 cars parked at one time at Devils Garden in the following hour.
- For every 100 hourly vehicle arrivals at each site, there are approximately 60 cars parked at one time at the Windows, approximately 76 cars parked at one time at Delicate Arch, and approximately 114 cars parked at one time at Devils Garden.

- For every 100 hourly vehicle arrivals at each site, there are approximately 120 trail use arrivals during the hour at the Windows, approximately 71 trail use arrivals during the hour at Delicate Arch, and approximately 127 trail use arrivals during the hour at Devils Garden.
- For every 100 vehicles parked at one time at each site, there are approximately 197 trail use arrivals during the hour at the Windows, approximately 102 trail use arrivals during the hour at Delicate Arch, and approximately 102 trail use arrivals during the hour at Devils Garden.
- For every 100 hourly trail use arrivals at each site, there are an average of 13 PAOT in the Windows viewscape during the hour, an average of 35 PAOT in the Delicate Arch viewscape during the hour, and an average of 8 PPV in the Devils Garden viewscape during the hour.
- For every 100 hourly trail use arrivals at each site, there is an hourly maximum of 20 PAOT in the Windows viewscape during the hour, an hourly maximum of 46 PAOT in the Delicate Arch viewscape during the hour, and an hourly maximum of 13 PPV in the Devils Garden viewscape during the hour.
- For every 100 hourly vehicle arrivals at the entrance station, there are approximately 56 vehicle arrivals at the Windows, approximately 60 vehicle arrivals at Delicate Arch, and approximately 52 vehicle arrivals at Devils Garden in the following hour.
- For every 100 daily vehicle arrivals at the entrance station, there are approximately 57 daily vehicle arrivals at the Windows, approximately 61 daily vehicle arrivals at Delicate Arch, and approximately 54 daily vehicle arrivals at Devils Garden.

### Simulation Modeling

*Analyses conducted with the computer simulation model suggest that current levels of visitor use exceed the site-level analysis thresholds for PAOT/PPV from 5% to 34% of the time during the 4:00 a.m. to 12:00 a.m. period on “typically busy” peak season days in the park. Results further suggest that current levels of visitor use on “typically busy” peak season days exceed the “effective parking capacity” (90% of striped spaces) at each site from 6% to 25% of the time during the 4:00 a.m. to 12:00 a.m. period. These results suggest current levels of visitor use in the park cause potentially unacceptable parking shortages, vehicle congestion, and visitor crowding across the Windows, Delicate Arch, and Devils Garden. More specifically, results of the computer simulation model suggest that, on “typically busy” days during the peak season in the park:*

- Vehicles-at-one-time (VAOT) at the Windows exceeds the effective parking capacity of the parking lot approximately 25% of the time and mean PAOT in the Windows viewscape exceeds the analysis threshold of 20 PAOT approximately 19% of the time during the 4:00 a.m. to 12:00 a.m. period.

- Vehicles-at-one-time (VAOT) at Delicate Arch exceeds the effective parking capacity of the main and overflow parking lots approximately 6% of the time and mean PAOT in the Delicate Arch viewscape exceeds the analysis threshold of 30 PAOT approximately 34% of the time during the 4:00 a.m. to 12:00 a.m. period.
- Vehicles-at-one-time (VAOT) at Devils Garden exceeds the effective parking capacity of the parking lot approximately 12% of the time and mean PPV in the Devils Garden viewscape exceeds the analysis threshold of 20 PPV approximately 5% of the time during the 4:00 a.m. to 12:00 a.m. period.
- The computer simulation model of parkwide vehicle volumes and patterns and site-level parking and visitor use conditions developed in this study provides the park with a tool that will be used to provide data-driven insights into the efficacy of visitor use and transportation congestion management scenarios to achieve desired conditions in the park. The results of these scenarios will be summarized in a separate technical memo.

## 1.0 INTRODUCTION

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Throughout the last decade, Arches National Park (ARCH) has experienced an unprecedented increase in visitation. During the time period from 2008 to 2018, the park experienced a 79% increase in annual recreation visits as reported by National Park Service Visitor Use Statistics (2019). Also during this 10-year time period, the peak visitor use season at ARCH has expanded earlier into the spring and later into the fall. These changes in visitation levels and patterns have created pressures on the park's transportation systems, natural and cultural resources, and the quality of visitors' experiences.

In response to the pressures from these changing visitation trends, the National Park Service (NPS) has initiated a wide variety of visitor use management strategies to address in-park congestion and the impacts of visitor use throughout the park. Additionally, the park has initiated research about the feasibility of a Transportation Congestion Management Plan (TCMP) to publicly vet decisions regarding how transportation and visitor use will be managed at the park into the future.

As part of the management and planning efforts at ARCH, NPS commissioned this study. The purposes of the study are to:

- Collect descriptive information about vehicle traffic volumes at the park entrance and on park roads, parking demand in key parking locations, and trail use levels and visitor densities at popular attraction sites;
- Estimate statistical relationships among transportation conditions, visitor use levels, and crowding at popular attraction sites, including analyses in relation to historic visitor-informed crowding thresholds<sup>1,2</sup>;
- Conduct simulation modeling-based analyses of transportation and visitor use/access-related scenarios to assess the efficacy of alternative visitor use management and congestion management strategies to achieve desired park conditions.

The research conducted to achieve these study purposes and presented in this report involves several interrelated components, including: 1) automated and observation-based vehicle traffic volume and queue length counts; 2) GPS- and delay card-based tracking of parkwide and site-level visitor use patterns; 3) observation-based parking data collection; 4) automated trail use counts; 5) observation-based counts of the number of people-at-one-time (PAOT) and people-per-view-scape (PPV) at popular visitor attractions; and 6) statistical and simulation modeling of study data. All data for the study were collected during the late summer and early fall season in 2019. An electronic copy of all data collected during the study (including associated codebooks) are archived with NPS.

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<sup>1</sup> Manning, R., Lime, D., Hof, M., & Freimund, W. 1995. The visitor experience and resource protection process: The application of carrying capacity to Arches National Park. *The George Wright Forum* 12, 41-55.

<sup>2</sup> National Park Service. 1995. *Visitor Experience and Resource Protection Implementation Plan: Arches National Park*. Denver, CO: Denver Service Center.

The remainder of this report is organized as follows: Section 2.0 describes the study methods, including the study area; Section 3.0 reports descriptive summaries and statistical results; Section 4.0 reports the results of statistical modeling of the study data; and Section 5.0 provides an overview and reports the baseline results of the computer simulation model. An addendum to this report will be provided to NPS at a later date with results of the simulation modeling-based scenario analyses.

## 2.0 METHODS

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This section of the report describes the study methods for the Arches National Park Visitor Use, Access, and Experience Study.

### 2.1 STUDY AREA

Data collection, analysis, and modeling for this study are both parkwide in scope and site-specific. The main travel corridor in ARCH is the area of focus for the parkwide components of the study and the Windows, Delicate Arch, and Devils Garden are the places of focus for the site-level components of the study. The main travel corridor and the three study sites are described in the following subsections.

#### Main Travel Corridor

Figure 1 provides a schematic diagram of Arches National Park, including points of access into the park, the main travel corridor in the park, and key sites of interest throughout the park. The vast majority of visitors enter and exit the park through the entrance station at the south end of the park off of U.S. Route 191, near Moab, Utah. During busy periods, traffic congestion can occur at the entrance station and can result in lines of vehicles waiting to enter the park. On occasions when parking lots at popular destinations in the park are full, vehicles are stopped from entering the park at the entrance station until there is less congestion in the park.

From the entrance station, visitors can drive along the main travel corridor to access the park's visitor center, hiking trails, world-renowned geological formations, and campground. Many of the popular geological formations in the park are visible from the main travel corridor and accessible from designated parking lots and roadside pull offs. The most popular attractions in the park accessible from the main travel corridor are the Windows, Delicate Arch, and Devils Garden (Figure 1).

A small percentage of park visitors enter and exit the park using two unpaved secondary roads (Figure 1). Willow Springs Road is a dirt road that is lightly used by the general visitor population due to the need for high clearance, four-wheel drive vehicles. Salt Valley Road is a gravel road, that provides access to Klondike Bluffs and the Tower Arch trailhead near the northwestern boundary of the park. Both secondary roads connect with the main travel corridor in the park.

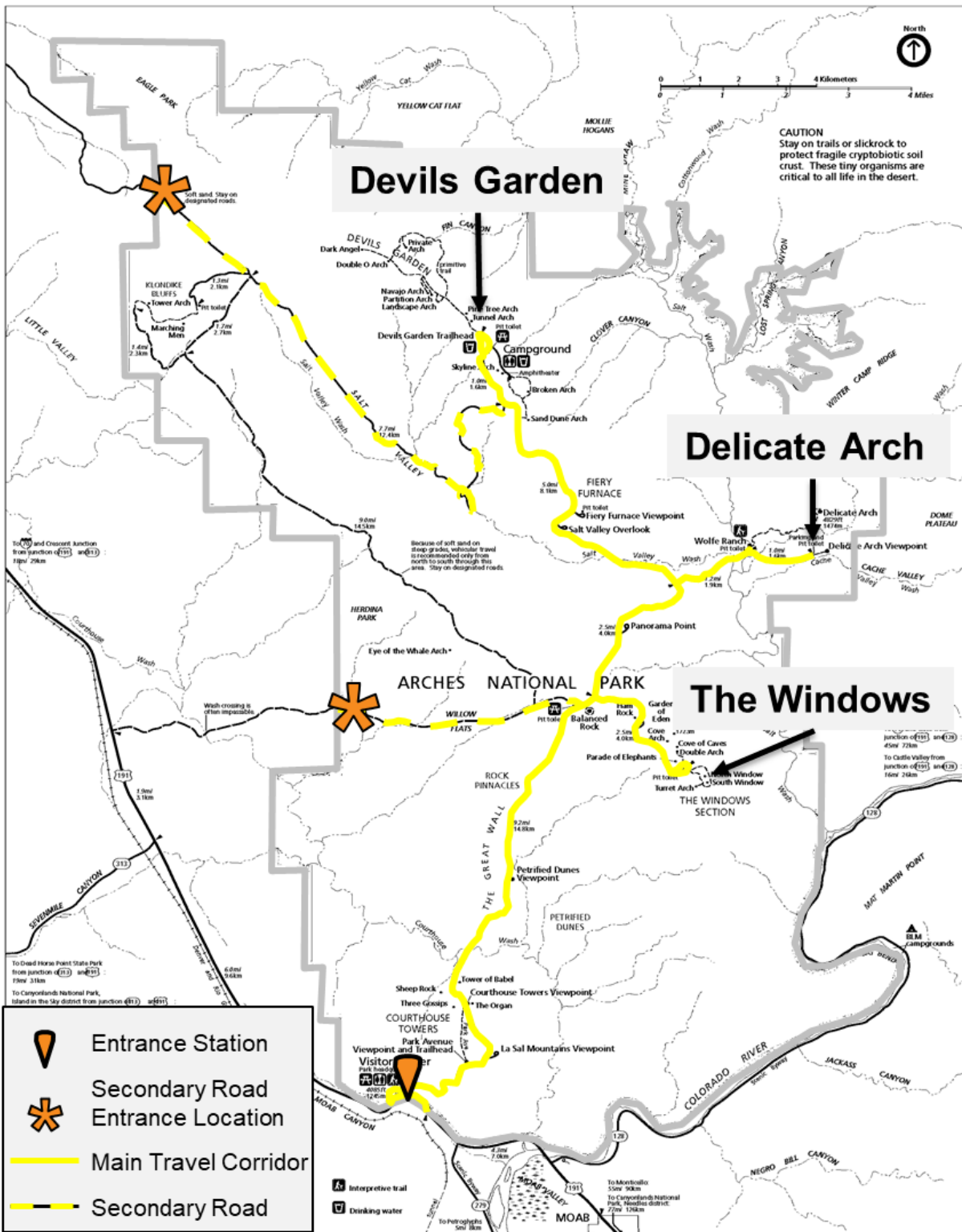


FIGURE 1. SCHEMATIC DIAGRAM OF STUDY AREA

## The Windows

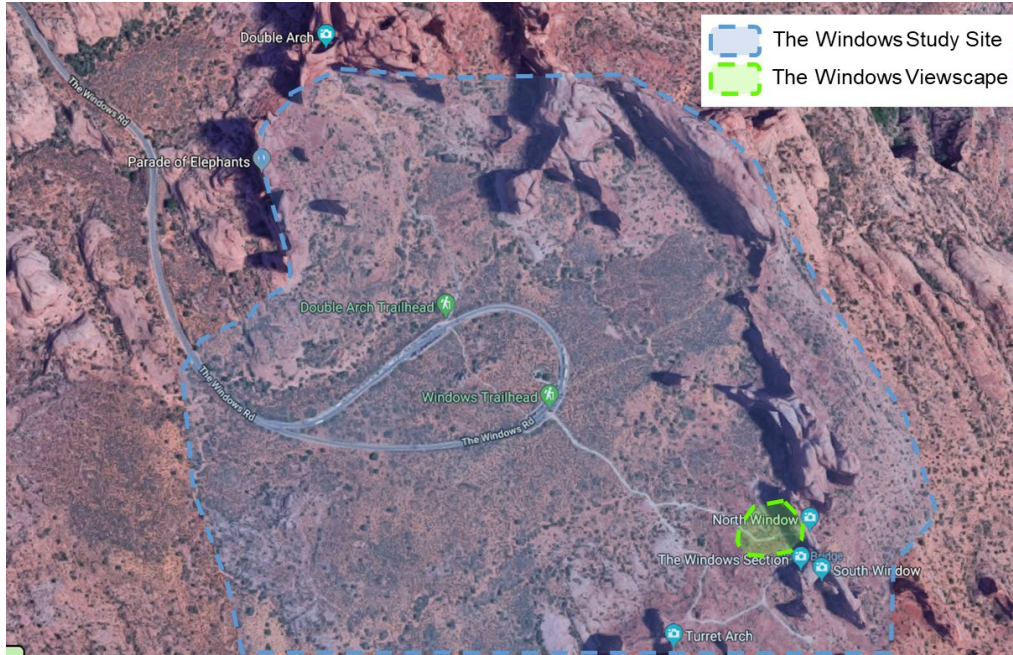
The Windows is approximately a 12 mile drive north of the entrance station and is one of the three sites of focus for this study (Figure 1). The Windows is one of the most scenic locations in the park with a large concentration of arches in just over two square miles, including North Window, South Window, Turret Arch, and Double Arch, all relatively accessible from a large parking oval (Figure 2). On busy days, the parking lot capacity can be exceeded and visitors may experience crowding on trails and at vistas, including in the North Window subarea referred to hereafter as “the Windows viewscape.” For these reasons, the Windows is an important site of focus for this study. Data collection, analysis and modeling in this study includes measures for the Windows site in its entirety and for the Windows viewscape.

The Windows study site is depicted with blue shading in Figure 2 and the Windows viewscape is denoted with green shading in Figure 2 and Figure 3. The Windows viewscape corresponds to the area of North Window depicted in a series of photo simulations used in crowding-related visitor surveys conducted in ARCH during the 1990s. Questions included in the survey about the photo simulations were used to measure visitor-based thresholds for crowding at the Windows<sup>3,4</sup> (Figure 3). The Windows viewscape was also used to “register” the location of people-at-one-time (PAOT) counts conducted as part of the current study. The methods and results of these study components are described later in this report.

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<sup>3</sup> Manning, R., Lime, D., Hof, M., & Freimund, W. 1995. The visitor experience and resource protection process: The application of carrying capacity to Arches National Park. *The George Wright Forum* 12, 41-55.

<sup>4</sup> National Park Service. 1995. *Visitor Experience and Resource Protection Implementation Plan: Arches National Park*. Denver, CO: Denver Service Center.



**FIGURE 2. THE WINDOWS STUDY SITE AND VIEWSCOPE**



**FIGURE 3. THE WINDOWS VIEWSCOPE BOUNDARY**

## Delicate Arch

Delicate Arch is approximately a 13 mile drive north of the entrance station and is one of the three sites of focus for this study (Figure 1). Delicate Arch is an iconic park feature and is a primary attraction for visitors to ARCH. Visitors who want to experience Delicate Arch from a closer distance will park at the main Delicate Arch parking lot and hike the 3-mile round trip trail over exposed slickrock to the arch (Figure 4). Alternatively, visitors can drive to the Delicate Arch Viewpoint and hike the 0.7 mile one-way trail to see the arch from a mile away (Figure 4). Parking is limited at both destinations and may fill especially on weekend days and holidays during the early morning. The number of visitors hiking to Delicate Arch can also be substantial and can result in visitors' experiencing crowding in the immediate vicinity of Delicate Arch, referred to hereafter as the "Delicate Arch viewscape". For these reasons, Delicate Arch is an important site of focus for this study. Data collection, analysis and modeling in the current study includes measures for the Delicate Arch site in its entirety and for the Delicate Arch viewscape.

The Delicate Arch study site is depicted with blue shading in Figure 4 and the Delicate Arch viewscape is denoted with green shading in Figure 4 and Figure 5. The Delicate Arch viewscape corresponds to the area of Delicate Arch depicted in a series of photo simulations used in crowding-related visitor surveys conducted in ARCH during the 1990s and early 2000s. Questions included in the survey about the photo simulations were used to measure visitor-based thresholds for crowding at Delicate Arch <sup>5,6</sup> (Figure 5). The Delicate Arch viewscape was also used to "register" the location of PAOT counts conducted as part of the current study. The methods and results of these study components are described later in this report.

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<sup>5</sup> Manning, R., Lime, D., Hof, M., & Freimund, W. 1995. The visitor experience and resource protection process: The application of carrying capacity to Arches National Park. *The George Wright Forum* 12, 41-55.

<sup>6</sup> National Park Service. 1995. *Visitor Experience and Resource Protection Implementation Plan: Arches National Park*. Denver, CO: Denver Service Center.

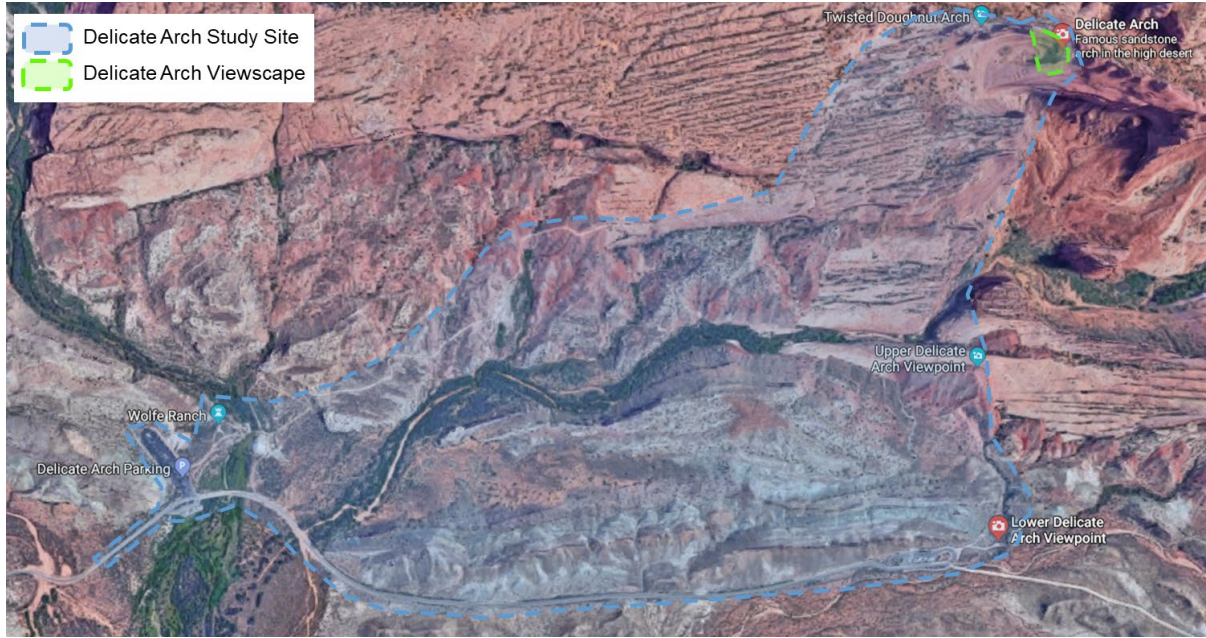


FIGURE 4. DELICATE ARCH STUDY SITE AND VIEWSCAPE

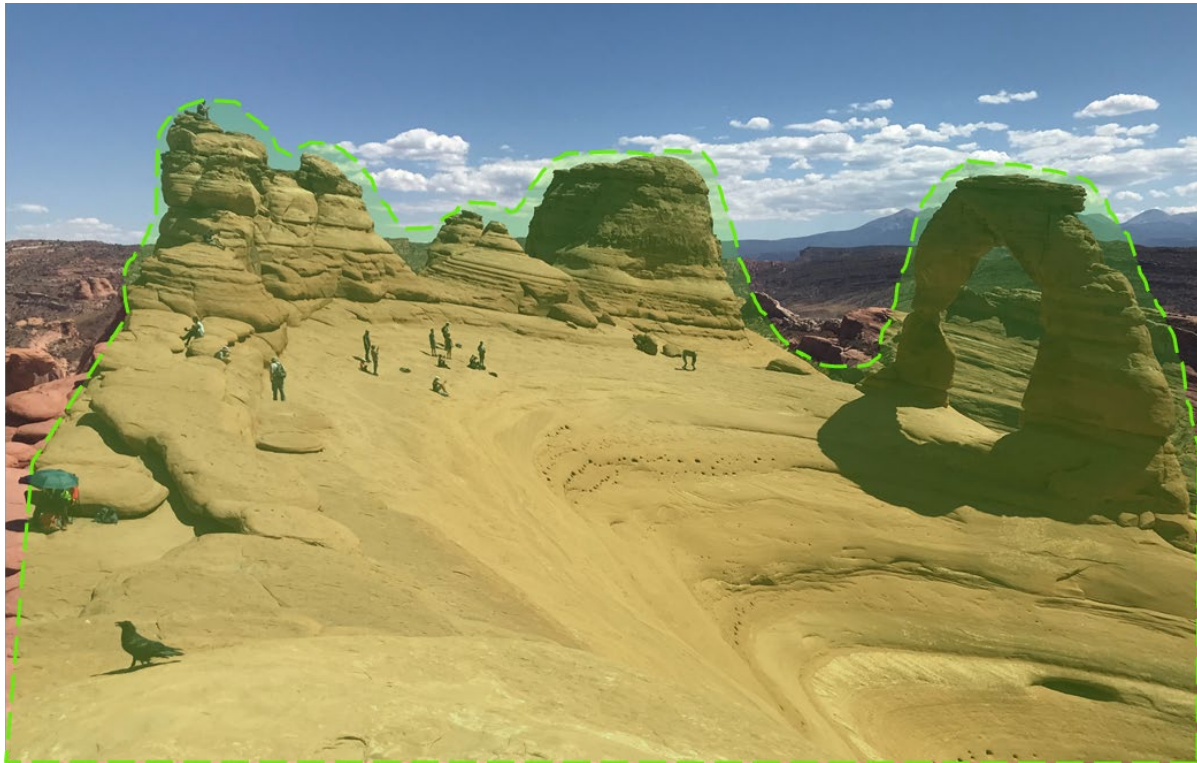


FIGURE 5. DELICATE ARCH VIEWSCAPE BOUNDARY

## Devils Garden

Devils Garden is approximately an 18 mile drive north of the entrance station, and is one of the three sites of focus for this study (Figure 1). With its arches, spires, and a large concentration of narrow rock walls called “fins”, Devils Garden is a premier location in the park for sightseers, hikers, and rock climbers. Landscape Arch, the longest stone arch in North America with a light opening of 306 feet, is one of the prominent geologic features in Devils Garden. On weekend days and holidays, the trail to Landscape Arch can receive high levels of visitor use, which can cause visitors to experience crowding. For these reasons, Devils Garden is an important site of focus for this study. Data collection, analysis and modeling in the current study includes measures for the Devils Garden site in its entirety and for a section of the trail to Landscape Arch, referred to hereafter as the “Devils Garden viewscape.”

The Devils Garden study site is depicted with blue shading in Figure 6 and the Devils Garden viewscape is denoted with green shading in Figure 6 and Figure 7. The Devils Garden viewscape corresponds to the section of trail to Landscape Arch depicted in photo simulations used in crowding-related visitor surveys conducted in ARCH during the 1990s. Questions included in the survey about the photo simulations were used to measure visitor-based thresholds for crowding at Devils Garden<sup>7,8</sup> (Figure 7). The Devils Garden viewscape was used to “register” the location of PPV counts conducted as part of the current study. The methods and results of these study components are described later in this report.

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<sup>7</sup> Manning, R., Lime, D., Hof, M., & Freimund, W. 1995. The visitor experience and resource protection process: The application of carrying capacity to Arches National Park. *The George Wright Forum* 12, 41-55.

<sup>8</sup> National Park Service. 1995. *Visitor Experience and Resource Protection Implementation Plan: Arches National Park*. Denver, CO: Denver Service Center.

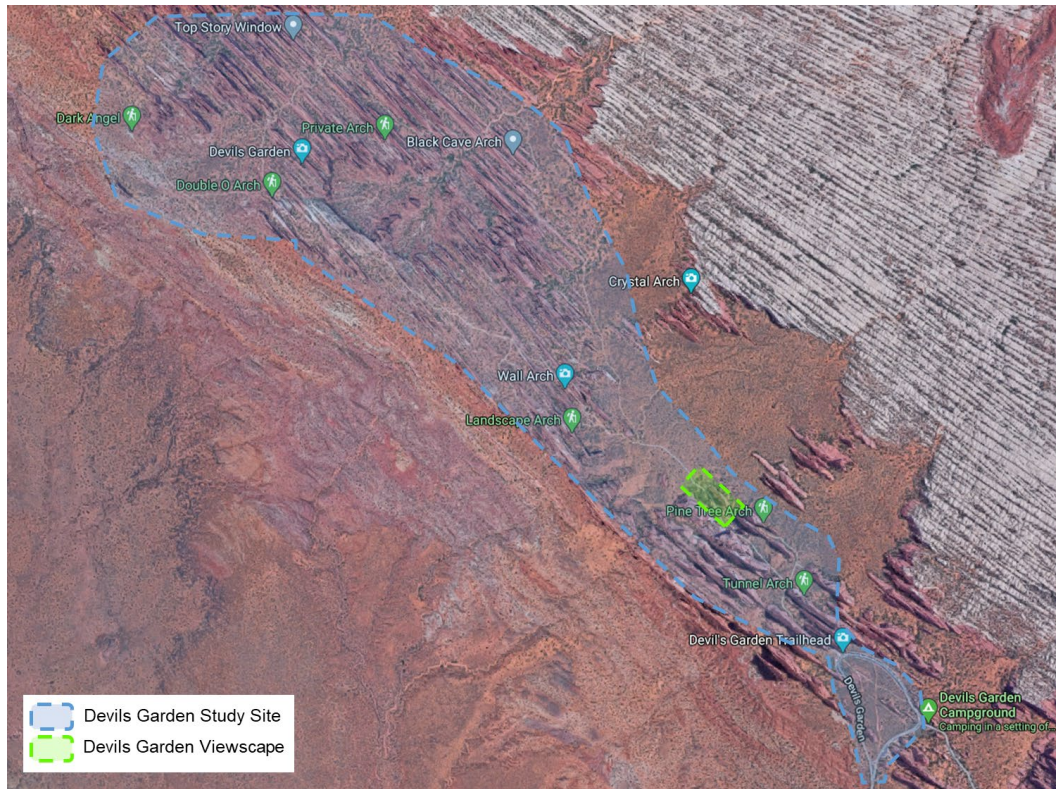


FIGURE 6. DEVILS GARDEN STUDY SITE AND VIEWSCAPE



FIGURE 7. DEVILS GARDEN VIEWSCAPE BOUNDARY

## 2.2 DATA COLLECTION

As noted, the study was designed to collect descriptive information about the types, volumes and patterns of visitor use in Arches National Park, analyze statistical relationships among these measures, and evaluate visitor volumes and patterns in relation to historic visitor-based crowding thresholds. Data collection methods for parkwide measures included entrance station queue counts conducted by direct observation, entrance station traffic counts via counters permanently installed at the entrance station, traffic counts on two secondary park roads via magnetic counters with collocated pneumatic-tube counters and trail cameras, and GPS-based tracking of vehicle travel routes (Figure 8). Data collection methods for site-specific measures at the three sites of interest included parking lot accumulation and turnover via direct observation, visitor use counts via infrared trail counters, dwell time durations measured with visitor delay cards, and people-at-one-time (PAOT) and people-per-viewscape (PPV) counts via direct observation. The location where each study component was administered at the three study sites is illustrated in Figure 9, Figure 10, and Figure 11.

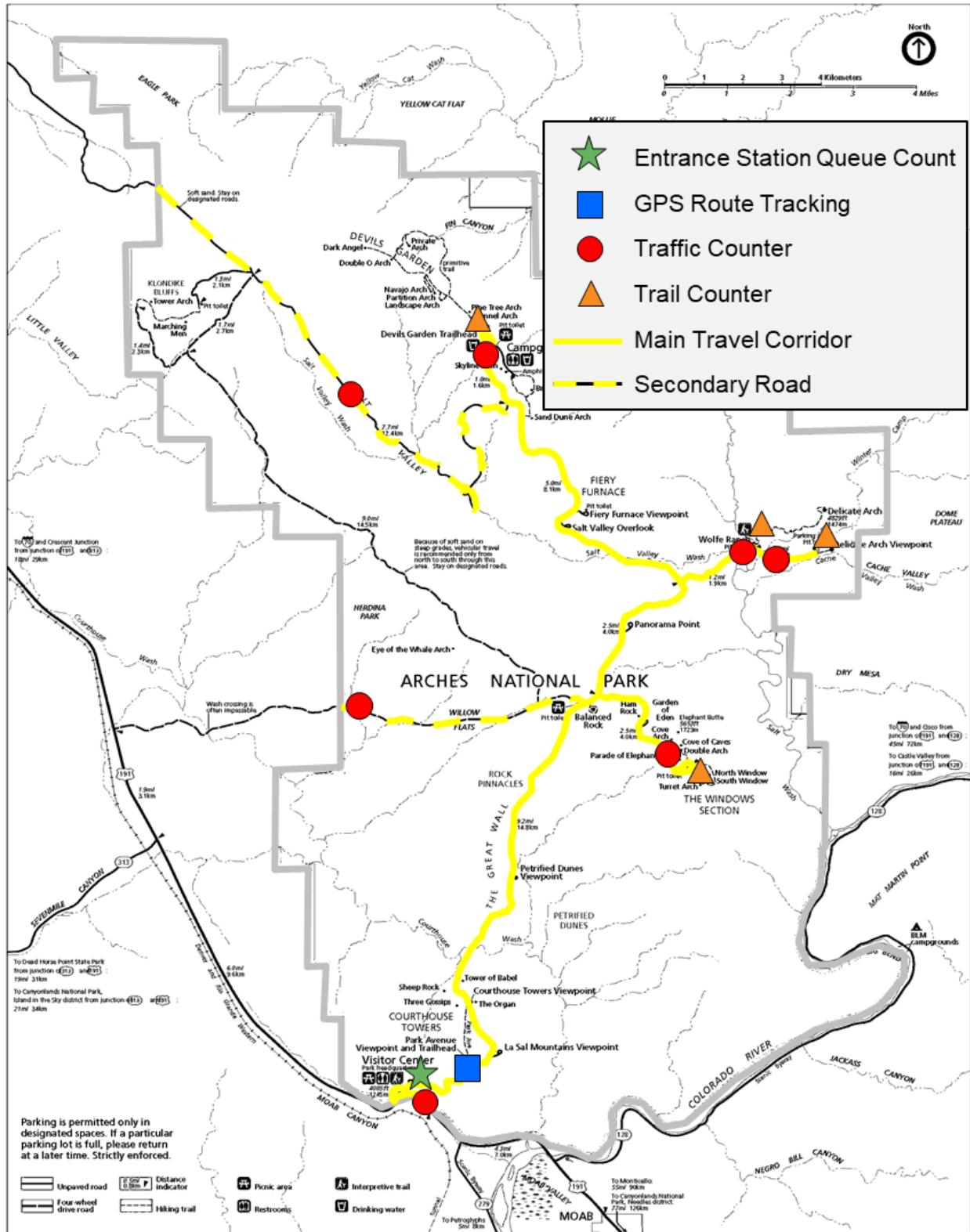


FIGURE 8. DATA COLLECTION DEPLOYMENT LOCATIONS FOR PARKWIDE MEASURES

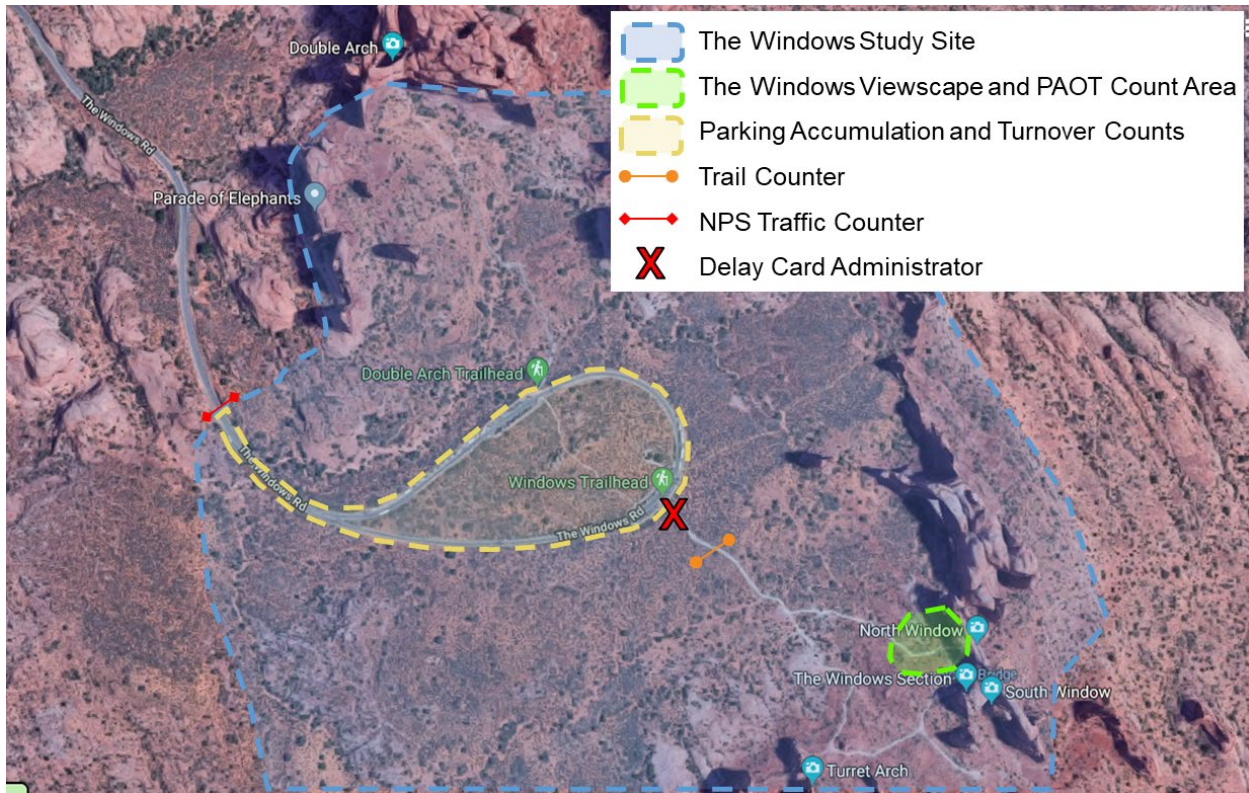


FIGURE 9. DATA COLLECTION DEPLOYMENT LOCATIONS: THE WINDOWS

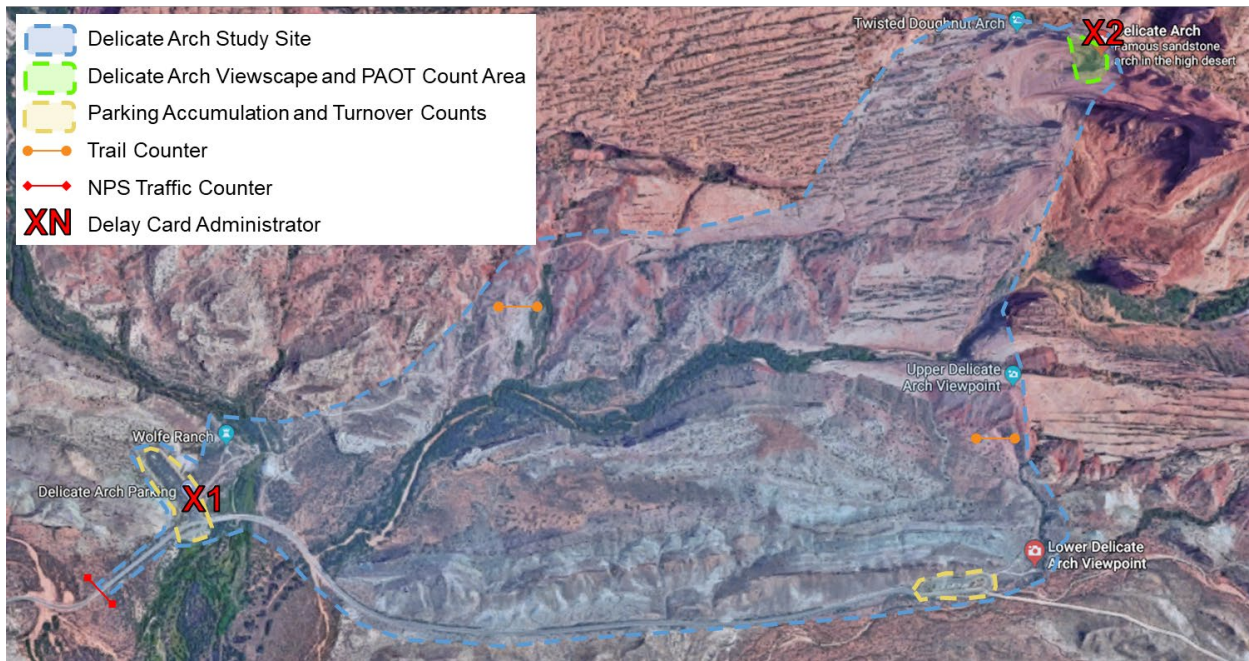
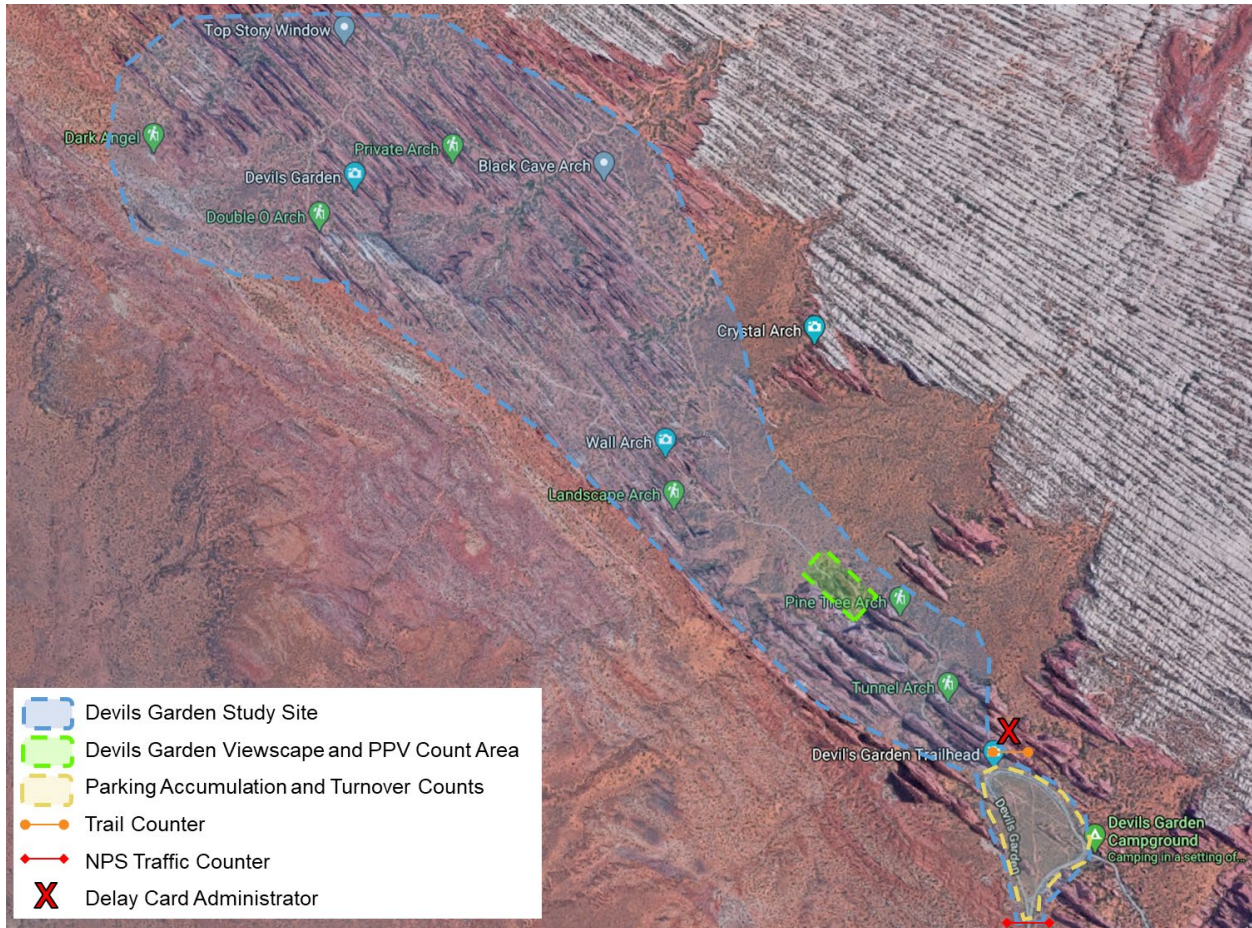


FIGURE 10. DATA COLLECTION DEPLOYMENT LOCATIONS: DELICATE ARCH



**FIGURE 11. DATA COLLECTION DEPLOYMENT LOCATIONS: DEVILS GARDEN**

Data collection for entrance station queue counts, GPS route tracking, parking lot accumulation and turnover, dwell time durations, PAOT, and PPV counts was conducted during the sampling period from August 31 through September 10, 2019<sup>9</sup>. Visitor use counts and traffic counts on secondary roads were conducted for a longer period of time (referred to hereafter as the “counting period”) from August 31 and through October 31, 2019. Entrance station traffic counts are routinely collected by the park and were made available to RSG by NPS for all of 2019. The sampling and counting periods were selected in consultation with NPS and chosen to coincide with part of the park’s peak use season in late summer and early fall, including Labor Day weekend. The following subsections describe the methods for each study component.

<sup>9</sup> September 3, 2019 was a scheduled day off for field staff and no data were collected on that date.

## Entrance Station Queue Counts

Entrance station queue counts were conducted each day during the 10-day sampling period at the beginning of each hour from 8:00 a.m. to 3:00 p.m. Five minutes prior to the beginning of each hour, one member of the GPS administration team drove a short distance to a roadside pull-off (Figure 8) to view the entire entrance road from Route 191 to the entrance station (Figure 12). At the start of each hour, the field technician conducted a nearly instantaneous count of the number of stopped and moving private (auto) and commercial (coach) vehicles in the two inbound lanes of the entrance road, including vehicles processing a transaction at the entrance station. The field technician also indicated whether the entrance station queue had backed up onto Route 191 in either direction. To be considered in the entrance station queue, a vehicle must have crossed the threshold where the entrance road intersects Route 191 by the time the count began, or was waiting in line extending from the entrance station onto Route 191 in either direction. A copy of the entrance station vehicle queue count log is included in Appendix A.

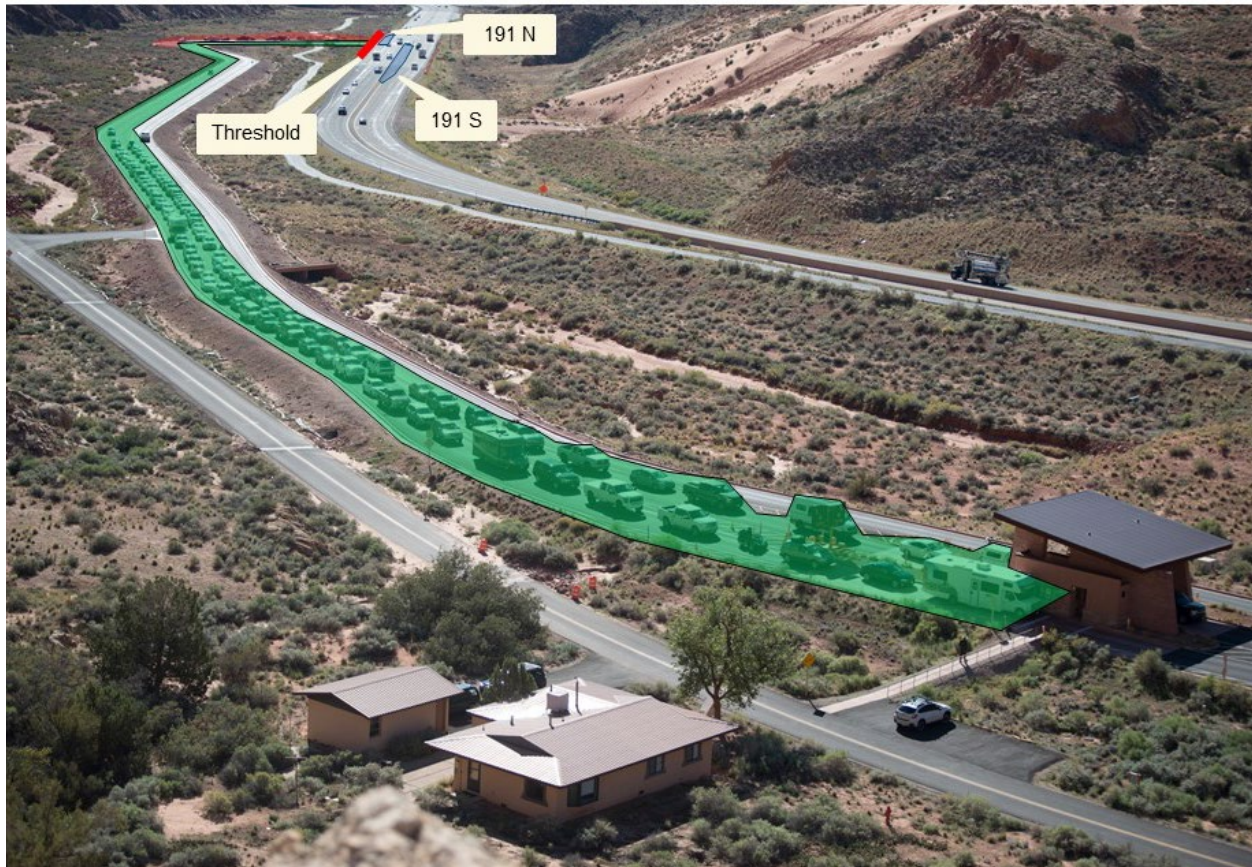


FIGURE 12. SCHEMATIC DIAGRAM OF ENTRANCE STATION QUEUE COUNT AREA

## Entrance Station Traffic Counts

Entrance station traffic counts are collected by NPS in each entrance lane at the park entrance station (location shown in Figure 1) via permanently installed inductive loop counters. The counters automatically record data in hourly bins and these data were provided to RSG for this study for each day in 2019.

## Secondary Road Traffic Calibration Counts

Secondary road traffic calibration counts were collected at two locations: Salt Valley Road and Willow Springs Road (Figure 8). These locations were selected by NPS staff to estimate the degree to which vehicle use of the two roads contributes to total visitation in the park. Field staff co-located pneumatic-tube automated traffic recorders (JAMAR TRAX Apollyon) and motion-activated trail cameras with park-owned magnetometer vehicle counters (TRAFx). The park-owned magnetometer vehicle counters at Salt Valley Road and Willow Springs Road were programmed by NPS to record counts in hourly bins. The pneumatic-tube counters installed by RSG for the study were programmed to record timestamped counts, which were postprocessed into hourly bins. The pneumatic-tube counters were deployed by RSG to collect calibration counts 24 hours per day, from August 27 through September 10, 2019. The trail cameras installed by RSG for the study were programmed to record a photograph each time motion was detected in the camera's detection zone; these photographs were postprocessed into hourly bins of vehicle counts, by direction of travel. The trail cameras were deployed by RSG as a secondary measure to collect calibration counts 24 hours per day, from September 4 through September 19, 2019. Data collected via the park-owned magnetometer vehicle counters were provided to RSG for the counting period. The counts from the pneumatic-tube counters and photographs from the motion-activated cameras were used to correct and adjust (i.e., calibrate) the raw magnetometer vehicle counter data as discussed in the results section of this report.

## GPS Route Tracking

### *GPS Tracking Units*

GPS tracking units (Qstarz model BT-Q1000XT) were distributed to visitor groups via roadway intercept sampling to collect information about the spatial and temporal patterns of vehicle travel throughout the park. Private and commercial vehicles were intercepted for the study. The GPS tracking units were configured to record vehicles' GPS coordinates and corresponding timestamps at regular time intervals. The GPS tracking data were postprocessed to derive:

- Vehicle routes through the park (e.g., which study sites were visited and in what sequence).
- Vehicle travel times for the park visit in its entirety and on each road segment traveled.
- Parking duration or “dwell time” in parking areas while visiting the Windows, Delicate Arch, and Devils Garden.

### Sampling Procedures

GPS route tracking was conducted on each day of the 10-day sampling period. Each GPS route tracking sampling day started at 8:00 a.m. and ended at 4:00 p.m. A total of 582 GPS tracking units were distributed and returned during the sampling period (Table 1).

**TABLE 1. ARCHES GPS ROUTE TRACKING SAMPLING EFFORT**

DATE	SOLICITATIONS	ACCEPTANCES	REFUSALS	INELIGIBLES
08/31/19	73	53	18	2
09/01/19	54	46	7	1
09/02/19	57	48	6	3
09/04/19	59	46	11	2
09/05/19	69	64	5	0
09/06/19	76	68	7	1
09/07/19	75	66	8	1
09/08/19	71	60	7	4
09/09/19	77	68	6	3
09/10/19	74	63	9	2
<b>Total</b>	<b>685</b>	<b>582</b>	<b>84</b>	<b>19</b>

*Note: Visitor groups were considered eligible for GPS route tracking if they had not previously participated in the study, were not camping in the park, were not park employees, were able to communicate with the English-speaking survey administrator (i.e., did not have a language barrier), and had at least one group member 18 years of age or older.*

Sampling for the GPS route tracking occurred at a pullover location on the inbound side of the park road between the Park Avenue trailhead and the La Sal Mountains Viewpoint (Figure 8). This sampling location was selected because it is the first location where vehicles could safely be pulled over after entering the park without causing traffic to become congested or sampling methods to interfere with park operations.

For the most part, the GPS administration team used a 10-minute interval approach to sample inbound vehicles. Specifically, at the start of each GPS route tracking sampling day, the GPS administration team pulled over the first vehicle to approach the sampling location traveling in the inbound direction and asked the occupants of the vehicle to participate in the study (Figure 13). The GPS administration team continued to pull over vehicles until a group agreed to participate. The team then waited until the start of the next 10-minute interval, at which point they intercepted the next arriving vehicle and continued until a group agreed to participate. The team continued this process throughout the sampling period. The sampling interval was nominally modified on several days to maintain a sufficient supply of GPS tracking units to continue sampling throughout the day.



**FIGURE 13. ROADWAY INTERCEPT FOR GPS ADMINISTRATION**

Each contacted visitor group was greeted, briefly introduced to the purpose of the study and asked to participate and screened for eligibility. Visitor groups were considered eligible for the study if they had not previously participated in the study, were not camping in the park, were not park employees, were able to communicate with the English-speaking survey administrator (i.e., did not have a language barrier), and had at least one group member 18 years of age or older. Information from all contacts was recorded on a contact log. For visitor groups that were eligible for the study and agreed to participate, the GPS administrator instructed participating groups to place the GPS tracking unit in their vehicle out of the sun and leave it in their vehicles for the duration of their visit. Study participants were further instructed to return the GPS tracking units to one of two drop boxes located outside the park visitor center and outside the multiagency visitor center in Moab.

An interview, lasting approximately two minutes, was conducted with each eligible visitor group, whether they agreed to participate in the study or not, to determine group size, vehicle type (private or commercial), and state or country of residence. The gender of the first-contacted group member and the time of contact was recorded for each contacted group, including those who were ineligible for the study. The phone number of one member of each group that agreed to participate was recorded, on a voluntary basis, to help facilitate the return of GPS units if

needed. In addition, the GPS devices were tagged with instructions for how to return the device and a phone number to contact the RSG research team. For all “hard refusals” (groups who refused to participate in the study and in the brief interview), observational data (group size, gender of first-contacted group member, and time of contact) were recorded on the contact log.

The response rate for GPS route tracking was 87.4%<sup>10</sup>. A copy of the GPS administration contact log used to record information about survey response rates is contained in Appendix B.

### ***Analysis Methods***

RSG developed algorithms to postprocess the GPS tracks and eliminate cases with incomplete routes (e.g., a route that ends in the middle of the park, likely due to a GPS unit malfunction). GPS track processing involved identifying each GPS waypoint in relation to a series of polygons, which represent the key study sites and access points in the study area. These include: 1) the GPS sampling location (Figure 8); 2) the Windows; 3) Delicate Arch; 4) Delicate Arch Viewpoint; 5) Devils Garden; 6) Salt Valley Road counter location; and 7) Willow Springs Road counter location.

Each GPS track retained for analysis was classified into one of four route profiles based on the number of study sites visited during the recorded trip: 1) none of the three study sites; 2) one of the three study sites; 3) two of the three study sites; 4) all three of the study sites. For example, a GPS track with waypoints in the Windows polygon but no waypoints in the Delicate Arch or Devils Garden polygon was classified as a “visited one of three study sites” route profile. RSG developed algorithms to calculate travel times on road segments and dwell times at the three study sites based on the timestamped location data in each GPS track. A total of 502 GPS routes was used in the postprocessing algorithms and study analysis and modeling.

### **Parking Lot Accumulation and Turnover**

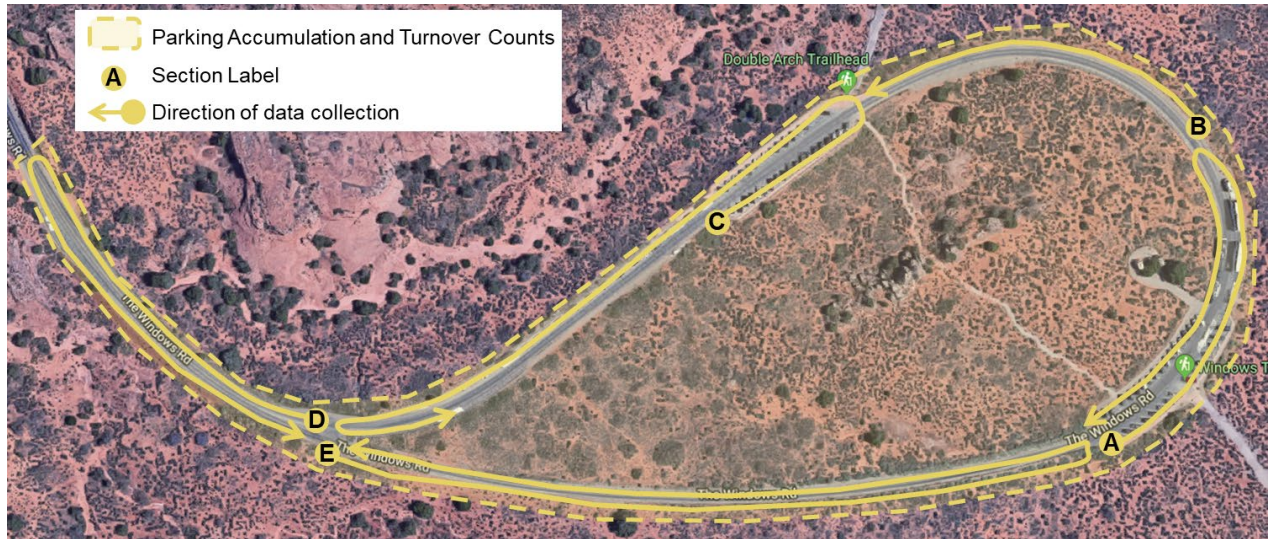
A license plate recording method was used in the Windows, Delicate Arch and Delicate Arch Viewpoint, and Devils Garden parking lots to record hourly counts of parked vehicles in each location (parking accumulation) and the amount of time (parking turnover) each vehicle was parked in each location. Parking data collection was conducted from 9:00 a.m. to 4:00 p.m. on each day of the 10-day sampling period. License plates were recorded according to a defined circuit for each parking lot and by specific parking spaces, including roadside and other overflow parking areas. As part of the parking lot accumulation and turnover data collection, the field technician also recorded a starting count of total vehicles parked in the lot just before the start of the 9:00 a.m. circuit at the Windows and Devils Garden. Appendix C contains a copy of the forms used to collect parking lot accumulation and turnover data.

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<sup>10</sup> No non-response bias analysis was conducted on these data. OMB Standards and Guidelines for Survey Research (2006) specify that non-response bias analysis is required when response rates are below 80%.

### ***The Windows***

Figure 14 depicts the circuit that the Windows parking data field technician walked each hour to record parking accumulation and turnover data at the Windows. The circuit included the main parking lots near the Windows and Double Arch trailheads and the roadside and pullouts from the loop to the location of the park-owned traffic counter. The field technician performed the data collection circuit by starting at section A and proceeding alphabetically through to section E. Data were collected in each section by starting at the location of the section label, then following the direction of the arrow.



**FIGURE 14. PARKING LOT ACCUMULATION AND TURNOVER DATA COLLECTION PROCEDURE: THE WINDOWS**

**Delicate Arch**

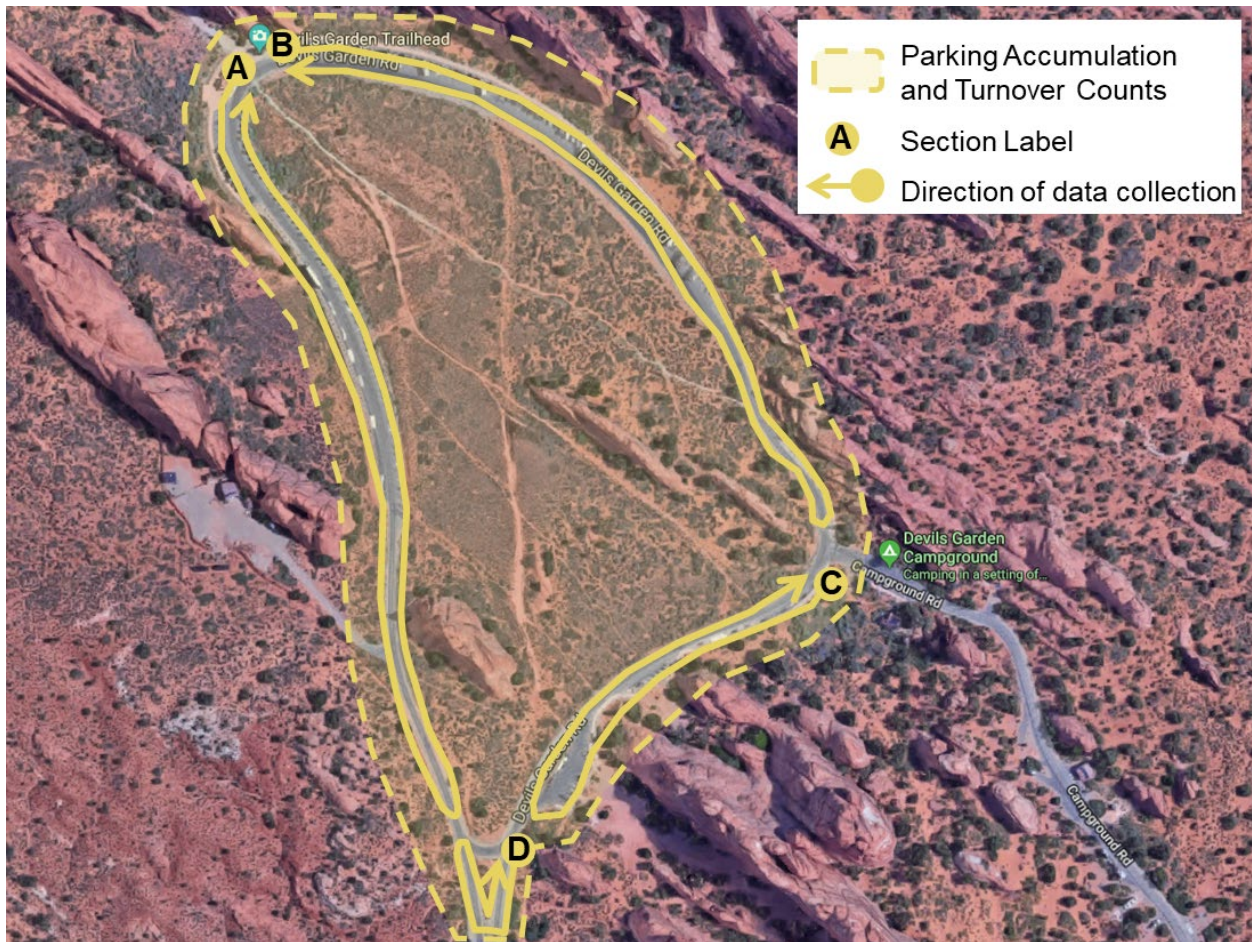
Figure 15 depicts the circuit that the Delicate Arch parking data field technician walked/drove each hour to collect information about parking accumulation and turnover at Delicate Arch and Delicate Arch Viewpoint. The circuit included the main parking lot and the overflow lot at Delicate Arch near Wolf Ranch, overflow roadside parking east of Delicate Arch parking, and the Delicate Arch Viewpoint parking lot, including overflow parking. The field technician performed the data collection circuit by starting at section A: Delicate Arch main and overflow parking lots. Next, the parking data field technician drove to section B: Delicate Arch Viewpoint parking lot. On the way to section B, the parking data field technician counted the number of vehicles, if any, parked along the section of the road depicted in yellow-highlighting in Figure 15. Turnover data were not collected for vehicles parked along the road due to safety concerns with recording license plate information while driving and the need to cover all areas noted within each hour.



**FIGURE 15. PARKING LOT ACCUMULATION AND TURNOVER DATA COLLECTION PROCEDURE: DELICATE ARCH**

## Devils Garden

Figure 16 depicts the circuit that the Devils Garden parking data field technician walked each hour to collect information about parking accumulation and turnover at Devils Garden. The circuit included the main parking lot, the picnic parking area, and the roadside in the yellow-highlighted area depicted in Figure 16. The Devils Garden campground was excluded from the parking data collection. The field technician performed the data collection circuit by starting at section A in Figure 16 and proceeding alphabetically through to section D. Data were collected in each section by starting at the location of the section label, then following the direction of the arrow.



**FIGURE 16. PARKING ACCUMULATION AND TURNOVER DATA COLLECTION PROCEDURE: DEVILS GARDEN**

## Visitor Use Counts

Visitor use count data were collected with infrared trail counters at four locations in the park including the Windows main trail, the trail to Delicate Arch, the trail to the Delicate Arch Viewpoint, and the trail to Landscape Arch at Devils Garden (Figure 9, Figure 10, Figure 11). The counting locations were selected in consultation with NPS staff to estimate visitor use at the three primary sites of focus for the study.

Because of the relatively high number of “events” (i.e., visitors passing the counter and triggering counts to be registered) on all of the trails and associated data storage capacity constraints of the counters, all counters were programmed to record counts in hourly bins instead of individual timestamps. The infrared trail counters recorded visitor use counts at the Windows, Delicate Arch Viewpoint, and Devils Garden 24 hours per day during the counting period, from August 31 through October 31, 2019. The counter installed on the trail to Delicate Arch was relocated on September 1, 2019 from a location where visitors were seen tampering with the counter and collected visitor use counts used in the study from September 1 through October 31, 2019.

Field staff conducted visitor use counts via direct observation for a minimum of 14 hours at each trail counter location (see Appendix D for a copy of the log sheet used to record visitor use counts via direct observation). The direct observation counts (or “calibration counts”) were used to correct and adjust (i.e., calibrate) the raw infrared trail counter data, as described in Section 3.6 of this report.

### People-at-One-Time (PAOT) and People-Per-Viewscope (PPV) Counts

People-at-one-time (PAOT) counts for the Windows and Delicate Arch viewsapes, and people-per-viewscope (PPV) counts for the Devils Garden viewscape were conducted using direct observation. The PAOT and PPV counts were recorded as instantaneous counts once every 10-minutes for approximately eight hours per day, starting at 9:00 a.m. each day of the 10-day sampling period. A total of 480 PAOT counts were recorded at the Windows, 423 PAOT counts were recorded at Delicate Arch, and 476 PPV counts were recorded at Devils Garden (Table 2). A copy of the PAOT and PPV count log forms are included in Appendix E.

**TABLE 2. SUMMARY OF PEOPLE-AT-ONE-TIME (PAOT) AND PEOPLE-PER-VIEWSCAPE (PPV) COUNTING EFFORT<sup>11</sup>**

DATE	THE WINDOWS # OF OBSERVATIONS	DELICATE ARCH # OF OBSERVATIONS	DEVILS GARDEN # OF OBSERVATIONS
08/31/19	48	45	44
09/01/19	48	48	48
09/02/19	48	48	48
09/04/19	48	48	48
09/05/19	48	48	48
09/06/19	48	48	48
09/07/19	48	48	48
09/08/19	48	32	48
09/09/19	48	47	48
09/10/19	48	11	48
<b>Total</b>	<b>480</b>	<b>423</b>	<b>476</b>

<sup>11</sup> There are fewer than 48 observations of PAOT at Delicate Arch and of PPV at Devils Garden on some dates due to a combination of staff comfort breaks, weather events, and a medical incident.

## **Vehicles-at-One-Time (VAOT) Calculation**

Due to the relatively large size of the Windows, Delicate Arch and Devils Garden sites, there was no suitable location for a field technician to accurately conduct instantaneous counts of the total number of people at each site (i.e., to conduct “whole area PAOT and PPV counts”). Instead, the number of vehicles-at-one-time (VAOT) was estimated for each site using data from park-owned traffic counters located at each site (Figure 9, Figure 10, Figure 11). These VAOT estimates were used in the study as instantaneous, site-wide (i.e., “whole area”) measures to correlate with the PAOT and PPV counts in the viewscape at each site.

The park-owned traffic counter data were postprocessed to derive VAOT counts for every 10-minute interval for which PAOT or PPV counts were recorded at each site’s viewscape (Table 2). At the Windows and Devils Garden, each sampling day’s first 10-minute interval VAOT count was calculated by adding the net number of vehicle counts (inbound minus outbound) in the first 10-minute interval bin to the starting count for the observation-based accumulation data collected by the parking data field technician (see Parking Lot Accumulation and Turnover section above). Each successive 10-minute interval VAOT count was calculated by adding the net number of vehicle counts in the 10-minute interval to the VAOT count for the previous 10-minute interval. At Delicate Arch, where a starting count for the observation-based parking accumulation data was not collected, the first 10-minute interval VAOT count was calculated as the net number of vehicle counts for the first 10-minute interval of the day when counts were recorded. Each successive 10-minute interval VAOT count was calculated by adding the net number of vehicle counts in the 10-minute interval to the VAOT count for the previous 10-minute interval. The 10-minute interval VAOT counts were reset to zero at midnight on each day for which the calculations were made and the process was repeated.

## **Delay Card Administration**

### ***Survey Instrument***

Delay cards were administered at the Windows, Delicate Arch, and Devils Garden to a systematic sample of visitors to collect information about the length of time visitors spend at each site visited. The delay cards administered at the three sites were designed by researchers at RSG in consultation with NPS staff. Appendix F contains a copy of the delay cards administered at each site. A copy of the delay card contact logs used to record information about response rates is contained in Appendix G.

### ***Sampling Procedure***

Delay card sampling was conducted at the Windows, Delicate Arch, and Devils Garden for five days per site, spread over the 10-day sampling period. Each delay card sampling day started at approximately 9:00 a.m. and continued for eight hours. On each sampling day, a delay card administrator was located at the trailhead for the assigned study site (denoted as “X” in Figure 9 for the Windows, as “X1” in Figure 10 for Delicate Arch, and as “X” in Figure 11 for Devils Garden) to distribute and collect delay cards for the entire sampling day. On sampling days at Delicate Arch, a second delay card administrator was located at the boundary of the Delicate

Arch viewscape (denoted as “X2” in Figure 10) to record the current time that visitor groups arrived to and departed from the Delicate Arch viewscape.

On each sampling day, the delay card administrator contacted the first arriving group and asked them if they would be willing to participate in the study. The delay card administrator continued to contact arriving visitor groups until a group agreed to participate. After completing a contact with a visitor group, the delay card administrator contacted the next arriving visitor group and asked them to participate (i.e., used a “first-after-last” sampling procedure). This procedure continued throughout the sampling day.

Each contacted visitor group was greeted, briefly introduced to the purpose of the study, and asked to participate and screened for eligibility. Visitor groups were considered eligible if a member of the group was at least 18 years old, the group had not previously participated in the study, were not actively using their cell phone, and were able to communicate with the English-speaking survey administrator (i.e., did not have a language barrier). Information from all contacts was recorded on a contact log. If visitors were eligible for the study and agreed to participate, they were asked which group member (at least 18 years old) had the next birthday. The individual with the next birthday was selected to carry the delay card for the group. An interview, lasting approximately one minute, was conducted with all eligible visitor groups, whether they agreed to participate in the study or not, to determine group size and state or country of residence. The gender of the first-contacted group member and the time of contact were also recorded for each contacted group. For visitor groups that agreed to participate, the delay card administrator recorded a unique card identification number, the date, and the current time on the delay card. The delay card administrator then handed the delay card to the member of the group with the next birthday and instructed the group member to carry the card during their visit and return the card to the administrator at the end of their visit. At Delicate Arch, visitors were also instructed to hand the delay card to the second administrator when they arrived to and departed the Delicate Arch viewscape. For all “hard refusals” (groups who refused to participate in the study and in the brief interview), only the observational data (group size, gender of first-contacted group member, and time of contact) and refusal reason were recorded on the contact log.

The administrator collected delay cards from visitor groups as they departed the study site and recorded the current time on the delay card. Visitor groups who departed after the sampling day was complete were instructed to write the current time on the delay card and return it to a drop box located at the trailhead. At the Windows, a second drop box was installed at the Double Arch trailhead for visitors to return their delay cards if they departed the Windows from that location.

Of the 476 eligible visitor groups asked to participate in the delay card study at the Windows, 457 agreed to participate (Table 3), resulting in an overall response rate of 96.0%. Of the 319 eligible visitor groups asked to participate in the delay card study at Delicate Arch, 310 agreed to participate (Table 4), resulting in an overall response rate of 97.2%. Of the 547 eligible visitor groups asked to participate in the delay card study at Devils Garden, 506 agreed to participate (Table 5), resulting in an overall response rate of 92.5%. Due to these high response rates, no nonresponse bias analyses were conducted on these data.<sup>12</sup>

**TABLE 3. DELAY CARD SAMPLING EFFORT: THE WINDOWS**

DATE	SOLICITATIONS	ACCEPTANCES	REFUSALS	INELIGIBLES
08/31/19	162	147	7	8
09/02/19	79	75	3	1
09/04/19	85	79	4	2
09/07/19	79	76	2	1
09/09/19	84	80	3	1
<b>Total</b>	<b>489</b>	<b>457</b>	<b>19</b>	<b>13</b>

**TABLE 4. DELAY CARD SAMPLING EFFORT: DELICATE ARCH**

DATE	SOLICITATIONS	ACCEPTANCES	REFUSALS	INELIGIBLES
09/01/19	59	54	3	2
09/05/19	67	67	0	0
09/06/19	77	75	2	0
09/08/19	61	59	2	0
09/10/19	57	55	2	0
<b>Total</b>	<b>321</b>	<b>310</b>	<b>9</b>	<b>2</b>

**TABLE 5. DELAY CARD SAMPLING EFFORT: DEVILS GARDEN**

DATE	SOLICITATIONS	ACCEPTANCES	REFUSALS	INELIGIBLES
08/31/19	162	147	7	8
09/02/19	79	75	3	1
09/04/19	85	79	4	2
09/07/19	79	76	2	1
09/09/19	84	80	3	1
<b>Total</b>	<b>556</b>	<b>506</b>	<b>41</b>	<b>9</b>

<sup>12</sup> No non-response bias analysis was conducted on these data. Office of Management and Budget Standards and Guidelines for Statistical Surveys (2006) specify that non-response bias analysis is required when unit response rate is below 80%.

## 3.0 RESULTS

This section of the report presents summary statistics for the parkwide and site-specific data collected at ARCH during the late summer and early fall of 2019. Results are presented in the following subsections, by data type. The percentages in some tables and figures of results in this section do not sum to 100% due to rounding.

### 3.1 ENTRANCE STATION QUEUE COUNTS

The entrance station queue length is a function of the volume and timing of vehicle arrivals, as well as the transaction processing times at the entrance station. Instantaneous counts of the entrance station queue were collected once each hour during the sampling period. The data summaries below aggregate data about vehicle type (automobile or coach) and whether the vehicle was stopped in the queue or moving along the park entrance road into the single variable “queue length”.

#### Mean and Maximum Daily Entrance Station Queue Length

Table 6 displays daily average and maximum entrance station queue lengths during the sampling period. These data suggest:

- The daily mean entrance station queue length ranged from 6 to 27 vehicles at one time, and the daily maximum entrance station queue ranged from 13 to 81 vehicles at one time.
- Peak queue lengths ranged from approximately 27-75 vehicles on weekend days and holidays. Peak queue lengths ranged from approximately 13-81 vehicles on weekdays.
- Average daily entrance queue length was slightly higher on weekend days and holidays (17.8 vehicles) than on weekdays (11.7 vehicles), but did not differ significantly ( $t = -1.77$ ,  $p = 0.08$ ).

**TABLE 6. AVERAGE AND MAXIMUM DAILY ENTRANCE STATION QUEUE LENGTH**

DATE	DAY TYPE	MEAN	MAX
08/31/19	WEEKEND/HOLIDAY	20	37
09/01/19	WEEKEND/HOLIDAY	27	75
09/02/19	WEEKEND/HOLIDAY	16	47
09/04/19	WEEKDAY	7	14
09/05/19	WEEKDAY	8	23
09/06/19	WEEKDAY	6	13
09/07/19	WEEKEND/HOLIDAY	15	33
09/08/19	WEEKEND/HOLIDAY	12	27
09/09/19	WEEKDAY	18	51
09/10/19	WEEKDAY	19	81

## Mean Hourly Entrance Station Queue Lengths

Statistical summaries of the range of entrance station queue length, by hour of the day, are presented in Figure 17. The points represent mean hourly entrance station queue lengths and the vertical lines represent the full range of entrance station queue lengths observed, from the minimum value at the bottom of the vertical line to the maximum value at the top of the vertical line. These data suggest:

- It is likely that queues at the entrance station occur outside of the hours of the day of the data collection period, since queues were always present at 8:00 a.m. and at 3:00 p.m.
- On weekend days and holidays, the average entrance station queue length peaked at 39 vehicles at 9:00 a.m., compared to the average entrance station queue length on weekdays which peaked at 34 vehicles at 10:00 a.m. In addition, the average entrance station queue had a secondary peak of 19 vehicles at 1:00 p.m. on weekend days and holidays.
- Hourly entrance station queue lengths were significantly higher in the morning hours, with approximately 21 vehicles on average, than in the afternoon hours with approximately 9 vehicles on average across all sampling days ( $t = 3.70, p < 0.001$ ).
- The maximum queue length observed during weekdays was approximately 80 vehicles, and the maximum observed on weekends and holidays was approximately 75 vehicles.

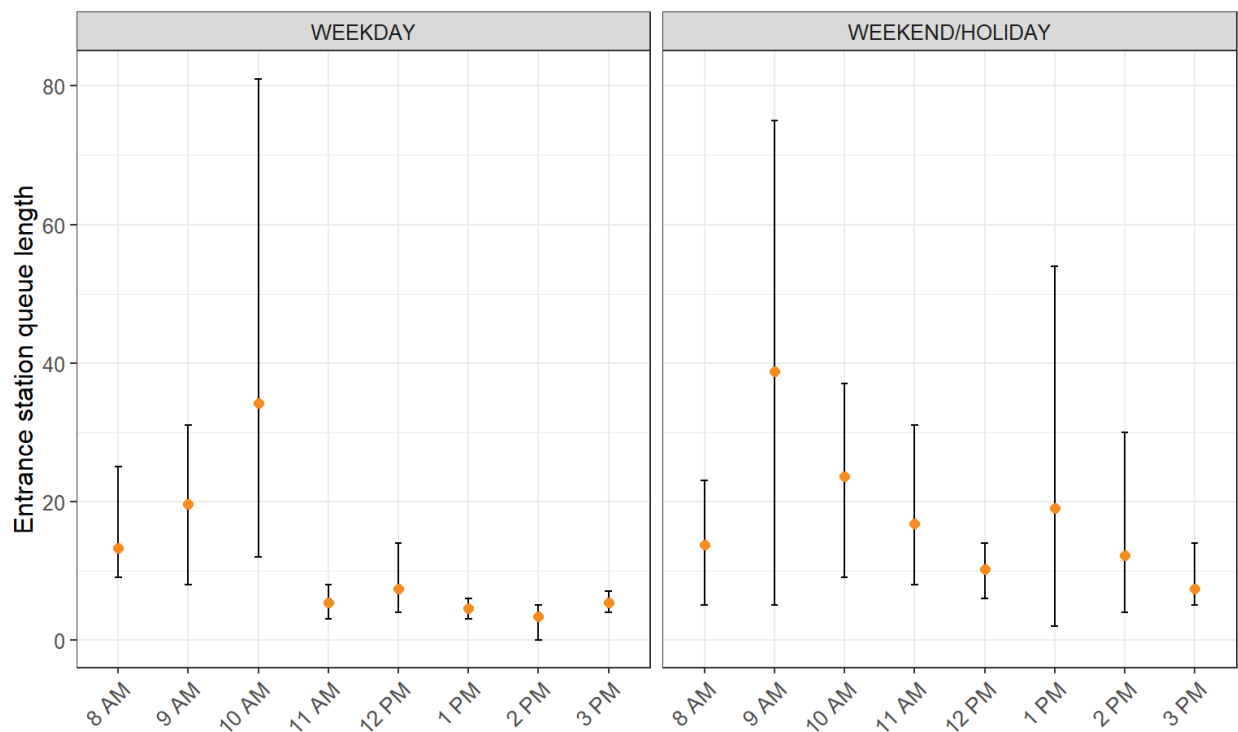


FIGURE 17. MEAN HOURLY ENTRANCE STATION QUEUE LENGTH

## 3.2 ENTRANCE STATION TRAFFIC COUNTS

### Vehicle Arrival Volumes

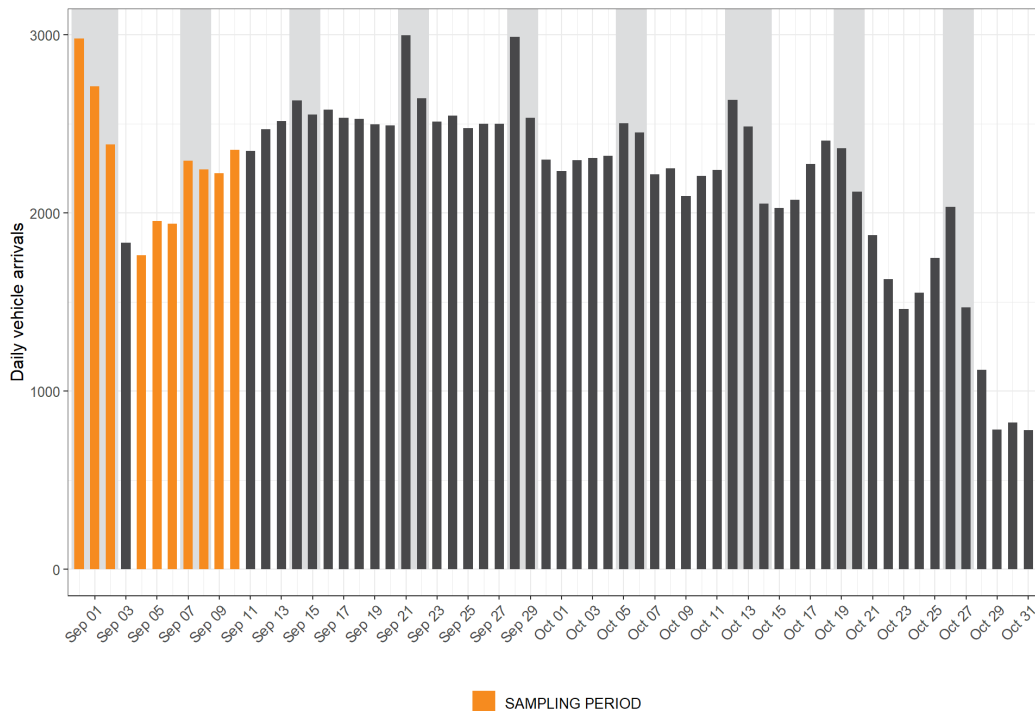
This subsection of the report summarizes vehicle arrival volumes recorded by the NPS-owned permanent inductive loop counter at the park entrance station (Figure 1). The following summaries of vehicle arrival volumes are presented in the subsections below:

- Daily vehicle arrivals during the counting period.
- Hourly vehicle arrivals during the counting and sampling periods.
- Mean hourly vehicle arrivals during the sampling period.

#### Daily Vehicle Arrivals

Figure 18 presents total daily vehicle arrivals at the park entrance station by date during the counting period. These data suggest:

- Vehicle arrivals are generally highest on weekend days and holidays (indicated by gray shading). Saturdays tend to have the highest daily vehicle arrivals.
- The highest daily arrivals during the counting period occurred on Saturday August 31, 2019, Saturday, September 21, 2019, and Saturday September 28, 2019 when daily vehicle arrivals approached 3,000.



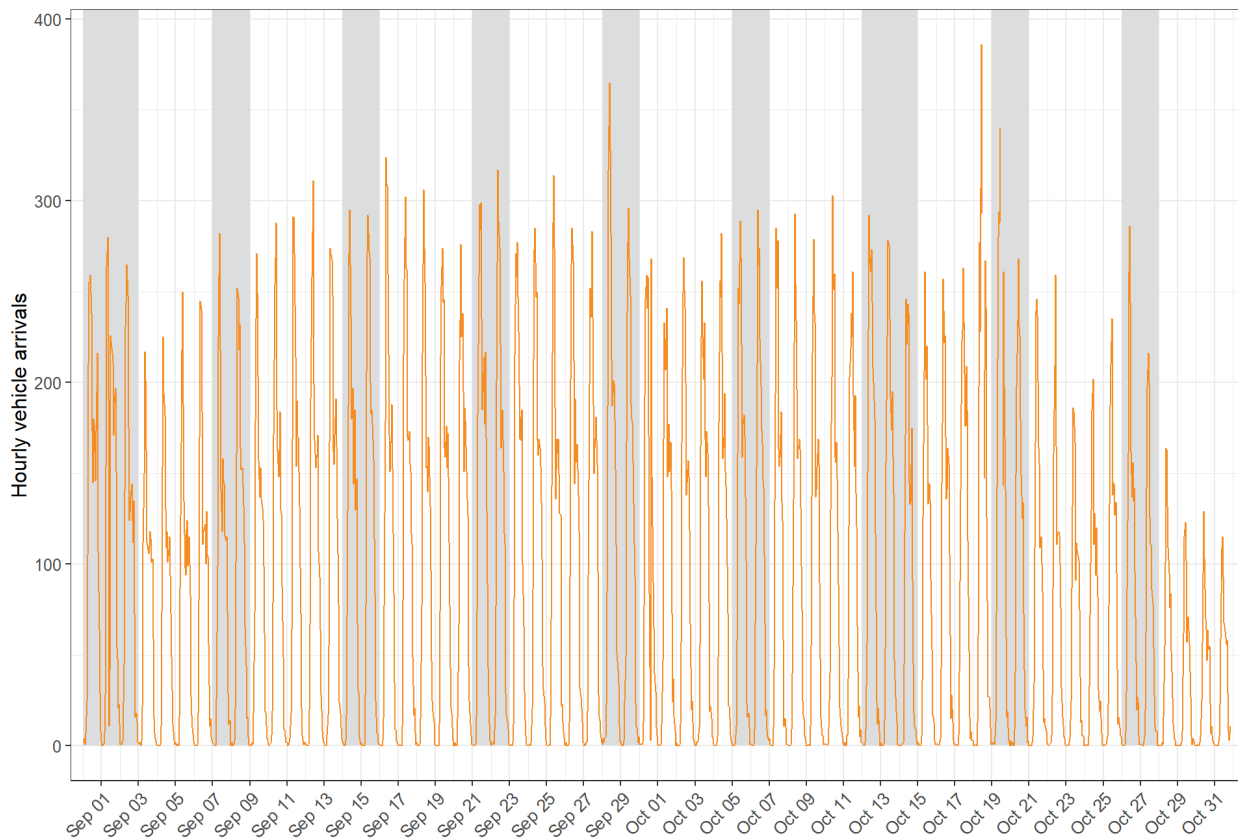
**FIGURE 18. DAILY TOTAL ENTRANCE STATION VEHICLE ARRIVALS (GRAY SHADING INDICATES WEEKENDS/HOLIDAYS)<sup>13</sup>**

<sup>13</sup> September 3, 2019 was a scheduled day off for field staff and no data were collected on that date.

### Hourly Vehicle Arrivals

Figure 19 displays hourly vehicle arrivals by date during the counting period. The plot in Figure 19 provides a “macro view” of hourly patterns of vehicle arrivals across the days of the counting period. These data suggest:

- Peak hourly vehicle arrivals at the park entrance station ranged from just over 100 vehicles to roughly 300 vehicles on the majority of days. Peak hourly vehicle arrivals stayed below 300 vehicles on all but 10 days during the counting period.
- On two days during the counting period (September 28, 2019 and October 18, 2019), peak hourly vehicle arrivals exceeded 350 vehicles.

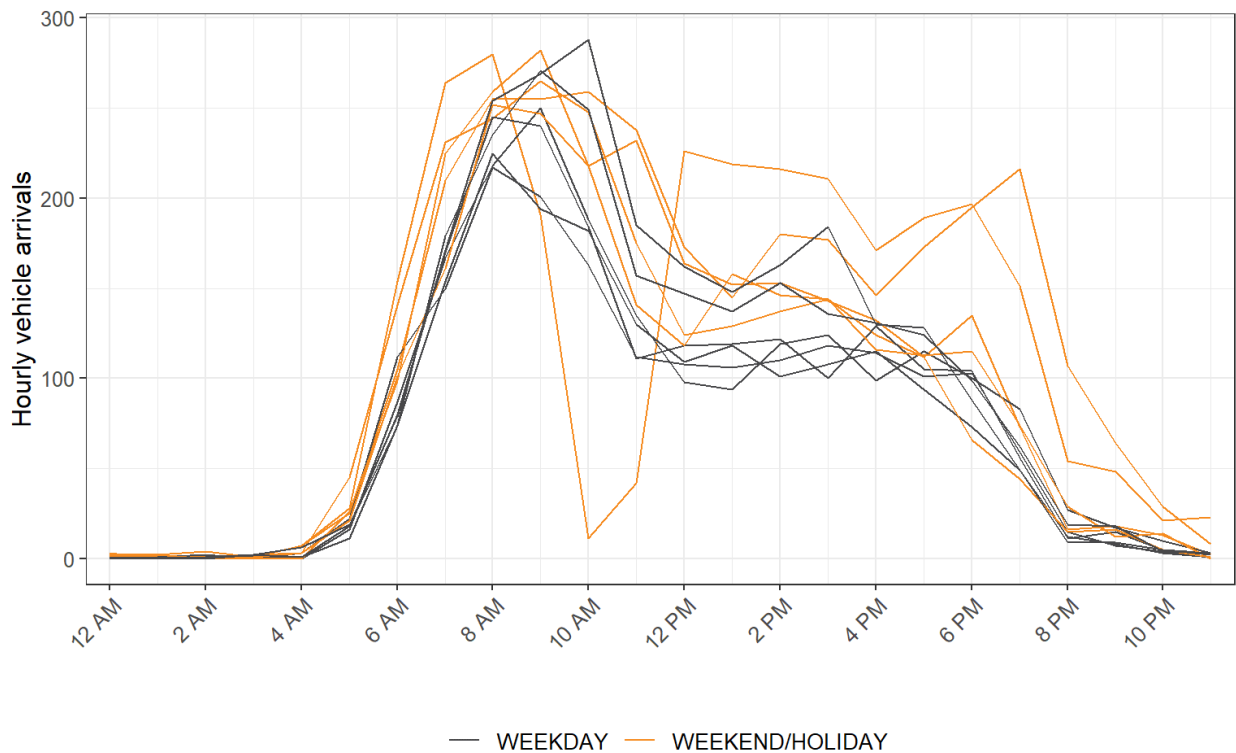


**FIGURE 19. HOURLY ENTRANCE STATION VEHICLE ARRIVALS (GRAY SHADING INDICATES WEEKENDS/HOLIDAYS)**

Figure 20 displays hourly vehicle arrivals by date during the sampling period in a complementary format to the plot in Figure 19 (separate lines, rather than a single continuous line, for each date displayed in the plot). The plot in Figure 20 provide a “micro view” of hourly patterns of vehicle arrivals across the hours of each day of the sampling period.

These data suggest:

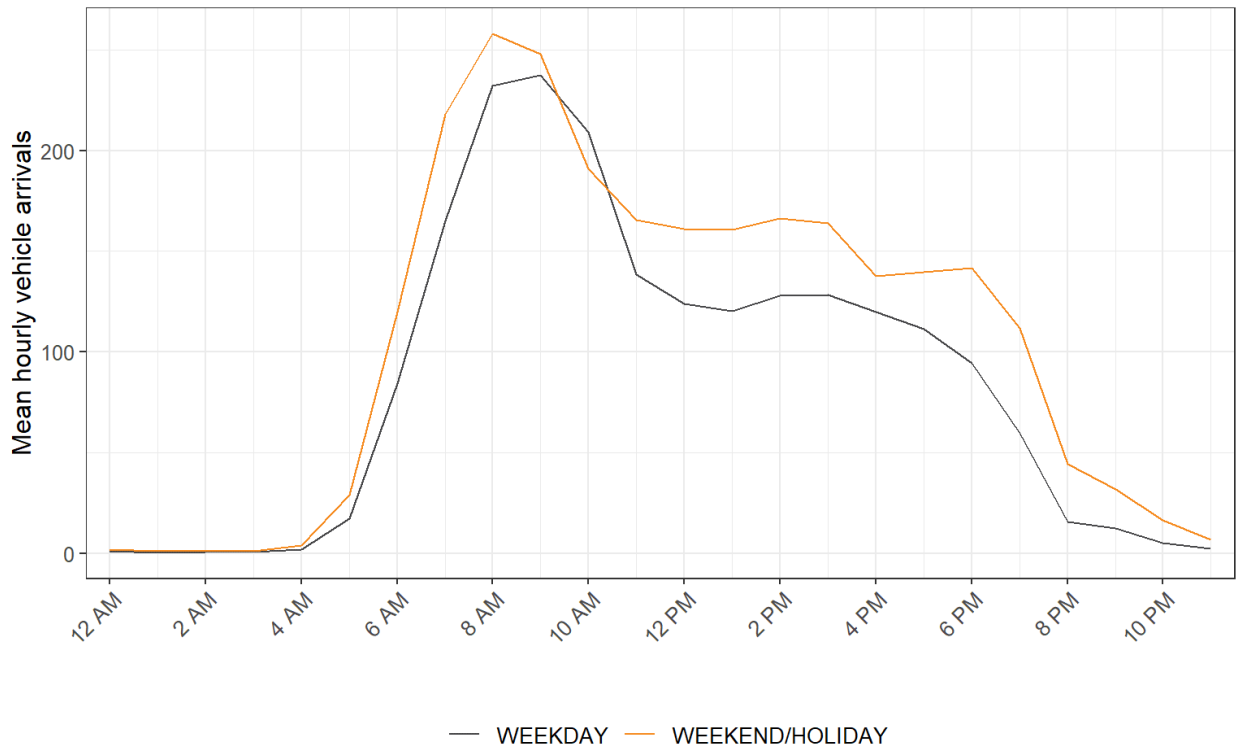
- Vehicle arrivals began as early as 4:00 a.m. on all sampling days.
- Vehicle arrivals “ramped up” slightly earlier on weekend days and holidays than on weekdays, reaching peak arrivals at approximately 8:00 a.m. to 9:00 a.m. on weekend days and holidays, and at 9:00 a.m. to 10:00 a.m. on weekdays.
- Morning peak hourly arrivals were similar on weekdays and weekend days and holidays, while afternoon hourly arrivals were generally higher on weekend days and holidays.
- A notable drop in hourly vehicle arrivals is evident in the plot on one weekend day. This line corresponds to September 1, 2019 (the Sunday of Labor Day weekend), when the park reached its vehicle capacity at 9:30 a.m. The park entrance was closed for approximately two hours.



**FIGURE 20. HOURLY ENTRANCE STATION VEHICLE ARRIVAL, BY SAMPLING DAY AND DAY OF WEEK CATEGORY**

Figure 21 presents mean hourly vehicle arrivals at the park entrance station, by day of week category during the sampling period. These data suggest:

- Average hourly vehicle arrivals were slightly higher on weekend days and holidays than on weekdays. Holiday and weekend mean vehicle arrivals peaked at approximately 250 vehicles in the 8:00 a.m. hour, while weekday mean vehicle arrivals peaked at approximately 230 vehicles. A similar pattern of average hourly vehicle arrivals was observed for most of the remaining hours of the day across day of week categories.
- On average, vehicle arrivals began at 4:00 a.m. and increased sharply starting at 5:00 a.m. to peaks at 8:00 a.m. on weekend days and holidays and at 9:00 a.m. on weekdays.
- After the peak hour, mean hourly arrivals drop off steeply after 9:00 a.m. and level off by 11:00 a.m. until approximately 6:00 p.m. After 6:00 p.m., mean hourly vehicle arrivals drops off steeply until 10:00 p.m., and drops nearly to zero by 11:00 p.m.



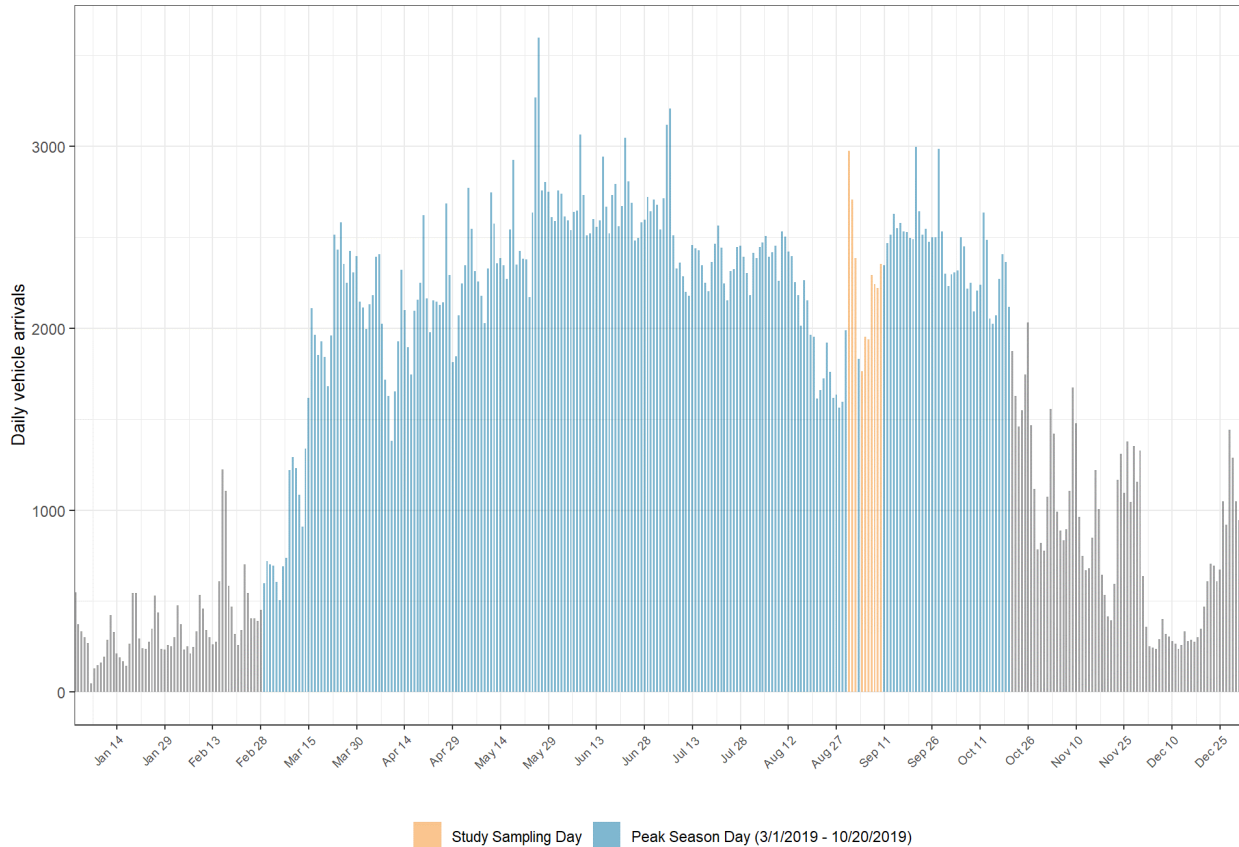
**FIGURE 21. MEAN HOURLY ENTRANCE STATION VEHICLE ARRIVALS, BY DAY OF WEEK CATEGORY**

## Design Day Analysis

The “design day” concept was applied in this project to focus analysis and modeling on “typically busy” traffic, parking, and visitor use conditions in ARCH during the peak visitation season. The design day provides a basis for designing transportation and visitor use management solutions for ARCH that are effective on most days, while recognizing it will be necessary to adapt under extreme conditions (i.e., the busiest of days) to avoid “overinvesting” in solutions to relative rare circumstances.

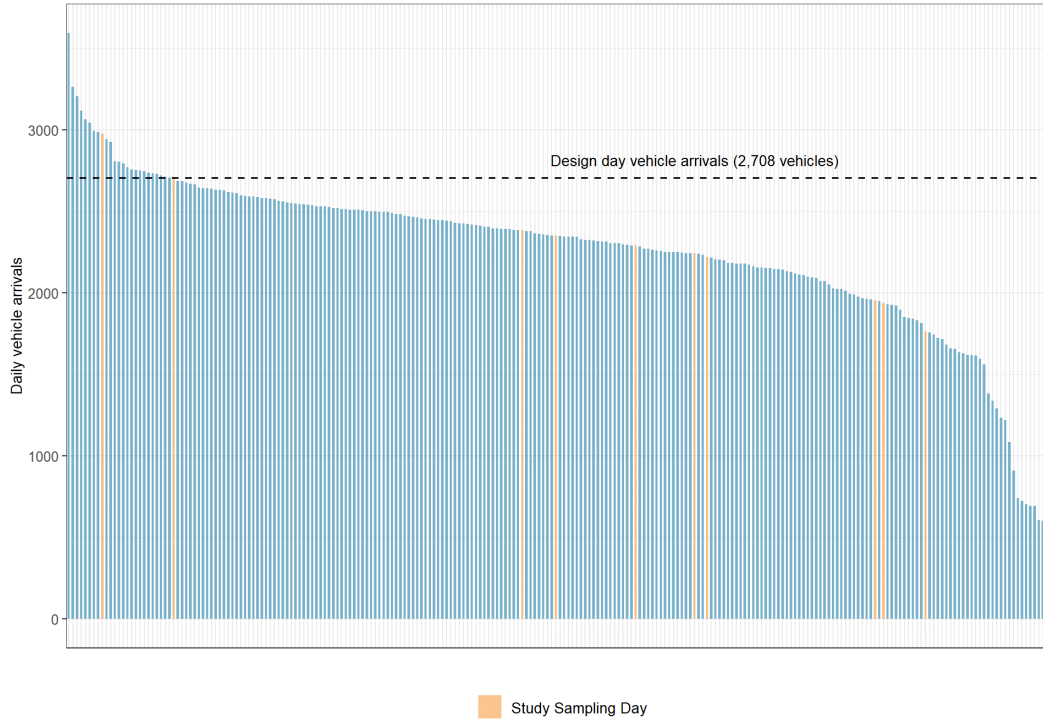
Commonly, the 85<sup>th</sup> percentile day of vehicle traffic volumes in a study area is selected as the design day for community and urban transportation planning. In the context of national parks, however, where visitor use tends to be temporally concentrated (e.g., during peak days and peak hours), it is arguably more suitable to select a design day based on the percentage of visitors (rather than days) that experience conditions similar to or better than design day conditions.

With that in mind, the 2019 daily total vehicle arrivals at the ARCH entrance station were analyzed to estimate a design day such that approximately 85% of peak season visitors to ARCH would experience transportation and visitor use conditions similar to or better than design day conditions. To do this, the 2019 daily total vehicle arrivals at the entrance station were plotted, by date, to assess seasonal visitation patterns to the park (Figure 22). Figure 22 also depicts the peak season, defined as March 1, 2019 through October 20, 2019 based on daily total vehicle arrivals. The sampling period dates are also depicted in Figure 22 to provide context for the study period and to assess the extent to which the study period represents peak periods of visitor use in ARCH.

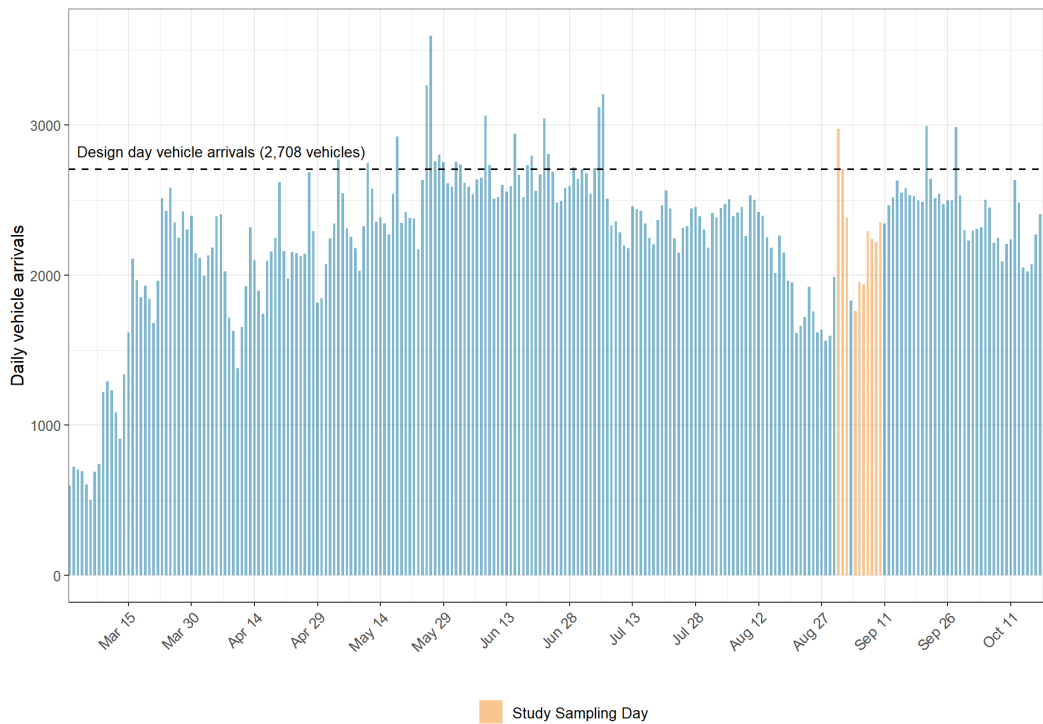


**FIGURE 22. DAILY ENTRANCE STATION VEHICLE ARRIVALS, BY DATE, JANUARY-DECEMBER 2019**

Next, the daily total vehicle arrivals for the peak season days were organized and plotted in descending order from the busiest day (May 26, 2019) to the least busy day (March 6, 2019) in Figure 23. Daily visitation was estimated from the vehicle arrivals data plotted in Figure 24 using the park’s seasonal Visitor Use Statistics persons-per-vehicle multipliers and summed to estimate a total peak season visitation of 1,414,829 people (see Appendix H for a tabular summary of daily visitation organized in descending order from the busiest to the least busy day of visitation during the peak period). The 85<sup>th</sup> percentile level of daily visitor use was estimated by multiplying the peak season visitation estimate by 85%. The results suggest that approximately 85% of visitors during the peak season visit the park on days with approximately 7,250 daily visitors or fewer and 2,688 daily vehicle arrivals or fewer. This result was used as the basis to specify the design day, with a slight adjustment to select a date during the sampling period (2,708 vehicles). As such, the design day level for this study is specified as 2,708 daily vehicle arrivals at the park entrance station and depicted with a horizontal line in Figure 23 and Figure 24.



**FIGURE 23. DAILY ENTRANCE STATION VEHICLE ARRIVALS AND DESIGN DAY, IN DESCENDING ORDER, 2019 PEAK SEASON**



**FIGURE 24. DAILY ENTRANCE STATION VEHICLE ARRIVALS AND DESIGN DAY, BY DATE, 2019 PEAK SEASON**

### 3.3 SECONDARY ROAD TRAFFIC COUNTS

#### Calibration

Regression analyses were conducted to model the relationship between the park-owned magnetometer traffic counter data on Salt Valley Road and Willow Springs Road and corresponding calibration counts measured by RSG. This was done to derive an empirical basis to convert raw data from the park-owned magnetometer traffic counters to estimates of actual vehicle use on the roads. A separate regression model was estimated for each of the two counter locations, with the RSG calibration count as the dependent variable in each model and the park-owned magnetometer traffic counter data as the independent variable in each model. Regression results suggest that there are strong statistical relationships between the RSG calibration counts and the traffic counts recorded by the park-owned magnetometer traffic counters.

- A regression model with no intercept term was the best fitting model for each of the two locations.
- Adjusted  $R^2$  values were 0.95 for the Salt Valley Road model and 0.98 for the Willow Springs Road model.
- The coefficient for the Salt Valley Road model was 0.78, and the coefficient for the Willow Springs Road model was 0.68
- The p-value for each regression model was less than 0.001

These results provide a high degree of confidence that applying the correction factors to calibrate the traffic counts recorded with the park-owned magnetometer traffic counters (i.e., multiplying the traffic counter data by the corresponding parameter estimates from the regression models) result in accurate estimates of vehicle use on the secondary park roads. The calibrated traffic counter data were used for analysis and results presented in this report.

## Vehicle Arrivals and Departures

This subsection of the report summarizes vehicle arrival and departure volumes<sup>14</sup> by traffic counter location. Arrival and departure splits were estimated based on the mean hourly proportion of arrival and departure traffic derived from the calibration counts recorded by RSG. The following summaries of traffic volumes are presented in the subsections below:

- Daily vehicle arrivals, by vehicle counter location and date during the counting period.
- Hourly vehicle arrivals, by vehicle counter location and date during the counting and sampling periods.
- Mean hourly vehicle arrivals and departures, by vehicle counter location and day of week category during the sampling period.

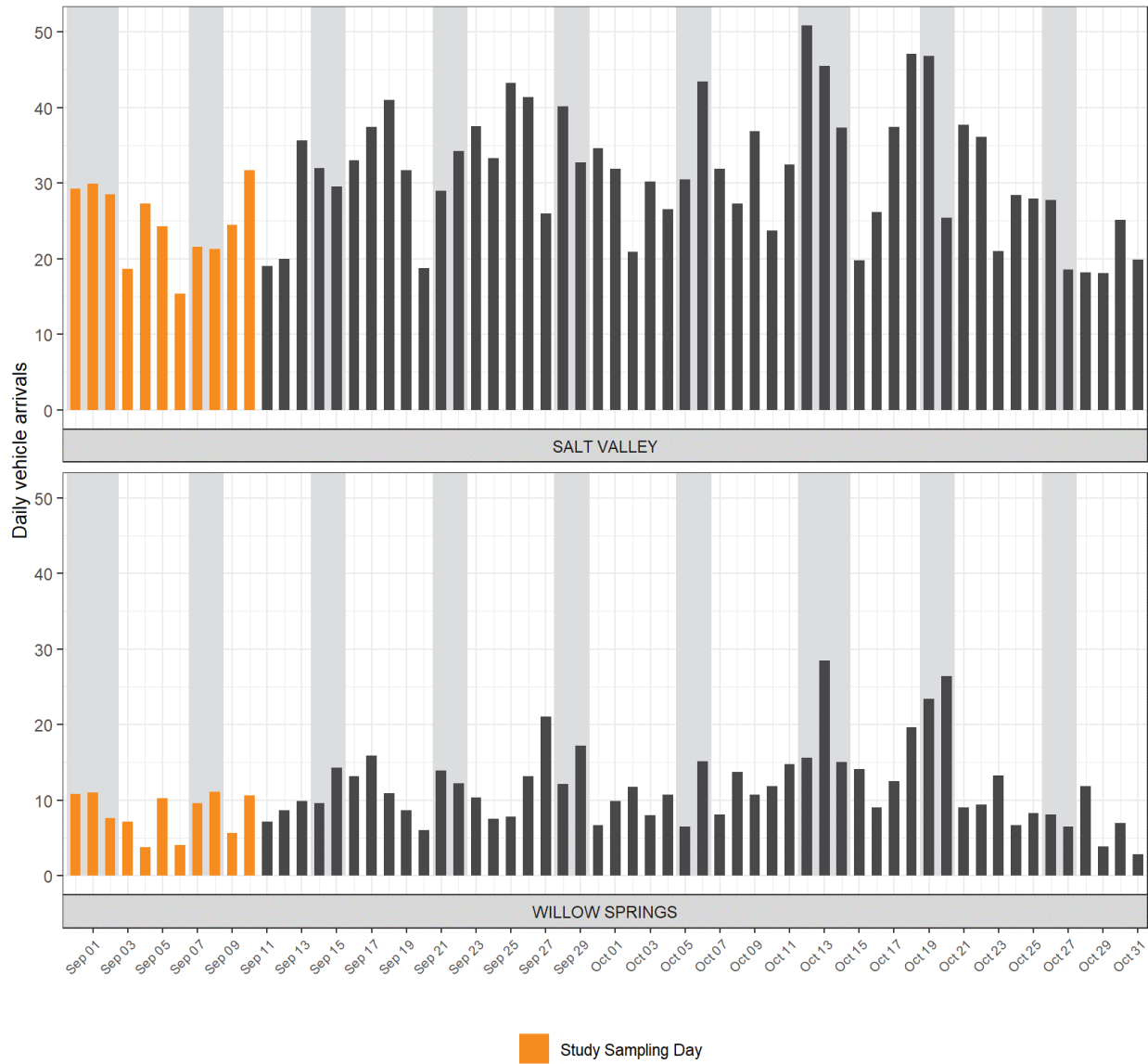
### *Daily Vehicle Arrivals*

Figure 25 presents total daily vehicle arrivals by traffic counter location and date during the counting period. These data suggest:

- In general, there do not appear to be discernable differences in total daily vehicle arrivals on weekdays versus weekend days and holidays at either counting location.
- Overall, total daily vehicle arrivals on both Salt Valley Road and Willow Springs Road are relatively low, but Salt Valley Road receives roughly twice as much traffic as Willow Springs Road on both weekdays and weekend days and holidays.
- Daily vehicle arrivals on Salt Valley Road ranged from 15 vehicles to a peak of 51 inbound vehicles on Saturday, October 12, 2019.
- Daily vehicle arrivals on Willow Springs Road ranged from 3 vehicles to a peak of 28 inbound vehicles on Sunday, October 13, 2019.

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<sup>14</sup> For the purposes of this study, all traffic traveling west to east on Salt Valley Road and Willow Springs Road (i.e., from the park boundary toward the main travel corridor) was considered arrival traffic. Correspondingly, all traffic traveling east to west on Salt Valley Road and Willow Springs Road (i.e., from the main travel corridor toward the park boundary) was considered departure traffic.



**FIGURE 25. DAILY TOTAL VEHICLE ARRIVALS, BY TRAFFIC COUNTER LOCATION AND DATE (GRAY SHADING INDICATES WEEKENDS/HOLIDAYS)**

### ***Hourly Vehicle Arrivals***

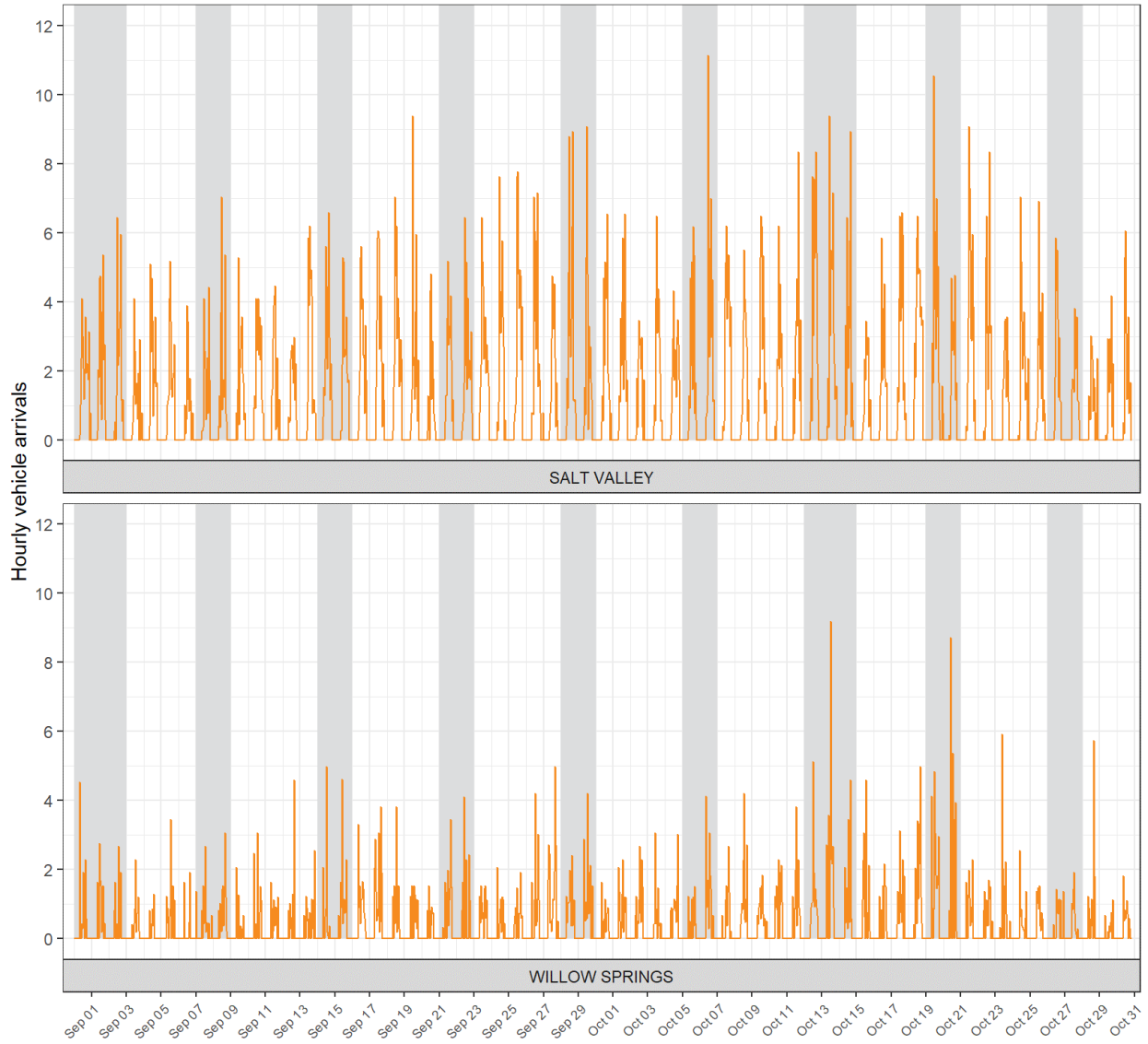
Figure 26 displays hourly vehicle arrivals by vehicle traffic counter location and date during the counting period. The plots with continuous lines across dates in Figure 26 provide a “macro view” of hourly patterns of vehicle arrivals across the days of the counting period. These data suggest:

#### **Salt Valley Road**

- Peak hourly vehicle arrivals at the Salt Valley Road traffic counter exceeded 10 vehicles on two weekend days (October 6, and October 19, 2019), and were less than 10 vehicles on every other day during the counting period.
- Peak hourly vehicle arrivals at the Salt Valley Road traffic counter ranged from 3 to 11 vehicles during the counting period.

#### **Willow Springs Road**

- Peak hourly vehicle arrivals at the Willow Springs Road traffic counter approached 10 vehicles on two weekend days (October 13, and October 20, 2019), and did not exceed six vehicles on any other day during the counting period.
- Peak hourly inbound traffic counts at the Willow Springs Road traffic counter ranged from one to nine vehicles during the counting period.



**FIGURE 26. HOURLY VEHICLE ARRIVALS, BY TRAFFIC COUNTER LOCATION AND DATE (GRAY SHADING INDICATES WEEKENDS/HOLIDAYS)**

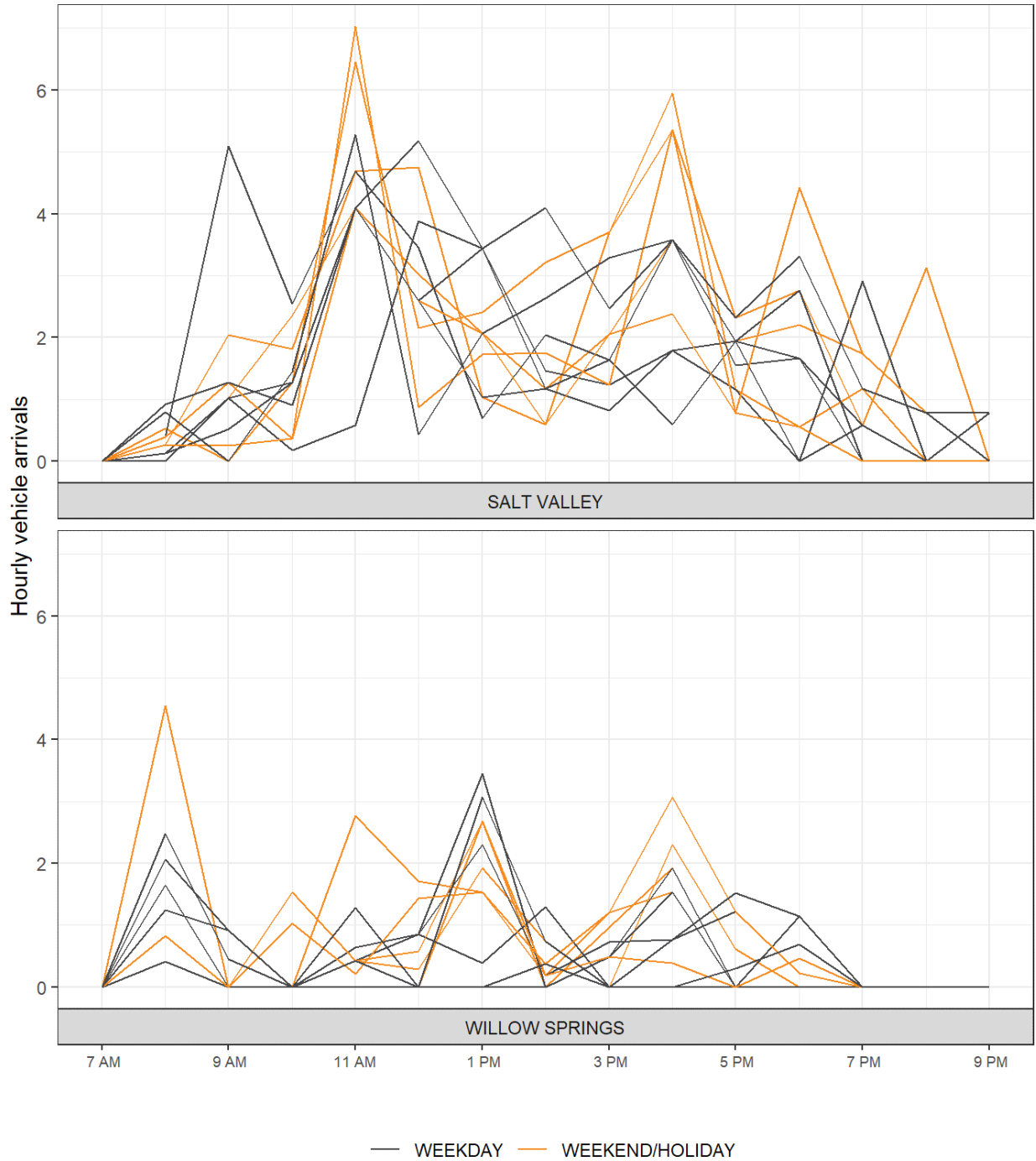
Figure 27 displays hourly vehicle arrivals, by vehicle traffic counter location and date during the sampling period in a complementary format to the plots in Figure 26 (separate lines, rather than a single continuous line, for each date displayed in the plot). Plots in Figure 27 provide a “micro view” of hourly patterns of inbound traffic across the hours of each day of the sampling period. These data suggest:

### Salt Valley Road

- Peak hourly vehicle arrivals were similar on weekdays and weekend days and holidays.
- Hourly vehicle arrivals at the Salt Valley Road traffic counting location was low and fluctuated throughout the day starting around 8:00 a.m. and dropping off at about 9:00 p.m.

### Willow Springs Road

- Peak hourly vehicle arrivals were similar on weekdays and weekend days and holidays.
- Hourly vehicle arrivals at the Willow Springs Road traffic counting location was low and fluctuated throughout the day starting around 8:00 a.m. and dropping off at 7:00 p.m.



**FIGURE 27. HOURLY VEHICLE ARRIVALS, BY COUNTER LOCATION, SAMPLING DAY, AND DAY OF WEEK CATEGORY**

### ***Mean Hourly Vehicle Arrivals and Departures***

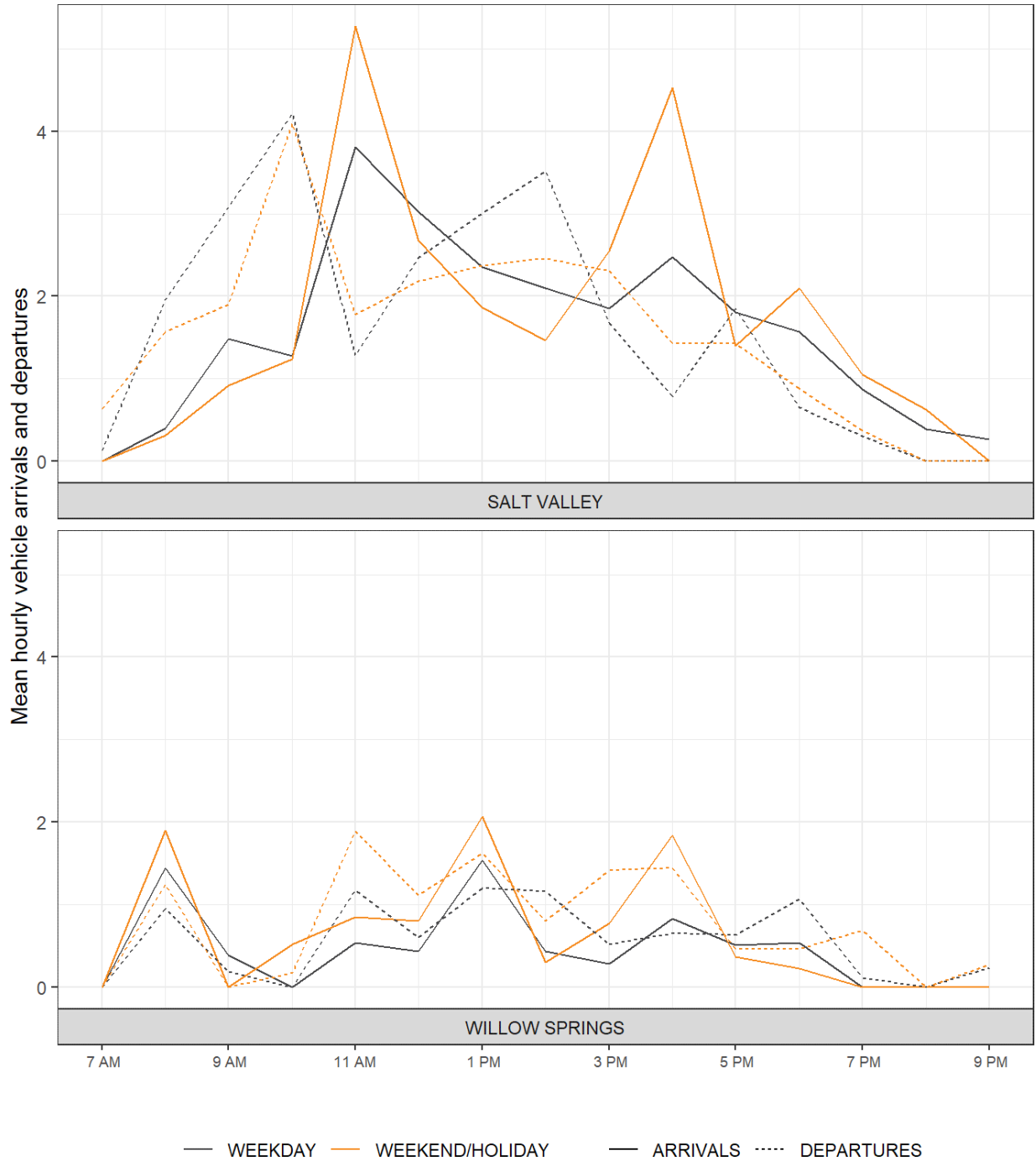
Figure 28 presents mean hourly vehicle arrivals and departures, by vehicle counter location and day of the week category during the sampling period at both secondary road counter locations. These data suggest:

#### **Salt Valley Road**

- Mean hourly vehicle arrivals and departures on Salt Valley Road first occurred starting at 7:00 a.m. and fluctuated at low levels throughout the day.
- Mean hourly vehicle arrivals and departures on Salt Valley Road peaked at 11:00 a.m., with a smaller afternoon peak at 4:00 p.m. on both weekdays and weekend days and holidays.
- Mean hourly vehicle arrivals were slightly higher on weekend days and holidays than on weekdays. There was no discernable difference in mean hourly departures on weekdays, compared to weekend days and holidays.
- Mean hourly vehicle departures peaked at 10:00 a.m. on both weekdays and weekend days and holidays. On weekdays, a secondary peak occurred at 2:00 p.m.

#### **Willow Springs Road**

- Mean hourly vehicle arrivals and departures on Willow Springs Road first occurred starting at 7:00 a.m. and fluctuated at low levels throughout the day.
- Mean hourly vehicle arrivals and departures were slightly higher on weekend days and holidays than on weekdays.



**FIGURE 28. MEAN HOURLY VEHICLE ARRIVALS AND DEPARTURES, BY COUNTER LOCATION AND DAY OF WEEK CATEGORY**

### 3.4 GPS ROUTE TRACKING

This subsection of the report presents descriptive summaries of visitor groups' vehicle-based, parkwide travel routes and times based on analyses of the GPS tracking data. Additional analyses with the GPS data are reported in the section of the report regarding simulation modeling (Section 5.0).

#### Travel Routes

As noted, visitor groups' travel routes derived from the GPS tracking data were classified into one of four route profiles based on the number of the three study sites traveled to in the recorded routes. Figure 29 presents the distribution of private vehicle route profiles and Figure 30 presents the distribution of commercial vehicle route profiles measured via GPS tracking. These data suggest:

- Slightly more than one-third (36%) of private vehicle visitor groups traveled to all three study sites. In contrast, a small proportion (8%) of commercial vehicle visitor groups traveled to all three sites.
- Roughly one-third (32%) of private vehicle visitor groups traveled to two of the three study sites, while half (50%) of commercial vehicle visitor groups traveled to two of the three study sites.
- Roughly one-third (29%) of private vehicle visitor groups traveled to one of the three study sites, compared to 40% of commercial vehicle visitor groups.
- A very small proportion (4%) of private vehicle visitor groups and an even smaller proportion (2%) of commercial vehicle visitor groups did not travel to any of the three study sites.

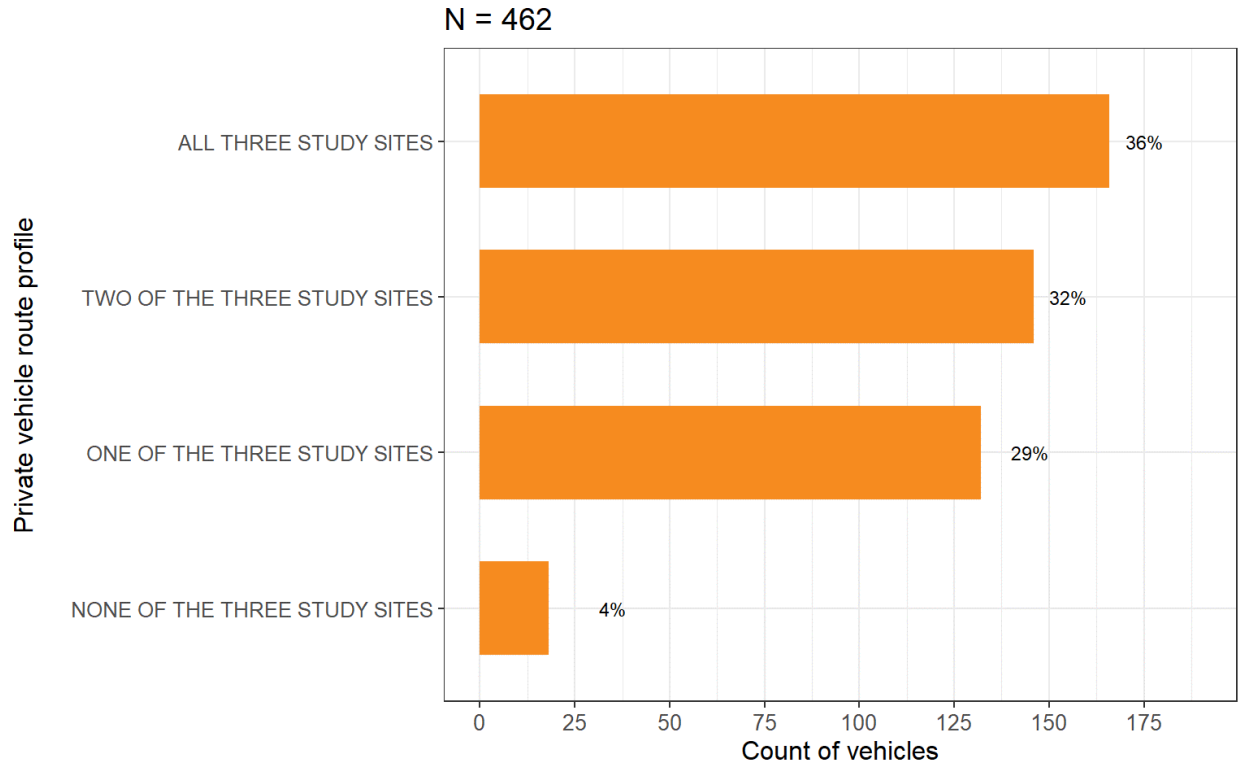


FIGURE 29. FREQUENCY DISTRIBUTION OF ROUTE PROFILES: PRIVATE VEHICLES

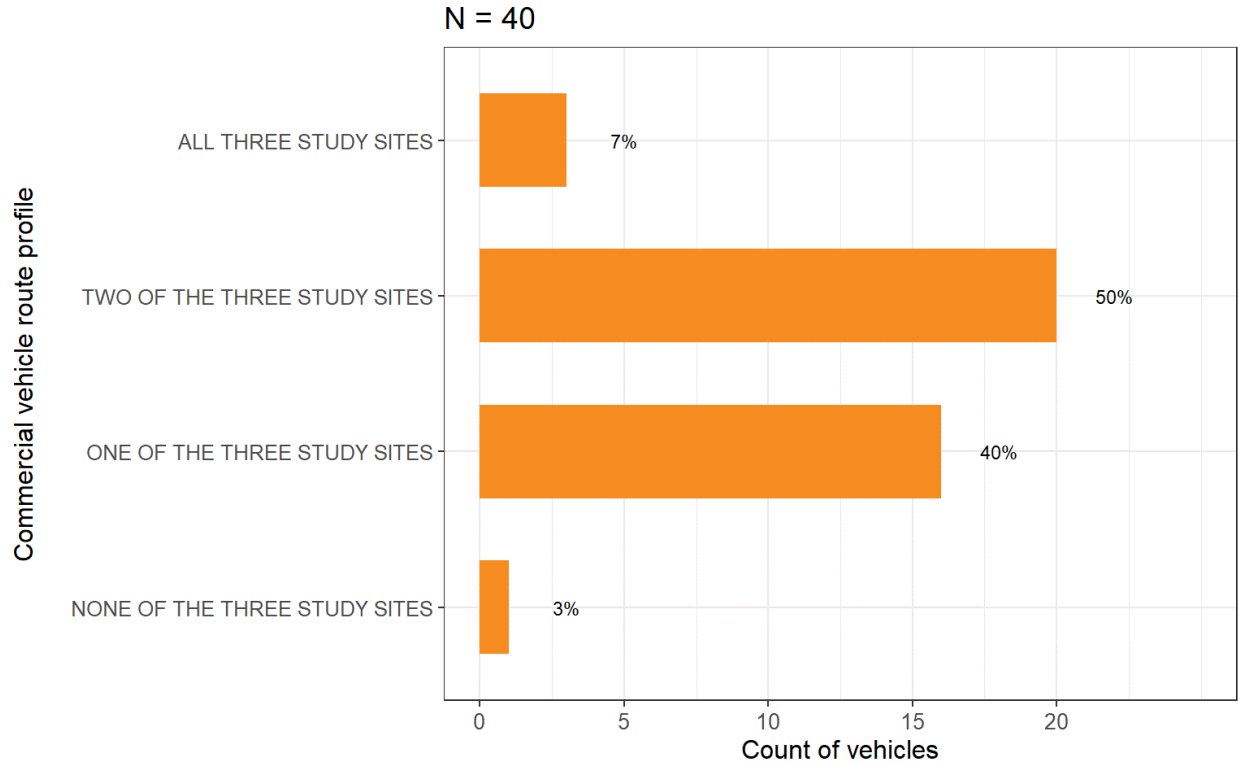


FIGURE 30. FREQUENCY DISTRIBUTION OF ROUTE PROFILES: COMMERCIAL VEHICLES

The travel routes of visitor groups who participated in the GPS tracking study are summarized in greater detail in Figure 31, Table 7, and Table 8. The results in Figure 31 illustrate a typology of 10 distinct route patterns that were observed within the GPS tracking data. Travel routes are summarized according to the study site(s) traveled to within a profile classification. Table 7 summarizes the distribution of travel routes by profile for private vehicle visitor groups. Table 8 summarizes the distribution of travel routes by profile for commercial vehicle visitor groups. These data suggest:

- The most common combinations of sites for private vehicle visitor groups that traveled to two of the three study sites were: The Windows and Delicate Arch (45%), and Delicate Arch and Devils Garden (37%).
- The most popular site for private vehicle visitor groups that traveled to only one study site was the Windows (42%), followed by Delicate Arch (31%), and Devils Garden (27%).
- The most common combination of sites for commercial vehicle visitor groups that traveled to two of the three study sites was, by far: The Windows and Delicate Arch (90%).
- The most popular site for commercial vehicle visitor groups that traveled to only one study site was, by far, the Windows (81%).
- No visitor groups that participated in the GPS tracking study traveled to Willow Springs Road.

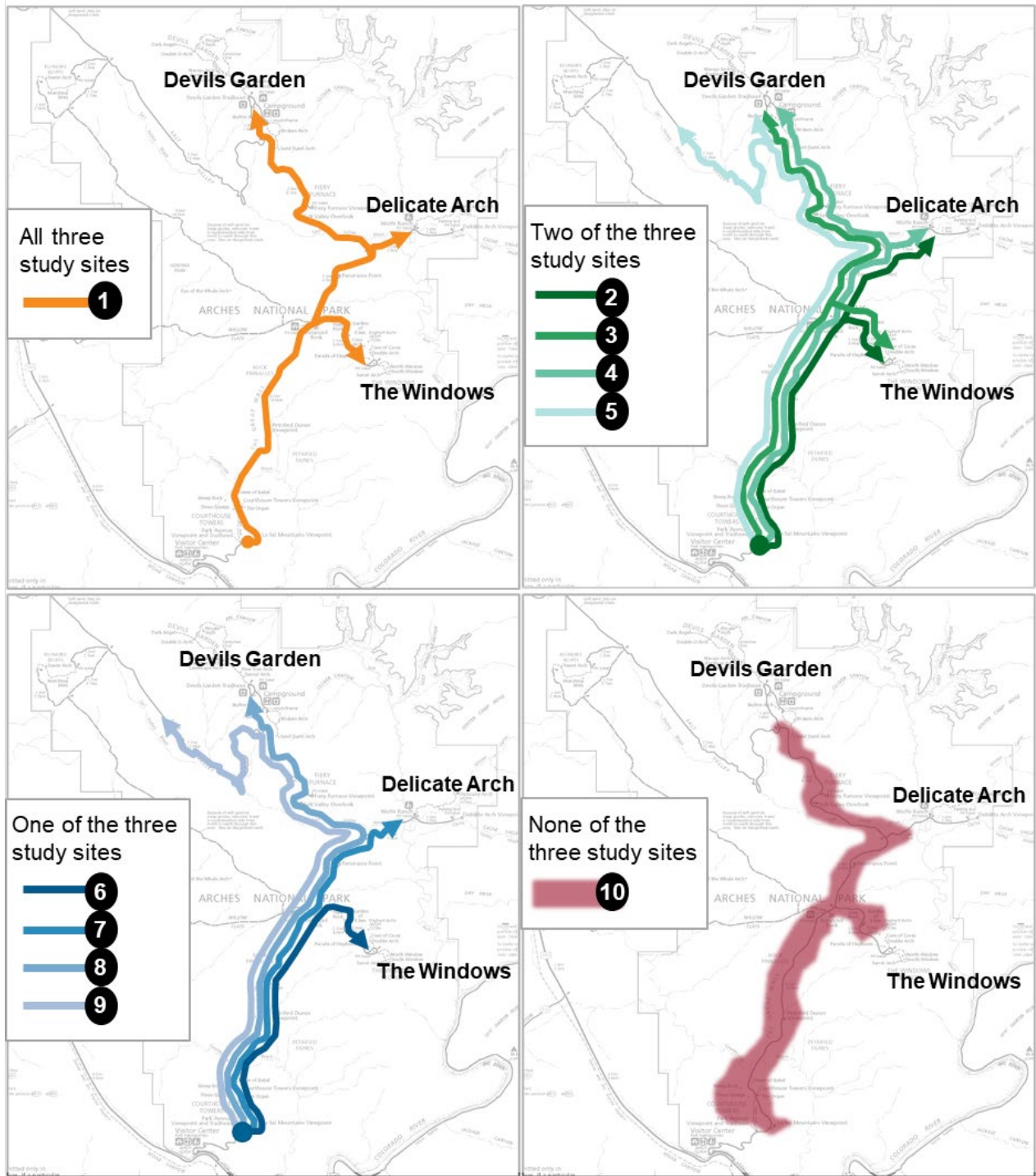


FIGURE 31. TYPOLOGY OF ROUTE PROFILES: PRIVATE AND COMMERCIAL VEHICLES (NUMBERS CORRESPOND TO DESCRIPTIONS IN TABLE 7 AND TABLE 8)<sup>15</sup>

<sup>15</sup> These are conceptual diagrams designed to illustrate combinations of the three most popular sites visited, if any, rather than complete routes from start to finish.

**TABLE 7. FREQUENCY DISTRIBUTION OF TRAVEL ROUTES, BY ROUTE PROFILE: PRIVATE VEHICLES**

PROFILE		STUDY SITE	COUNT	PERCENT
All three study sites	1.	THE WINDOWS, DELICATE ARCH, DEVILS GARDEN	166	36%
	2.	THE WINDOWS, DELICATE ARCH	65	14%
Two of the three study sites	3.	THE WINDOWS, DEVILS GARDEN	26	6%
	4.	DELICATE ARCH, DEVILS GARDEN	54	12%
	5.	DEVILS GARDEN, SALT VALLEY ROAD	1	<1%
One of the three study sites	6.	THE WINDOWS	56	12%
	7.	DELICATE ARCH	41	9%
	8.	DEVILS GARDEN	35	8%
None of the three sites	10.	NONE OF THE STUDY SITES	18	4%
<b>Total</b>			<b>462</b>	<b>100%</b>

**TABLE 8. FREQUENCY DISTRIBUTION OF TRAVEL ROUTES, BY ROUTE PROFILE: COMMERCIAL VEHICLES**

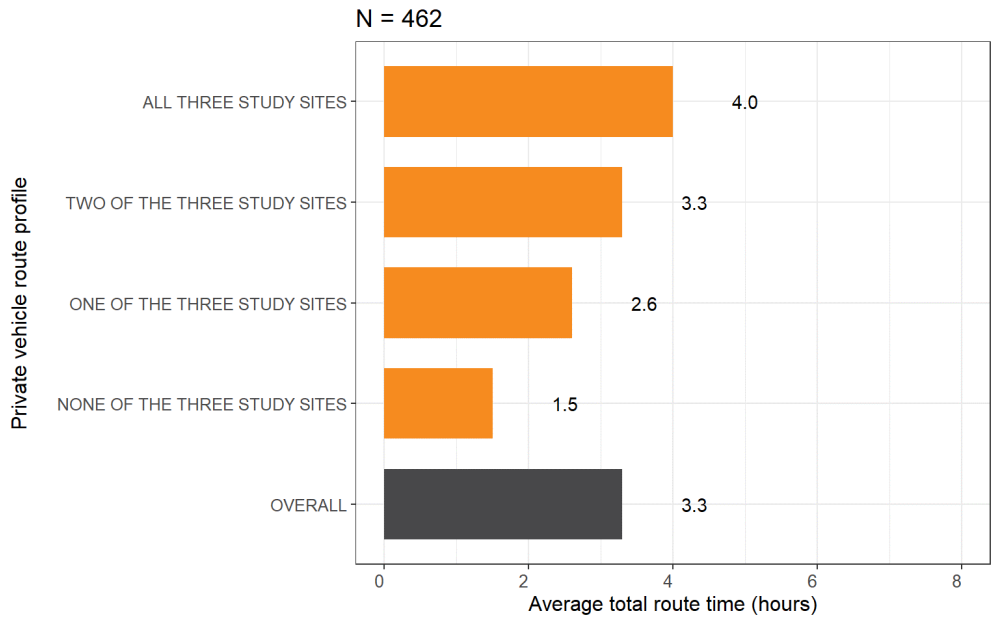
PROFILE		STUDY SITE	COUNT	PERCENT
All three study sites	1.	THE WINDOWS, DELICATE ARCH, DEVILS GARDEN	3	8%
	2.	THE WINDOWS, DELICATE ARCH	18	45%
Two of the three study sites	3.	THE WINDOWS, DEVILS GARDEN	1	2%
	4.	DELICATE ARCH, DEVILS GARDEN	1	2%
One of the three study sites	6.	THE WINDOWS	13	32%
	7.	DELICATE ARCH	1	2%
	8.	DEVILS GARDEN	1	2%
	9.	SALT VALLEY ROAD	1	2%
None of the three study sites	10.	NONE OF THE STUDY SITES	1	2%
<b>Total</b>			<b>40</b>	<b>100%</b>

## Total Trip Times

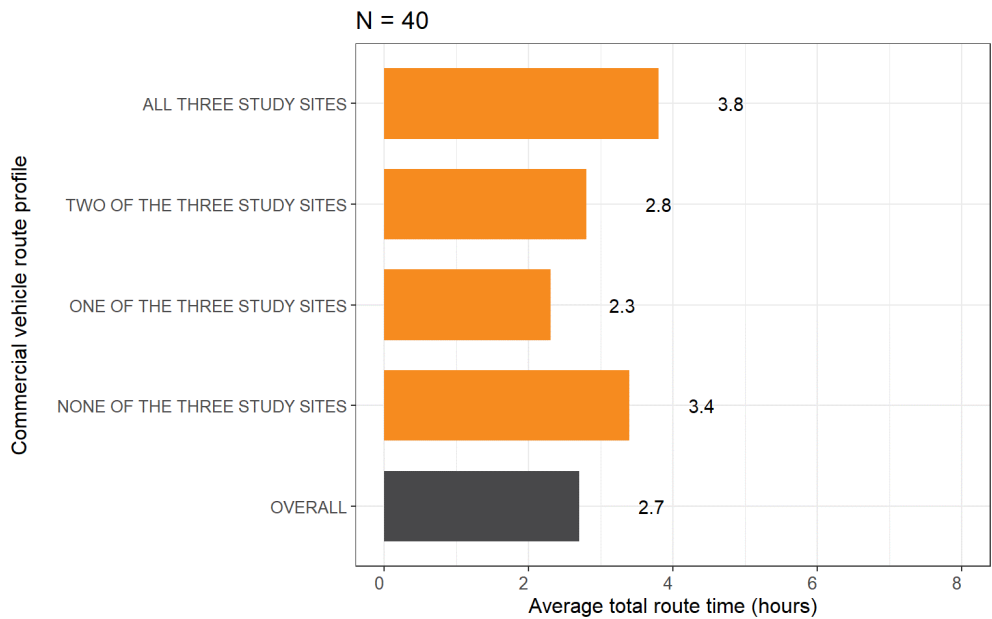
Figure 32 and Figure 33 present mean total trip time in ARCH, by route profile and vehicle type, of visitor groups who participated in the GPS tracking study. These data suggest:

- The mean total trip time in the park for private vehicle visitor groups that traveled to all three study sites was four hours.
- Private vehicle visitor groups that traveled to two of the three study sites spent on average, just over three hours on their trip in the park, while groups that traveled to only one of the three study sites spent just over 2.5 hours in the park.
- The mean total trip time for private vehicle visitor groups that did not travel to the three study sites of interest was approximately 1.5 hours.
- Overall, the average total trip time in the park for private vehicle visitor groups, regardless of route profile, was 3.3 hours.
- The mean total trip time in the park for commercial vehicle visitor groups that traveled to all three study sites was approximately four hours.

- Commercial vehicle visitor groups that traveled to two of the three study sites spent on average, approximately three hours on their trip in the park, while groups that traveled to only one site spent just over two hours in the park.
- Overall, the average total trip time in the park for commercial vehicle visitor groups, regardless of route profile, was 2.7 hours.



**FIGURE 32. MEAN TOTAL TRAVEL TIME, BY ROUTE PROFILE AND OVERALL: PRIVATE VEHICLES**



**FIGURE 33. MEAN TOTAL TRAVEL TIME, BY ROUTE PROFILE AND OVERALL, COMMERCIAL VEHICLES**

Table 9 and Table 10 present the distribution of total trip times by vehicle type of visitor groups who participated in the GPS tracking study. These data suggest:

- The majority (78%) of private vehicle visitor groups spent between one and five hours in the park.
- Of the private vehicle visitor groups that traveled to all three study sites, 90% spent two hours or more in the park.
- Private vehicle visitor groups that traveled to none of the study sites had the shortest total trip times, with 67% spending less than one hour in the park.
- The vast majority (92%) of commercial vehicle visitor groups spent between one and four hours in the park.
- Of the commercial vehicle visitor groups that traveled to all three study sites, 100% spent between three and five hours in the park.

**TABLE 9. FREQUENCY DISTRIBUTION OF TOTAL TRIP TIMES: PRIVATE VEHICLES**

TOTAL TIME	ALL THREE STUDY SITES (N = 166)	TWO OF THE THREE STUDY SITES (N = 146)	ONLY ONE STUDY SITE (N = 132)	NONE OF THE STUDY SITES (N = 18)	OVERALL (N = 462)
<1 hour	0%	1%	8%	67%	5%
1 to < 2 hours	10%	27%	38%	6%	23%
2 to < 3 hours	30%	24%	24%	6%	25%
3 to < 4 hours	17%	16%	12%	11%	15%
4 to < 5 hours	18%	18%	8%	6%	15%
5 to < 6 hours	8%	8%	7%	6%	8%
6+ hours	17%	5%	2%	0%	8%
<b>Total</b>	<b>100%</b>	<b>99%</b>	<b>99%</b>	<b>102%</b>	<b>100%</b>

**TABLE 10. FREQUENCY DISTRIBUTION OF TOTAL TRIP TIMES: COMMERCIAL VEHICLES**

TOTAL TIME	ALL THREE STUDY SITES (N = 3)	TWO OF THE THREE STUDY SITES (N = 20)	ONLY ONE STUDY SITE (N = 16)	NONE OF THE STUDY SITES (N = 1)	OVERALL (N = 40)
1 to < 2 hours	0%	5%	50%	0%	22%
2 to < 3 hours	0%	65%	31%	0%	45%
3 to < 4 hours	67%	25%	12%	100%	25%
4 to < 5 hours	33%	5%	6%	0%	8%
<b>Total</b>	<b>100%</b>	<b>100%</b>	<b>99%</b>	<b>100%</b>	<b>100%</b>

## Site Dwell Times

Figure 34 presents the mean and distribution of GPS-based dwell times by vehicle type and study site for sites visited.<sup>16</sup> These data suggest:

### *The Windows*

- Private vehicle visitor groups who traveled to the Windows spent an average of 40.5 minutes at the site. Commercial vehicle visitor groups who traveled to the Windows spent an average of 59.4 minutes at the site, roughly 47% longer than private vehicle visitor groups.
- About one-third (33%) of private vehicle visitor groups spent less than 20 minutes at the Windows, while only 3% of commercial vehicle visitor groups spent less than 20 minutes at the Windows. Just over one-third (37%) of commercial vehicle visitor groups spent between 40 and 59 minutes at the Windows.

### *Delicate Arch*<sup>17</sup>

- Private vehicle visitor groups who traveled to Delicate Arch spent an average of 71.5 minutes at the site. Commercial vehicle visitor groups who traveled to Delicate Arch spent an average of 31.4 minutes at the site, roughly 56% less time than private vehicle visitor groups.
- The majority (54%) of private vehicle visitor groups spent less than 40 minutes at the site, while the vast majority (85%) of commercial vehicle visitor groups spent less than 40 minutes at the site.

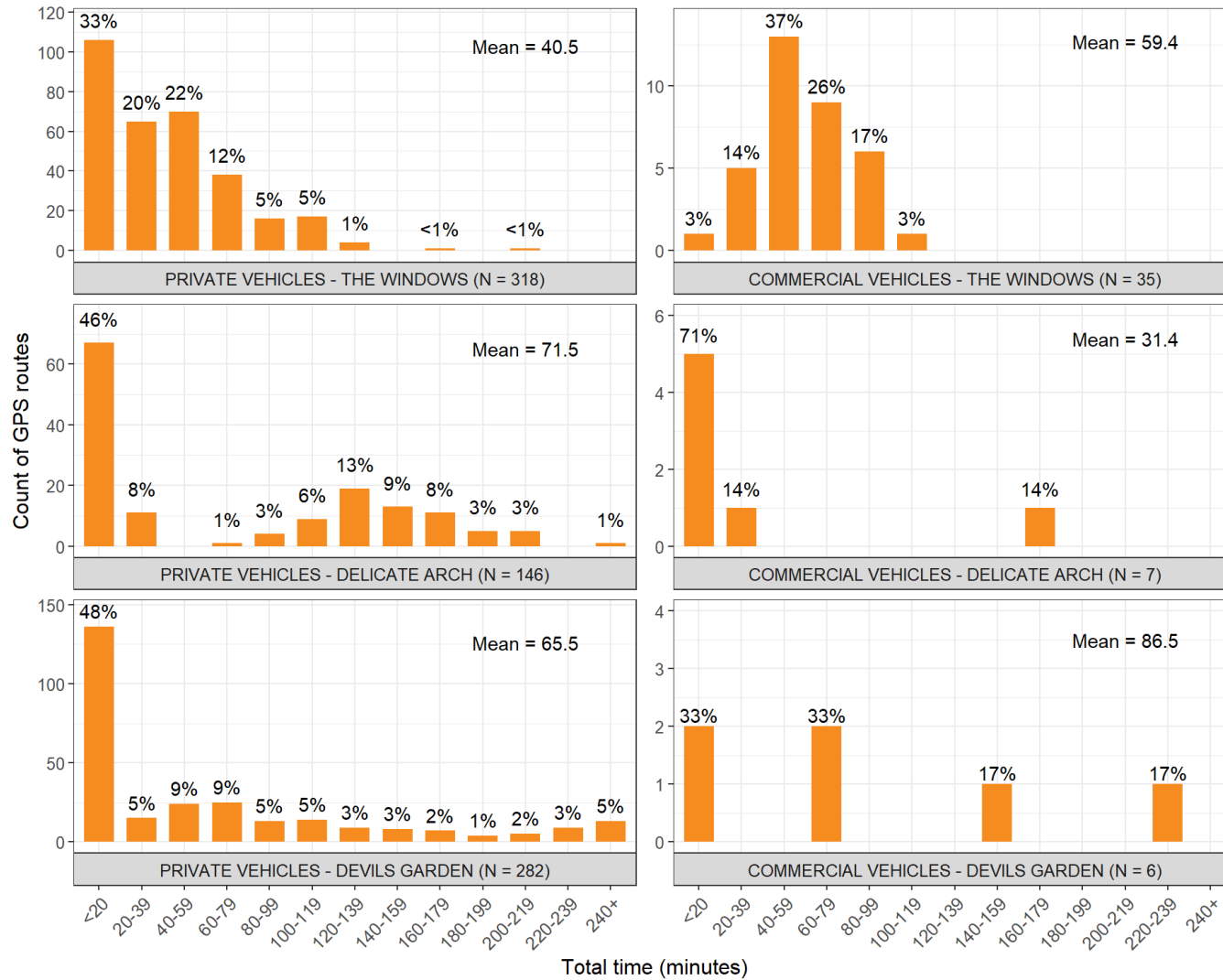
### *Devils Garden*

- Private vehicle visitor groups who traveled to Devils Garden spent an average of 65.5 minutes at the site. Commercial vehicle visitor groups who traveled to Devils Garden spent an average of 86.5 minutes at the site, roughly 32% longer than private vehicle visitor groups.
- The majority (53%) of private vehicle visitor groups spent less than 40 minutes at the site, while two-thirds (66%) of commercial vehicle visitor groups spent less than 80 minutes at the site.

<sup>16</sup> Results reflect dwell time and travel patterns measured during the GPS sampling period and hours of the day. The results do not represent visitor travel patterns for groups who enter the park and pass the GPS administration location prior to 8:00 a.m. or after 4:00 p.m.

<sup>17</sup> All calculated dwell times of less than one minute were classified as a travel time along the road through Delicate Arch on the way to Delicate Arch Viewpoint and are not reported as dwell times.

# Arches National Park



**FIGURE 34. FREQUENCY DISTRIBUTION OF GPS-BASED DWELL TIMES, BY STUDY SITE AND VEHICLE TYPE<sup>18</sup>**

<sup>18</sup> The Y-axis scale varies by location to account for differences in the overall scale of GPS-based dwell times calculated for each location.

## 3.5 PARKING LOT ACCUMULATION AND TURNOVER ANALYSIS AND RESULTS

### Parking Accumulation

Figure 35 displays the hourly parking accumulation by date for all four parking lots during the sampling period. The horizontal lines in Figure 35 represent the designated capacity (i.e., total number of striped parking spaces) of each parking lot. These data suggest:

- Parking areas at all three study sites were at least partially full on all days when parking accumulation data collection began at 9:00 a.m. Hourly parking accumulation in the Windows, Devils Garden, and Delicate Arch parking lots exceeded designated capacities on several occasions during the sampling period.
- Hourly parking accumulation at the Windows was generally at or above designated capacity on weekend days and holidays from about 10:00 a.m. 2:00 p.m.; the only exception was on one date when the entrance station was closed for a period of time to manage congestion in the park. On weekdays, hourly parking accumulation was near or above capacity for multiple hours on two of the three sampling days.
- Hourly parking accumulation at Delicate Arch was near or above the designated capacity of the main and overflow lots at the start of each sampling day on weekend days and holidays. It stayed near or above capacity through 11:00 a.m. on all but one weekend/holiday sampling day, and then declined through the afternoon hours. On weekdays, there were approximately 100 vehicles parked at Delicate Arch at the start of each sampling day and hourly parking accumulation declined throughout the remainder of the morning and afternoon sampling hours.
- Hourly parking accumulation never exceeded the designated capacity of the Delicate Arch Overlook parking lot during the sampling period.
- Hourly parking accumulation at Devils Garden reached or exceeded the designated capacity parking during the morning hours of each sampling day on weekend days and holidays. However, hourly parking accumulation never exceeded designated capacity at Devils Garden in the afternoon on weekend days and holidays during the sampling period. Hourly parking accumulation exceeded designated capacity at Devils Garden from 10:00 a.m. to 2:00 p.m. on one weekday sampling day and reached capacity during the midday of another weekday sampling day. Hourly parking accumulation was otherwise below the designated capacity at Devils Garden on weekdays during the sampling period.

Arches National Park

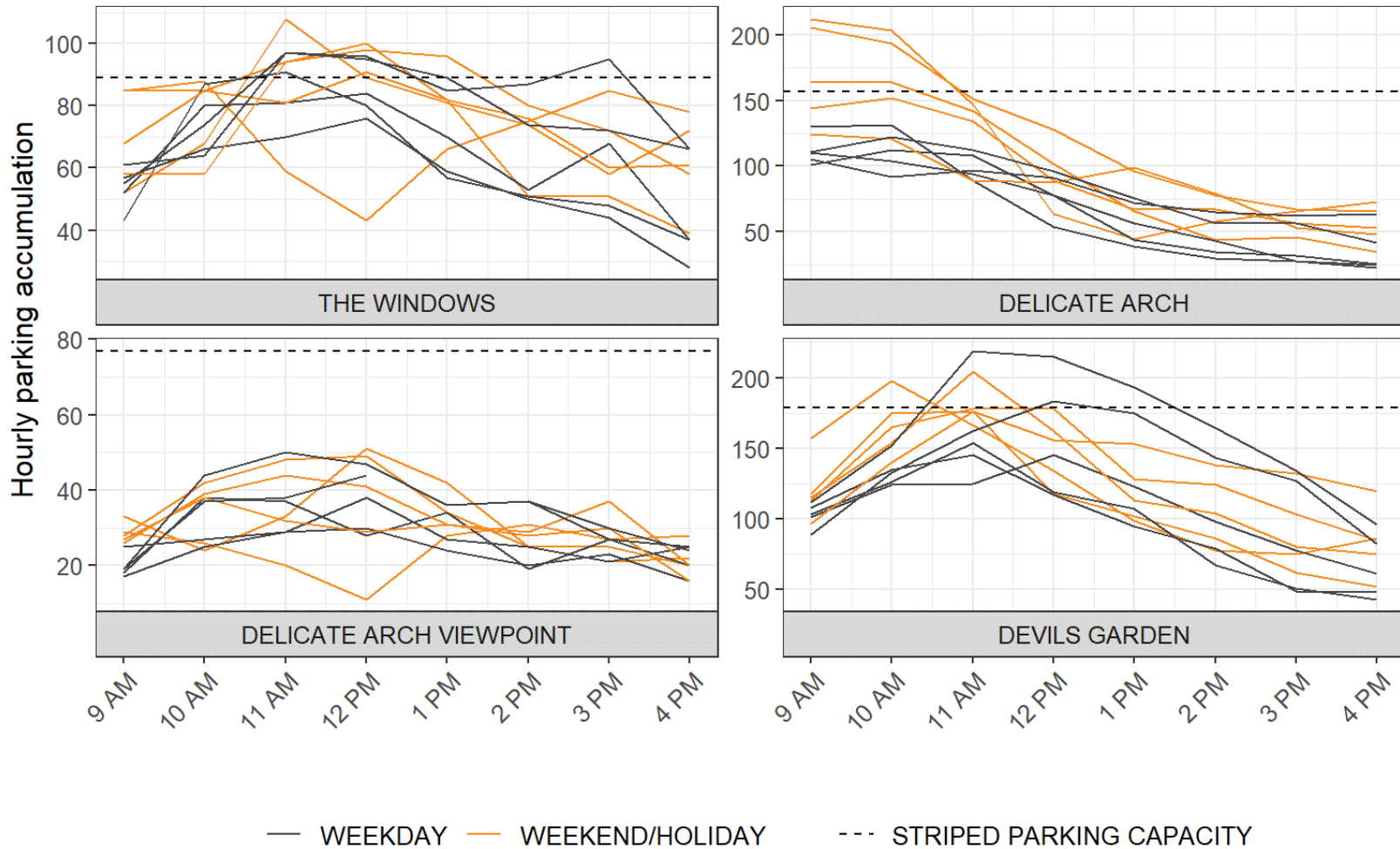


FIGURE 35. HOURLY PARKING ACCUMULATION, BY LOCATION, SAMPLING DAY, AND DAY OF WEEK CATEGORY<sup>19,20</sup>

<sup>19</sup> Vehicles were stopped from entering the park from 9:30 a.m. to approximately 11:30 a.m. on 09/01/2019 to manage congestion in the park.

<sup>20</sup> The Y-axis scale varies by location to account for differences in the overall scale of parking accumulation at each location.

Figure 36 displays average hourly parking accumulation by location across the sampling period. As in Figure 35, the horizontal lines in Figure 36 represent the designated capacity of each parking lot. These data suggest:

- Average hourly parking accumulation in the Windows parking lot increased during the morning hours to peaks at 11:00 a.m. on weekdays and on weekend days and holidays. Average hourly parking accumulation remained near its peak level through 12:00 p.m. and then decreased throughout the afternoon on weekdays and on weekend days and holidays.
- Average hourly parking accumulation at Delicate Arch was greater throughout the day on weekend days and holidays than on weekdays. On weekend days and holidays, average hourly parking accumulation was above the designated capacity of the main and overflow lots and then declined steadily through the remainder of the sampling hours. Average hourly parking accumulation on weekdays never exceeded the designated capacity of the Delicate Arch main and overflow parking lots and declined from about 100 vehicles at 9:00 a.m. and 10:00 a.m. steadily through morning and afternoon sampling hours.
- On weekdays and on weekend days and holidays, average hourly parking accumulation in the Delicate Arch Viewpoint parking lot peaked well below the designated capacity at 12:00 p.m. and then decreased slightly through the remainder of the afternoon.
- Average hourly parking accumulation in the Devils Garden parking lot increased during the morning hours to peaks at 11:00 a.m. on weekdays and on weekend days and holidays. The peak average hourly accumulation was below the designated parking capacity on weekdays but reached capacity on weekend days and holidays. Average hourly parking accumulation declined consistently from the peaks throughout the afternoon on weekdays and on weekend days and holidays.
- There was an average of more than 100 vehicles parked at Delicate Arch and at Devils Garden on weekdays and on weekend days and holidays at 9:00 a.m. when data collection started.

Arches National Park

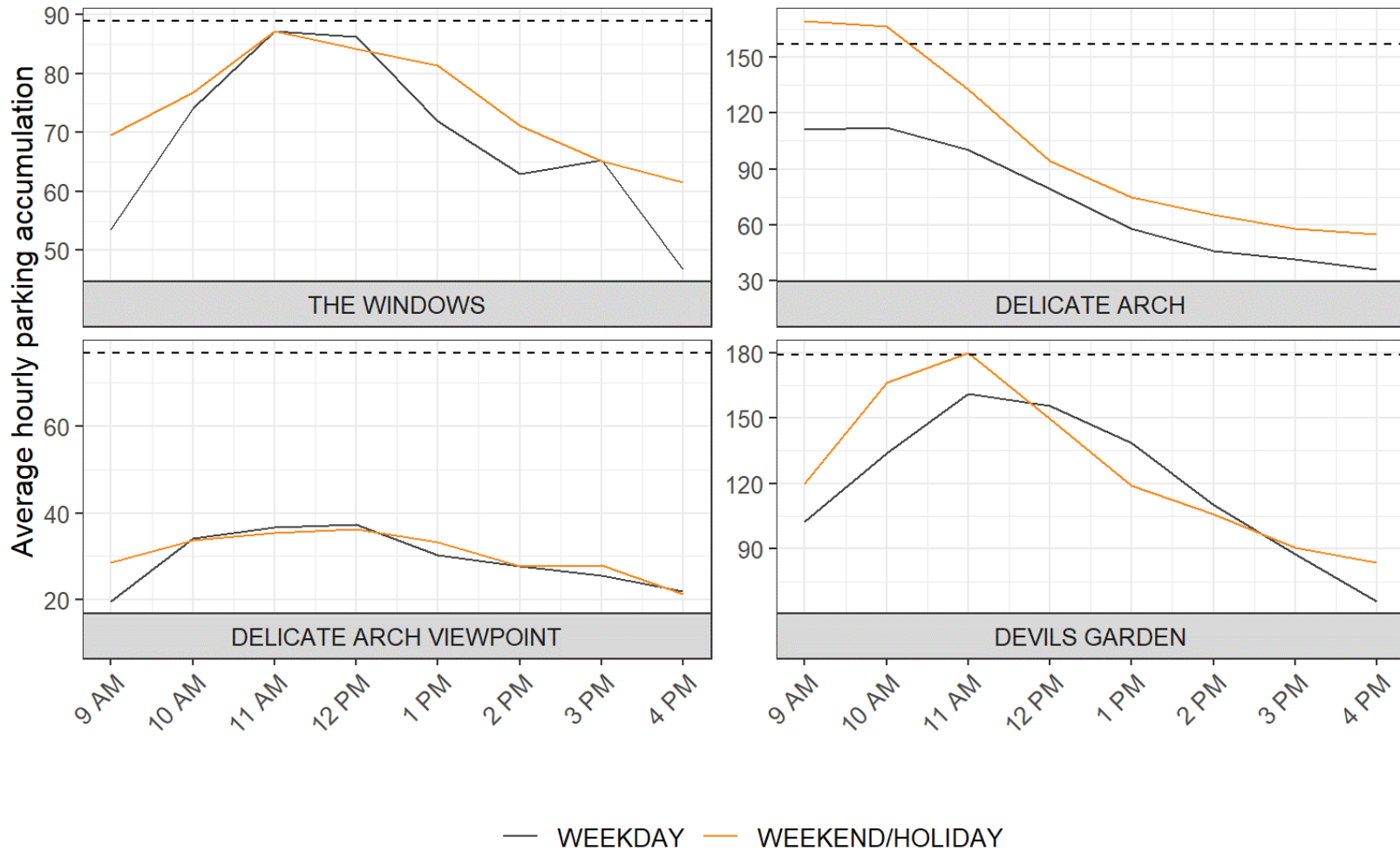


FIGURE 36. HOURLY AVERAGE PARKING ACCUMULATION, BY LOCATION AND DAY OF WEEK CATEGORY<sup>21</sup>

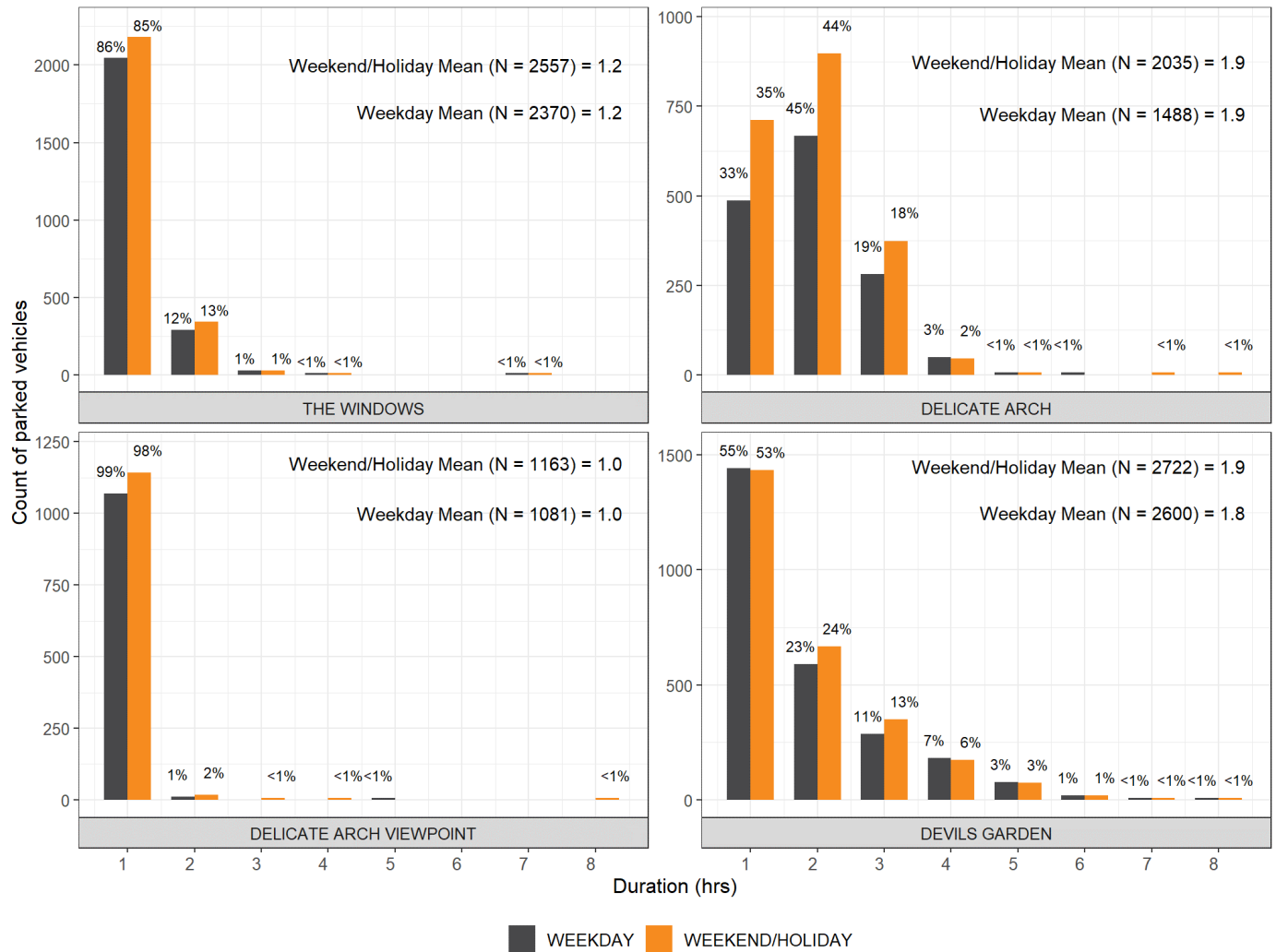
<sup>21</sup> The Y-axis scale varies by location to account for differences in the overall scale of parking accumulation at each location.

## Parking Duration

Figure 37 reports parking turnover rates (i.e., the duration of time vehicles were parked in the respective parking lots) estimated in hourly bins, with a minimum duration of one hour or less. These data suggest:

- On average, vehicles were parked in the Windows parking lot for just over one hour. The vast majority (86% on weekdays and 85% on weekend days and holidays) of vehicles spent one hour or less in the Windows parking lot. Average parking duration did not differ significantly between weekend days and holidays and weekdays ( $t=-0.712$ ,  $p=0.476$ ).
- On average, vehicles were parked at Delicate Arch for approximately two hours. Average parking duration did not differ significantly between weekend days and holidays and weekdays ( $t=-1.577$ ,  $p=0.115$ ).
- On average, vehicles were parked in the Delicate Arch Viewpoint parking lot for approximately one hour or less. Nearly all (99% on weekdays and 98% on weekend days and holidays) vehicles remained in the parking lot for one hour or less. Average parking duration did not differ significantly between weekend days and holidays and weekdays ( $t=-1.320$ ,  $p=0.187$ ).
- On average, vehicles were parked in the Devils Garden parking lot for approximately two hours. Average parking duration did not differ significantly between weekend days and holidays and weekdays ( $t=-0.867$ ,  $p=0.386$ ).

# Arches National Park



**FIGURE 37. AVERAGE AND FREQUENCY DISTRIBUTION OF PARKING DURATION, BY LOCATION AND DAY OF WEEK CATEGORY<sup>22,23</sup>**

<sup>22</sup> Means should be interpreted with caution, since parking turnover times were recorded in hourly bins rather than to the minute.

<sup>23</sup> The Y-axis scale varies by location to account for differences in the overall scale of parking accumulation at each location.

## 3.6 VISITOR USE COUNTS

### Calibration

Regression analyses were conducted to model the relationship between raw mechanical trail counter data and the calibration counts collected via direct observation during the sampling period. This was done to derive an empirical basis to convert raw trail counter data to estimates of actual visitor use. Separate regression models were estimated for each counter, with direct observation counts of visitor use as the dependent variable and corresponding TRAFx infrared trail counter data as the independent variable in each model, to estimate correction factors for the infrared trail counter data.<sup>24,25</sup> Regression results suggest that there are strong statistical relationships between the direct observation counts and visitor use counts recorded by the infrared trail counters.

- Regression models with no intercept terms were the best fitting regression models for all four trail counters, and were the models used to calibrate trail counter data.
- Adjusted R<sup>2</sup> values range from 0.98 to 0.99.
- Coefficients ranged from 1.01 to 1.24.
- The p-values for all three regression models were less than 0.01.

These results provide a high degree of confidence that applying the correction factors to calibrate the visitor use counts recorded with the infrared trail counters (i.e., multiplying the infrared trail counter data by the corresponding parameter estimates from the regression models) results in accurate estimates of visitor use at each trail counter. The calibrated trail counter data were used for analysis and results reported in this report.

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<sup>24</sup> Delicate Arch calibration regression excludes unusually high TRAFx event counts from 1:00 – 4:00 p.m. on September 9, 2019 that we attribute to disturbance from high winds.

<sup>25</sup> The Delicate Arch Viewpoint counter was calibrated using a limited number of data points (n=3) due device malfunction.

## Visitor Arrivals and Departures

This subsection of the report summarizes visitor arrivals and departures, by trail counter location. Daily visitor arrivals and departures were calculated by dividing the total visitor counter per day by two, since each study site is a day use area. Hourly visitor arrivals and departures were estimated based on the mean hourly proportion of arrivals and departures derived from the calibration counts recorded by RSG. The following summaries of visitor use counts are presented in the subsections below:

- Daily visitor arrivals, by trail counter location and date during the counting period.
- Hourly visitor volumes (arrivals and departures combined), by trail counter location and date during the counting period.
- Mean hourly visitor arrivals, by trail counter location and day of week category during the sampling period.
- Mean hourly visitor arrivals and departures, by trail counter location and day of week category during the sampling period.

### Daily Visitor Arrivals

Figure 38 presents daily visitor arrivals, by trail counter location and date during the counting period. All days with five or more hours of missing data or outlier values are excluded from the daily summaries. All days with four or fewer hours of missing data or outlier values are included in daily summaries using imputed values as needed<sup>26</sup>. For hourly summaries, days with five or more outlier values are excluded. Otherwise, all days are included in hourly summaries, with missing data or outlier values excluded (i.e., no imputed values were estimated for hourly summaries). Missing values are due to a combination of equipment malfunction and theft of equipment.

In general, there do not appear to be consistent differences in daily visitor arrivals on weekend days and holidays compared to that on weekdays, at any of the counter locations. Further, these data suggest:

#### *The Windows*

- Daily visitor arrivals at the Windows were variable during the counting period, ranging from a low of about 500 visitors to as many as 2,000 visitors.
- The highest use days at the Windows tended to occur on weekend days and holidays. That said, daily visitor arrivals were fairly consistently between 1,000 and 2,000 visitors per day, regardless of the day of week, through most of the counting period.
- There were more than 1,000 visitor arrivals per day at the Windows on a majority of days during the counting period.

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<sup>26</sup> Imputed values were calculated as the average of all calibrated counts by counter location, hour, and day of week category.

### ***Delicate Arch***

- Daily visitor arrivals at Delicate Arch were variable during the counting period, ranging from a low of about 500 visitors to as many as over 3,000 visitors.
- The highest use days at Delicate Arch tended to occur on weekend days and holidays throughout the counting period.
- There were 1,000 visitor arrivals or more per day at Delicate Arch on the majority of days during the counting period.

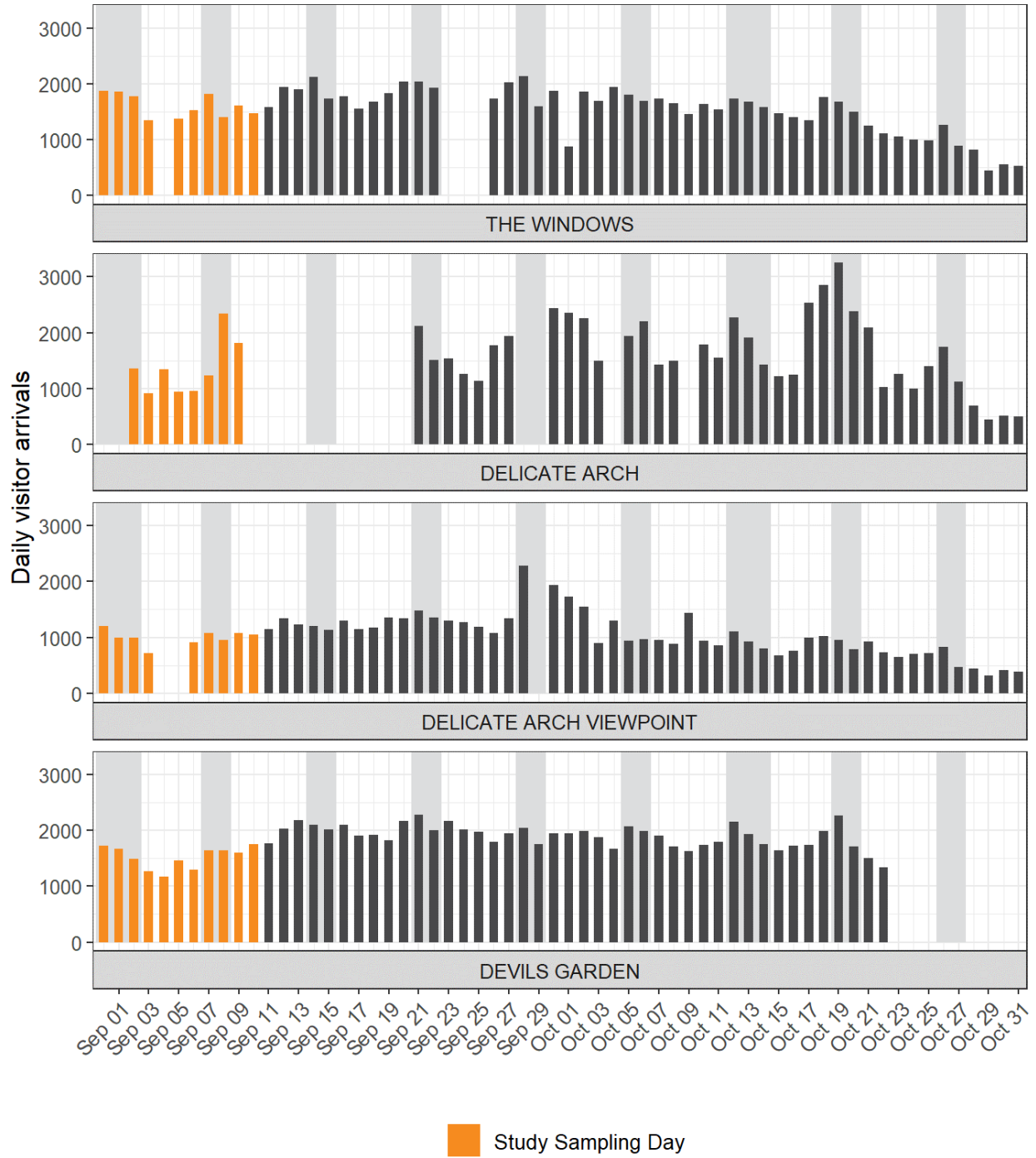
### ***Delicate Arch Viewpoint***

- Daily visitor arrivals at Delicate Arch Viewpoint were variable during the counting period, ranging from a low of less than 500 visitors to as many as just over 2,000 visitors.
- Daily visitor arrivals generally ranged between 1,000 and 1,500 visitors during the counting period.

### ***Devils Garden***

- Daily visitor arrivals at Devils Garden was consistently between about 1,500 and 2,000 visitors throughout the counting period. The lowest use days occurred during the weekdays of the sampling period, with daily visitor arrivals of about 1,000 to 1,500 visitors.
- Daily visitor arrivals tended to be slightly higher on weekend days and holidays than on weekdays during the counting period, but the differences were not pronounced.

# Arches National Park



**FIGURE 38. DAILY VISITOR ARRIVALS, BY TRAIL COUNTER LOCATION AND DATE (GRAY SHADING INDICATES WEEKENDS/HOLIDAYS)**

## Hourly Visitor Use Volumes

Figure 39 displays hourly visitor use volumes (arrivals and departures combined) by trail counter location and date during the counting period. The plots with continuous lines across dates in Figure 39 provide a “macro view” of hourly patterns of visitor use across the days of the counting period. These data suggest:

### ***The Windows***

- Peak hourly visitor use volumes at the Windows typically ranged between just under 300 total visitors to just over 400 total visitors during the counting period. On a few days, peak hourly visitor use volumes exceeded 500 total visitors.
- The highest hourly volumes of visitor use at the Windows tended to occur on or near weekend days and holidays, though weekdays were consistently close in volume to weekend days and holidays.
- Visitor use volumes trended downward to some degree later in the counting period.

### ***Delicate Arch***

- Peak hourly visitor use volumes at Delicate Arch were variable during the counting period, ranging from around 250 total visitors to over 625 total visitors.
- On a few days during the counting period, peak hourly visitor use volumes exceeded 750 total visitors.
- The highest hourly volumes of visitor use at Delicate Arch tended to occur on or near weekend days and holidays, though weekdays were consistently close in volume to weekend days and holidays.

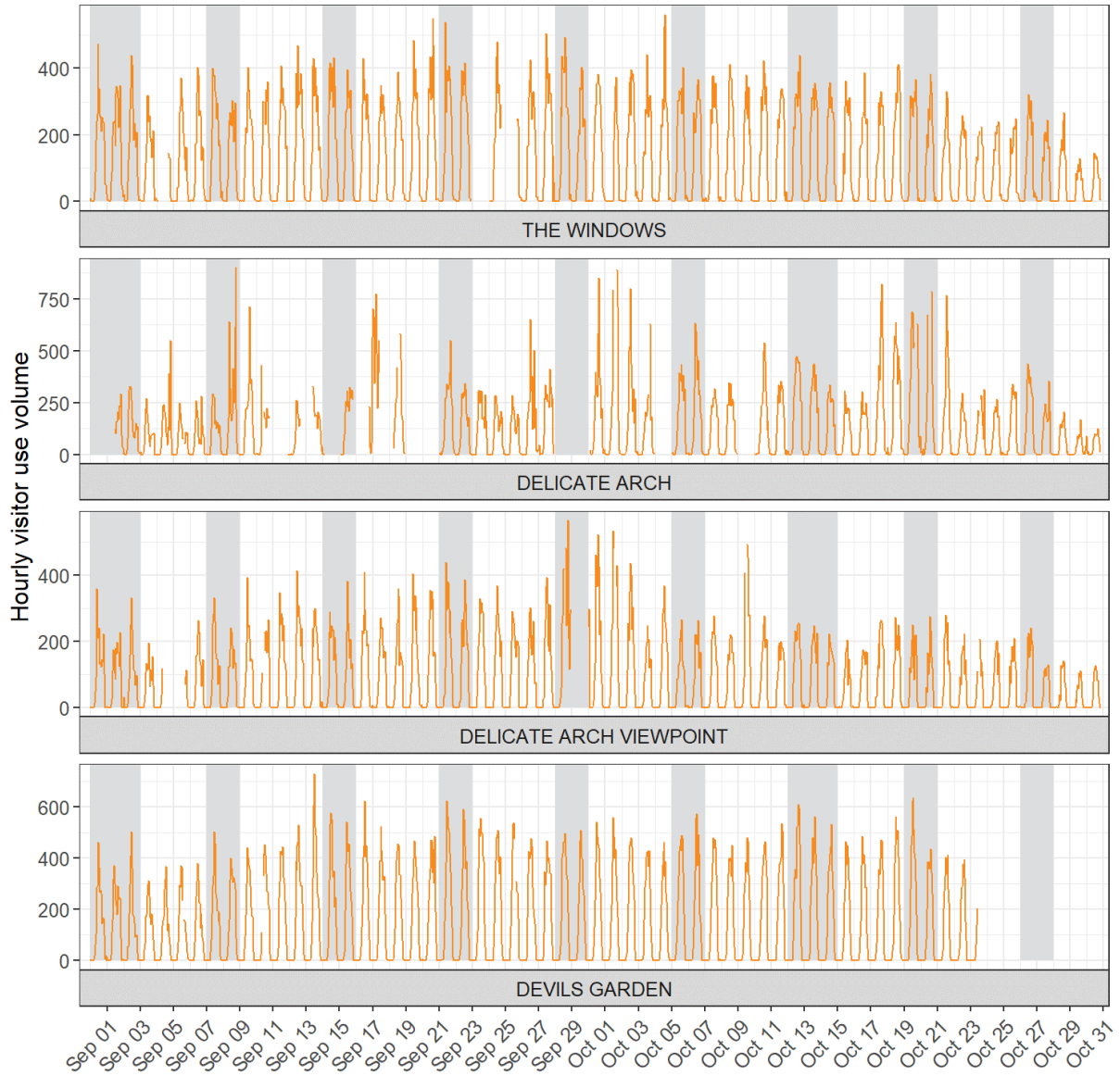
### ***Delicate Arch Viewpoint***

- Peak hourly visitor use volumes at Delicate Arch Viewpoint typically ranged between 250 total visitors to just over 375 total visitors during the counting period.
- On a few days, peak hourly visitor use volumes exceeded 450 total visitors.

### ***Devils Garden***

- Peak hourly visitor use volumes at Devils Garden typically ranged between just under 400 total visitors to just over 600 total visitors during the counting period.
- On a few days, peak hourly visitor use volumes exceeded 600 total visitors.
- The highest hourly volumes of visitor use at Devils Garden tended to occur on or near weekend days and holidays.

# Arches National Park



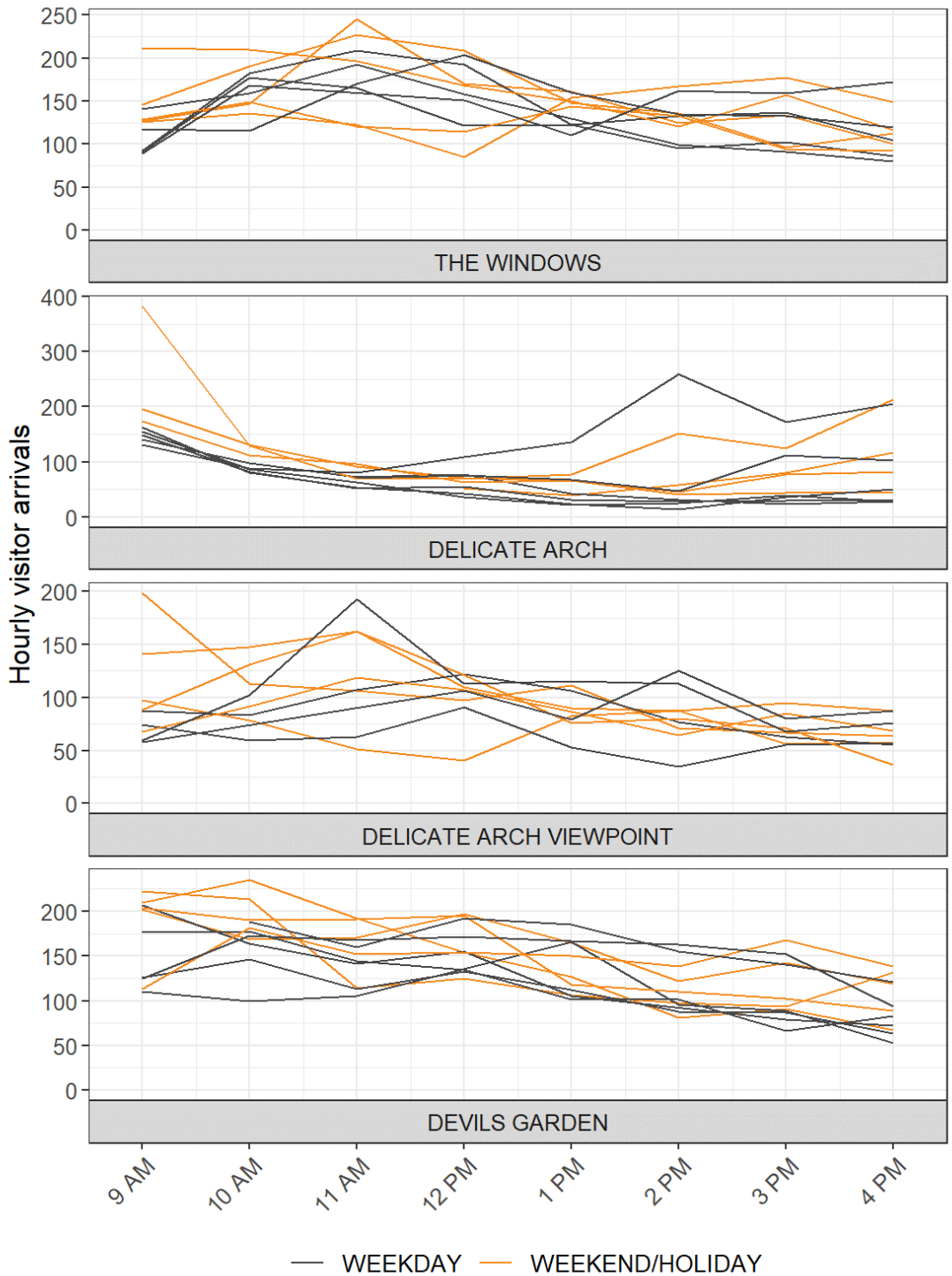
**FIGURE 39. HOURLY VISITOR USE VOLUME (ARRIVALS AND DEPARTURES), BY TRAIL COUNTER LOCATION AND DATE (GRAY SHADING INDICATES WEEKENDS/HOLIDAYS)<sup>27</sup>**

<sup>27</sup> The Y-axis scale varies by location to account for differences in the overall scale of visitor use at each location.

Figure 40 displays hourly visitor arrivals, by trail counter location and date during the sampling period in a complementary format to the plots in Figure 39 (separate lines, rather than a single continuous line, for each date displayed in the plot). Plots in Figure 40 provide a “micro view” of hourly patterns of visitor arrivals across the hours of each day of the sampling period when direct observation counts, including direction of travel, were also conducted at the trail counters. These data suggest:

- No discernable differences exist in hourly visitor arrivals on weekdays compared to weekend days and holidays at any of the counter locations.
- Hourly visitor arrivals at the Windows generally peaked around 11:00 a.m. at 250 or fewer visitors. Hourly visitor arrivals generally declined slightly or stayed flat through the afternoon hours.
- Hourly visitor arrivals at Delicate Arch was generally highest early in the morning and late in the afternoon, with hourly peaks of about 200 visitors and a maximum hourly peak of 383 visitors. Hourly visitor arrivals at Delicate Arch were relatively low during the midday hours.
- Hourly visitor arrivals at the Delicate Arch Viewpoint ranged from lows around 25 to 50 visitors to a high of 200 visitors. Generally, hourly visitor arrivals were between 75 and 125 visitors. Hourly visitor arrivals were fairly consistent across the hours of the day, with a slight decline later in the afternoon.
- Hourly visitor arrivals at Devils Garden were generally somewhat higher in the morning and had a slight downward trend through the late morning and afternoon hours. Hourly visitor arrivals were consistently between approximately 100 and 200 visitors from 9:00 a.m. to 2:00 p.m. throughout the sampling period.

Arches National Park



**FIGURE 40. HOURLY VISITOR ARRIVALS, BY TRAIL COUNTER LOCATION, SAMPLING DAY, AND DAY OF WEEK CATEGORY<sup>28</sup>**

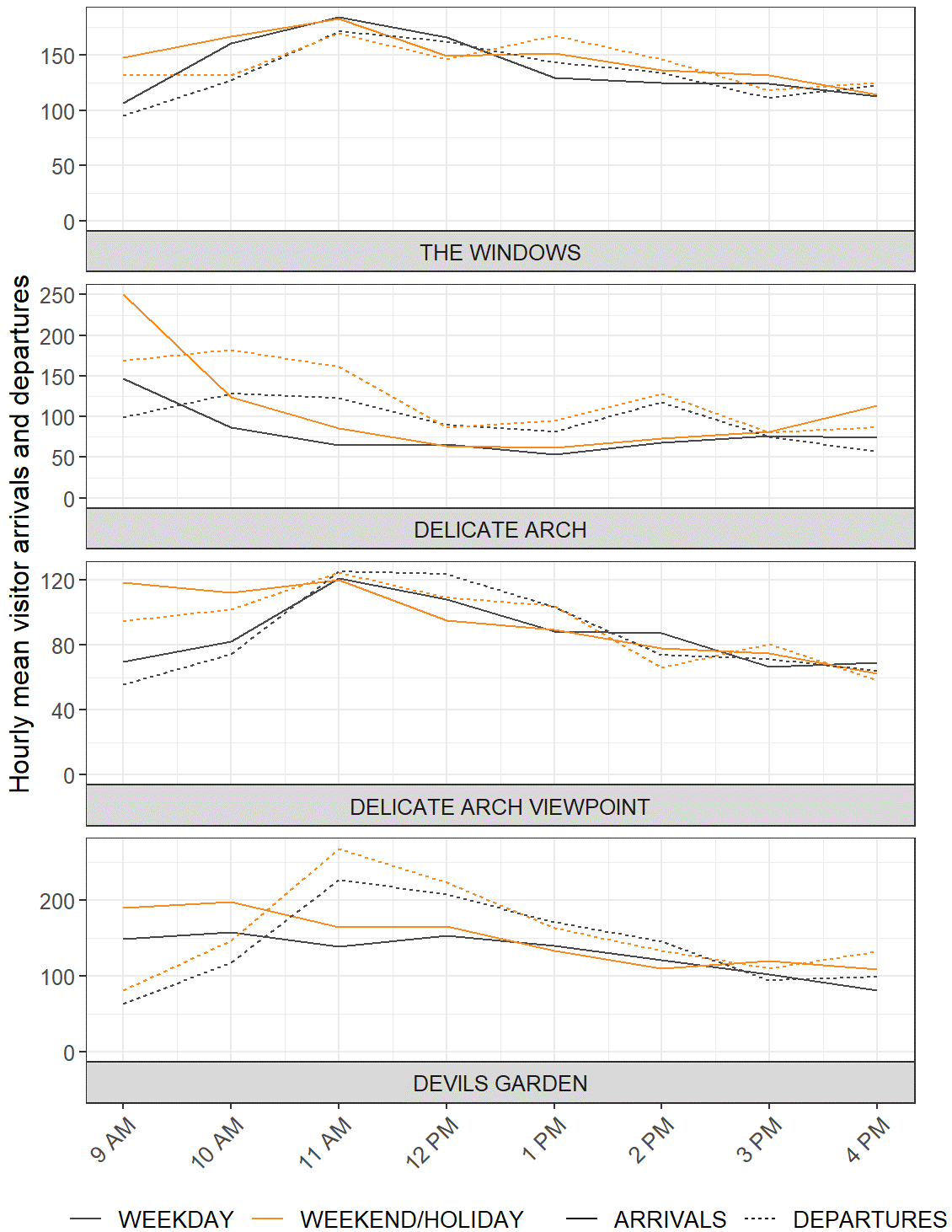
<sup>28</sup> The Y-axis scale varies by location to account for differences in the overall scale of visitor use at each location.

## Mean Hourly Visitor Arrivals and Departures

Figure 41 presents mean hourly visitor arrivals and departures, by trail counter location and day of week category across the hours of each day of the sampling period. These data suggest:

- Mean hourly visitor arrivals at the Windows were consistently between approximately 100 and 175 visitors throughout the day and peaked at 11:00 a.m., regardless of the day of week. Mean hourly visitor arrivals and departures were similar in magnitude within each hour, suggesting that visitors generally spend about an hour or less at the Windows.
- Mean hourly visitor arrivals at Delicate Arch were highest, by far, during the early morning and declined fairly sharply from 9:00 a.m. to about noon. Departures tended to lag arrivals by about one hour.
- Mean hourly arrivals at the Delicate Arch Viewpoint trended slightly upward during the morning to a peak on weekdays between 11:00 a.m. and 12:00 p.m. and to a peak on weekend days and holidays at 11:00 a.m. Mean hourly visitor arrivals and departures were similar in magnitude within each hour, suggesting that visitors generally spend about an hour or less at the Delicate Arch Viewpoint.
- Mean hourly visitor arrivals at Devils Garden were highest during the early morning and remained fairly steady through the remainder of the day on weekdays and declined a bit more steadily from the morning peak on weekend days and holidays. Mean hourly departures from Devils Garden had a pronounced peak at 11:00 a.m., which likely includes a relatively high number of visitors who arrived earlier than 9:00 a.m. for longer hikes on the trail system.

# Arches National Park



**FIGURE 41. HOURLY MEAN ARRIVALS AND DEPARTURES, BY TRAIL COUNTER LOCATION AND DAY OF WEEK CATEGORY<sup>29</sup>**

<sup>29</sup> The Y-axis scale varies by location to account for differences in the overall scale of mean hourly visitor arrivals and departures at each location.

### 3.7 PEOPLE-PER-VIEWSCAPE (PPV) AND PEOPLE AND VEHICLE-AT-ONE-TIME (PAOT AND VAOT) COUNTS

This subsection of the report describes the results of PAOT, PPV, and VAOT counts conducted at each study site. This subsection also compares PAOT and PPV values to crowding-related thresholds derived from the results of visitor surveys conducted in the park in 1993<sup>30</sup> and specified in the park’s 1995 Visitor Experience and Resource Protection Implementation Plan (referred to in this section as “Analysis Thresholds”).

#### The Windows

##### *Mean and Maximum PAOT*

Daily mean and maximum PAOT and VAOT at the Windows are presented in Table 11. These data suggest:

- The daily mean PAOT in the Windows viewscape ranged from 15 to 23 PAOT, and the daily maximum PAOT ranged from 31 to 57 PAOT.
- The daily mean VAOT at the Windows site ranged from 61 to 119 VAOT, and the daily maximum VAOT ranged from 97 to 154 VAOT.
- Daily mean and maximum PAOT and VAOT were similar in range on weekdays and on weekend days and holidays.

**TABLE 11. AVERAGE, STANDARD DEVIATION, AND MAXIMUM NUMBER OF PEOPLE-AT-ONE-TIME AND VEHICLES-AT-ONE-TIME (PAOT AND VAOT): THE WINDOWS<sup>31</sup>**

DATE	DAY TYPE	VIEWSCAPE PAOT			SITE VAOT		
		MEAN	STANDARD DEVIATION	MAX	MEAN	STANDARD DEVIATION	MAX
2019-08-31	WEEKEND/HOLIDAY	22	9	53	78	23	126
2019-09-01	WEEKEND/HOLIDAY	18	7	38	83	21	115
2019-09-02	WEEKEND/HOLIDAY	20	10	46	73	25	115
2019-09-04	WEEKDAY	15	6	31	77	20	115
2019-09-05	WEEKDAY	16	9	36	61	18	98
2019-09-06	WEEKDAY	15	8	32	64	20	97
2019-09-07	WEEKEND/HOLIDAY	23	10	48	79	17	117
2019-09-08	WEEKEND/HOLIDAY	17	9	42	85	19	120
2019-09-09	WEEKDAY	17	12	57	86	20	118
2019-09-10	WEEKDAY	19	9	39	119	22	154

<sup>30</sup> The 1993 survey results are presented in a 1994 report entitled *Indicators and Standards of Quality for the Visitor Experience at Arches National Park: Phase II Research*. A range of other potential crowding-related thresholds are reported in the simulation modeling section of the report.

<sup>31</sup> Mean and standard deviation values were rounded to the nearest whole number.

**Comparison of PAOT Levels to Analysis Threshold**

Table 12 summarizes PAOT count data for the Windows viewscape and suggests that current visitor use often exceeds the analysis threshold level of 20 PAOT on both weekdays and weekend days and holidays. For example:

- On weekend days and holidays, about half (51%) of all PAOT counts recorded in the Windows viewscape exceeded the analysis threshold of 20 PAOT. On weekdays, nearly one-third (30%) of the PAOT counts in the Windows viewscape exceeded the analysis threshold.
- The maximum PAOT count at the Windows viewscape exceeded the analysis threshold on every day PAOT counts were conducted (Table 11).

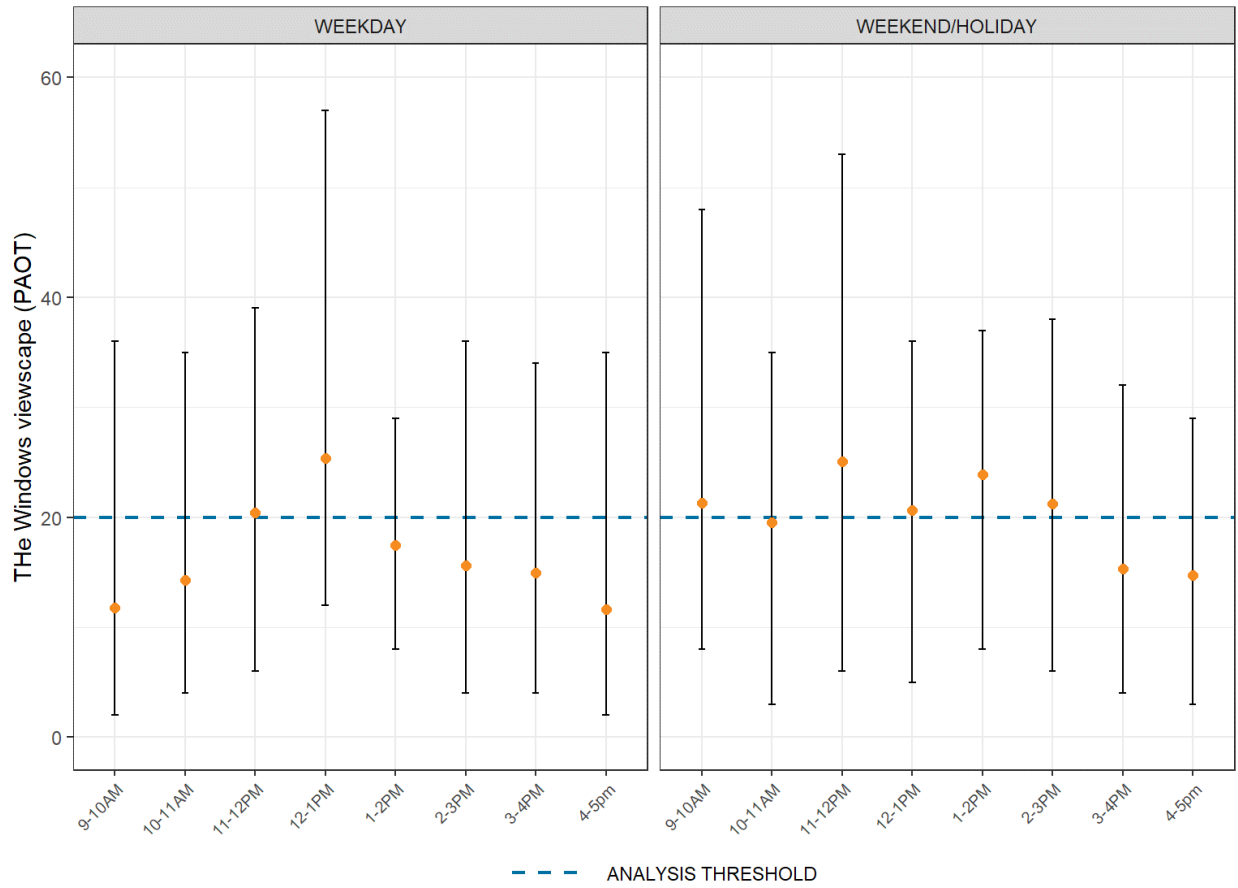
**TABLE 12. PERCENTAGE OF PAOT COUNTS EXCEEDING ANALYSIS THRESHOLD: THE WINDOWS**

DAY TYPE	ANALYSIS THRESHOLD (PAOT)	TOTAL COUNTS	PERCENTAGE OF COUNTS EXCEEDING ANALYSIS THRESHOLD
Weekday	20	240	30%
Weekend/Holiday	20	240	51%

Statistical summaries of the range of PAOT counts at the Windows viewscape, by hour of the day, are presented in Figure 42. The points represent mean hourly PAOT values and the vertical lines represent the full range of PAOT values observed, from the minimum value at the bottom of the vertical line to the maximum value at the top of the vertical line.

These data suggest:

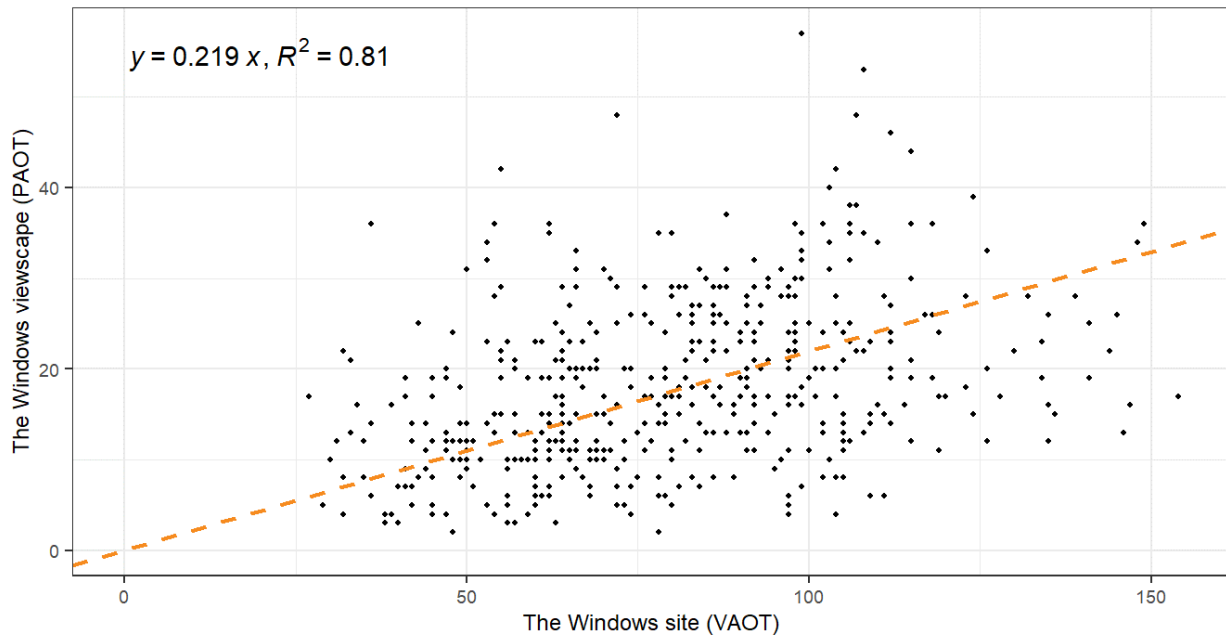
- On weekdays, hourly mean PAOT generally remained below the analysis threshold of 20 PAOT but did exceed the threshold during the 11:00 a.m. and 12:00 p.m. hours. Weekday hourly maximum PAOT was above the 20 PAOT threshold every hour of the day.
- On weekend days and holidays, hourly mean PAOT reached or exceeded the analysis threshold from 9:00 a.m. to 3:00 p.m. Hourly maximum PAOT was above the 20 PAOT threshold every hour of the day for weekend days and holidays.
- PAOT at the Windows ranged widely during the hours of the day on weekdays and on weekend days and holidays. On weekdays, the hourly minimum PAOT values ranged from 2 to 12 PAOT and hourly maximum values ranged from 29 to 57 PAOT. On weekend days and holidays, hourly minimum PAOT values ranged from 3 to 8 PAOT and hourly maximum values ranged from 29 to 53 PAOT.



**FIGURE 42. HOURLY AVERAGE, MINIMUM, AND MAXIMUM NUMBER OF PEOPLE-AT-ONE-TIME (PAOT): THE WINDOWS VIEWSCAPE**

### Regression Analysis

A regression analysis was conducted to estimate the statistical relationship between VAOT in the Windows site, and PAOT in the Windows viewscape (Figure 43). The purpose of the regression analysis was to derive an empirical basis to convert estimates of site VAOT counts from the park-owned traffic counter at the Windows to estimates of viewscape PAOT counts. The resulting coefficient of the linear regression equation (0.219) suggests that, on average, for every 10 vehicles at the Windows at one time, there are two people in the Windows viewscape.



**FIGURE 43. SCATTERPLOT AND REGRESSION EQUATION: VAOT AT THE WINDOWS AND PAOT IN THE WINDOWS VIEWSCAPE**

## Delicate Arch

### *Mean and Maximum PAOT*

Daily mean and maximum PAOT and VAOT at Delicate Arch (in the main parking lot, overflow parking lot, and on the roadside) are presented in Table 13. These data suggest:

- The daily mean PAOT in the Delicate Arch viewscape ranged from 21 to 63 PAOT, and the daily maximum PAOT ranged from 51 to 160 PAOT.
- The daily mean VAOT at Delicate Arch ranged from 58 to 115 VAOT, and the daily maximum VAOT ranged from 106 to 238 VAOT.
- Daily mean and maximum PAOT were generally higher on weekend days and holidays than on weekdays.

**TABLE 13. AVERAGE, STANDARD DEVIATION, AND MAXIMUM NUMBER OF PEOPLE-AT-ONE-TIME AND VEHICLES-AT-ONE-TIME (PAOT AND VAOT): DELICATE ARCH<sup>32</sup>**

DATE	DAY TYPE	VIEWSCAPE PAOT			SITE VAOT		
		MEAN	STANDARD DEVIATION	MAX	MEAN	STANDARD DEVIATION	MAX
2019-08-31	WEEKEND/HOLIDAY	63	50	160	115	63	216
2019-09-01	WEEKEND/HOLIDAY	51	47	150	115	65	238
2019-09-02	WEEKEND/HOLIDAY	46	36	114	86	58	175
2019-09-04	WEEKDAY	28	18	68	58	43	126
2019-09-05	WEEKDAY	21	16	80	64	43	127
2019-09-06	WEEKDAY	22	22	77	62	47	149
2019-09-07	WEEKEND/HOLIDAY	39	22	83	88	46	156
2019-09-08	WEEKEND/HOLIDAY	27	13	51	71	36	135
2019-09-09	WEEKDAY	31	20	64	72	44	130
2019-09-10	WEEKDAY	32	14	62	87	18	106

<sup>32</sup> Mean and standard deviation values were rounded to the nearest whole number.

### **Comparison of PAOT Levels to Analysis Threshold**

Table 14 summarizes PAOT count data for the Delicate Arch viewscape and suggests that current visitor use often exceeds the analysis threshold of 30 PAOT on weekdays and on weekend days and holidays. For example:

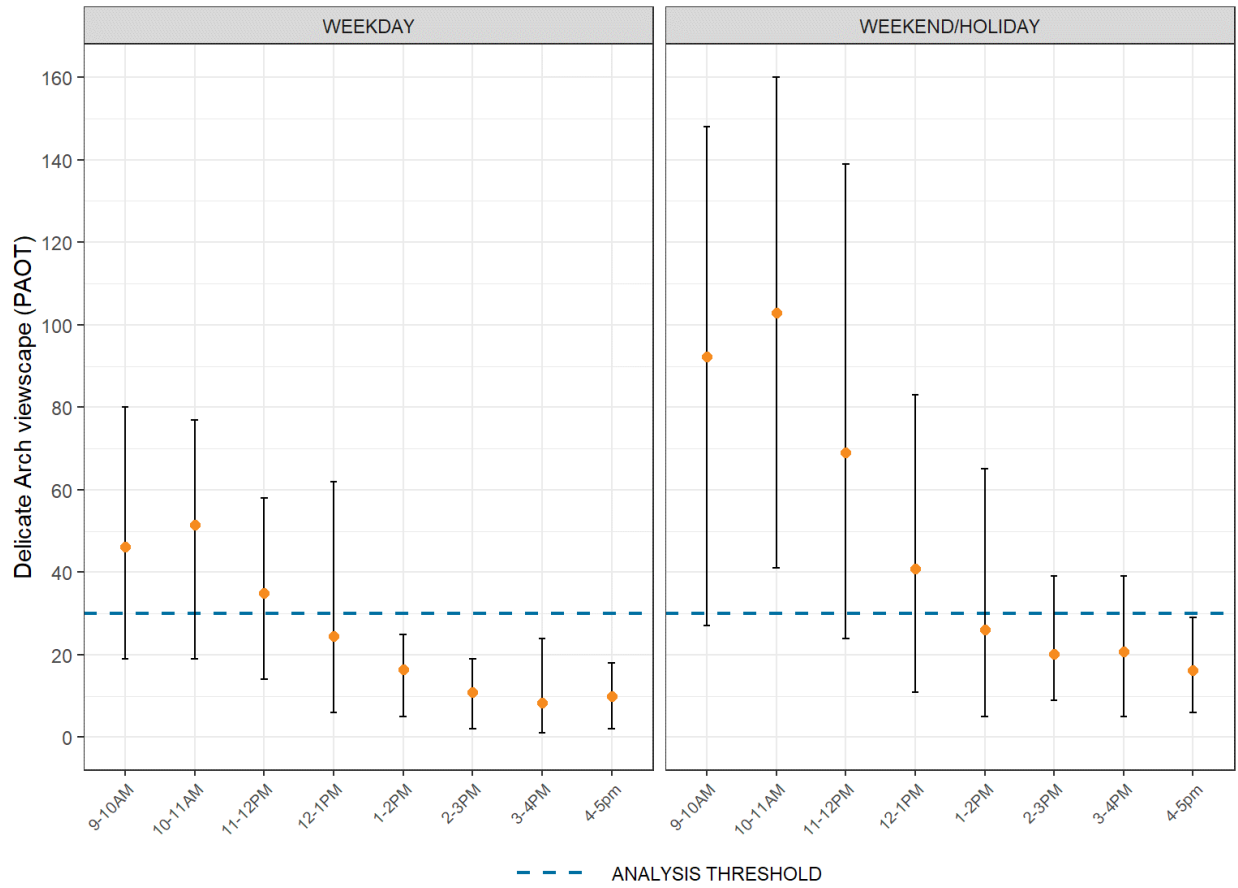
- On weekend days and holidays, nearly half (48%) of all PAOT counts recorded in the Delicate Arch viewscape exceeded the analysis threshold of 30 PAOT. On weekdays, more than one-third (35%) of the PAOT counts in the Delicate Arch viewscape exceeded the analysis threshold.
- The maximum PAOT count at the Delicate Arch viewscape substantially exceeded the analysis threshold on every day PAOT counts were conducted (Table 13).

**TABLE 14. PERCENTAGE OF PAOT COUNTS EXCEEDING ANALYSIS THRESHOLD: DELICATE ARCH**

DAY TYPE	ANALYSIS THRESHOLD (PAOT)	TOTAL COUNTS	PERCENTAGE OF COUNTS EXCEEDING ANALYSIS THRESHOLD
Weekday	30	202	35%
Weekend/Holiday	30	221	48%

Statistical summaries of the range of PAOT counts at Delicate Arch, by hour of the day, are presented in Figure 44. The points represent mean hourly PAOT values and the vertical lines represent the full range of PAOT values observed, from the minimum value at the bottom of the vertical line to the maximum value at the top of the vertical line. These data suggest:

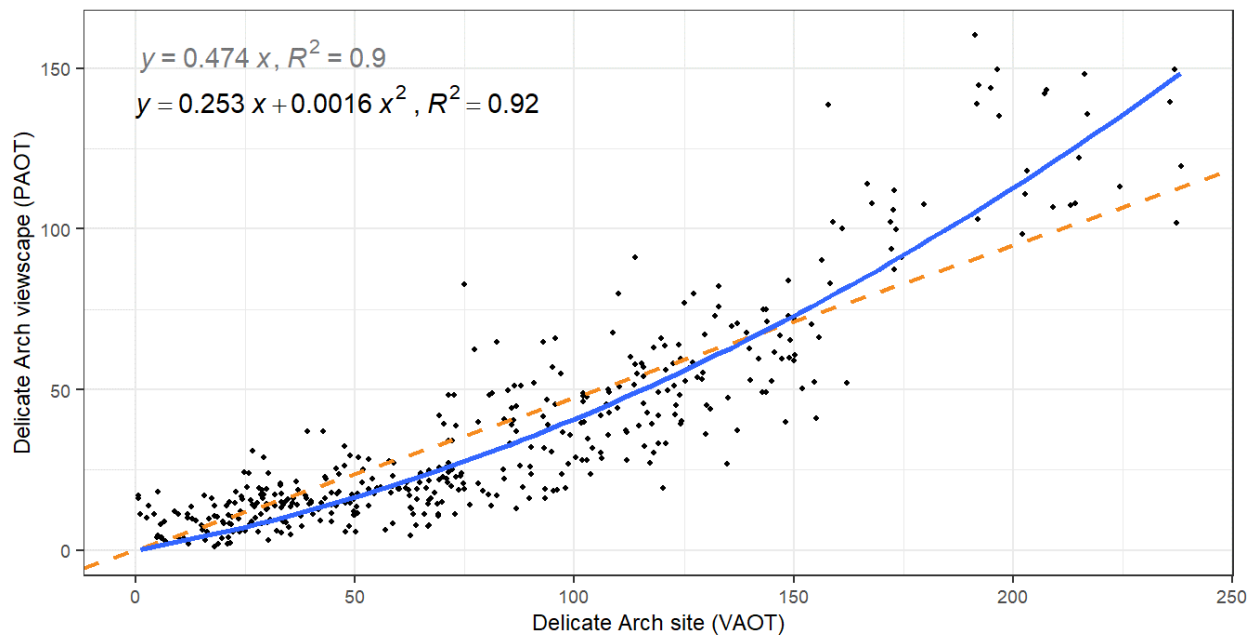
- On weekdays, hourly mean PAOT exceeded the analysis threshold of 30 PAOT during all morning hours and through the noon hour. Hourly maximum PAOT substantially exceeded the threshold during these same hours of the day. Hourly mean and maximum PAOT were below the threshold at Delicate Arch throughout the remainder of the afternoon.
- On weekend days and holidays, hourly mean PAOT was more than double the analysis threshold of 30 PAOT during all of the morning hours and was above or near the threshold from noon to 3:00 p.m. Hourly maximum PAOT far exceeded the threshold throughout the morning and early afternoon, and was at or above the threshold all hours of the day.
- PAOT at Delicate Arch ranged widely during the day on weekdays and on weekend days and holidays. On weekdays, the hourly minimum PAOT values ranged from 1 to 19 PAOT and hourly maximum values ranged from 18 to 80 PAOT. On weekend days and holidays, hourly minimum PAOT values ranged from 5 to 41 PAOT and hourly maximum values ranged from 29 to 160 PAOT.



**FIGURE 44. HOURLY AVERAGE, MINIMUM, AND MAXIMUM NUMBER OF PEOPLE-AT-ONE-TIME (PAOT): DELICATE ARCH VIEWSCAPE**

### Regression Analysis

A regression analysis was conducted to estimate the statistical relationship between VAOT at Delicate Arch and PAOT in the Delicate Arch viewscape (Figure 45)<sup>33</sup>. The purpose of the regression analysis was to derive an empirical basis to convert estimates of site VAOT counts from the park-owned traffic counters at Delicate Arch to estimates of viewscape PAOT counts. As the results in Figure 45 illustrate, the relationship between VAOT at Delicate Arch and PAOT in the Delicate Arch viewscape exhibits a nonlinear relationship best fit with a quadratic functional form. This statistical relationship implies that PAOT in the Delicate Arch viewscape increases at an increasing rate as VAOT at Delicate Arch increases. Results of the quadratic regression equation suggest that, when there are 10 vehicles at Delicate Arch at one time, there are roughly three people in the Delicate Arch viewscape. The regression equation further suggests that when there are 100 vehicles at Delicate Arch at one time, there are roughly 41 people in the Delicate Arch viewscape.



**FIGURE 45. SCATTERPLOT AND REGRESSION EQUATIONS: VAOT AT DELICATE ARCH AND PAOT IN THE DELICATE ARCH VIEWSCAPE**

<sup>33</sup> A quadratic regression was identified through analysis as the best fitting functional form to model the relationship between viewscape PAOT and site VAOT based on the scatterplot and adjusted  $R^2$  values for alternative model specifications. The quadratic and linear regression lines and equations are included for comparison.

## Devils Garden

### *Mean and Maximum PPV*

Daily mean and maximum PPV and VAOT at Devils Garden are presented in Table 15.

These data suggest:

- The daily mean PPV in the Devils Garden viewscape ranged from 9 to 15 PPV, and the daily maximum PPV ranged from 24 to 35 PPV.
- The daily mean VAOT at Devils Garden ranged from 70 to 141 VAOT, and the daily maximum VAOT ranged from 121 to 209 VAOT.
- Daily mean and maximum PPV and VAOT were similar in range on weekdays and on weekend days and holidays.
- Daily mean and maximum VAOT were generally higher on weekend days and holidays than on weekdays.

**TABLE 15. AVERAGE, STANDARD DEVIATION<sup>34</sup>, AND MAXIMUM NUMBER OF PEOPLE-PER-VIEWSCAPE AND VEHICLES-AT-ONE-TIME (PPV AND VAOT): DEVILS GARDEN**

DATE	DAY TYPE	VIEWSCAPE PPV			SITE VAOT		
		MEAN	STANDARD DEVIATION	MAX	MEAN	STANDARD DEVIATION	MAX
2019-08-31	WEEKEND/HOLIDAY	13	6	31	111	37	162
2019-09-01	WEEKEND/HOLIDAY	11	7	34	92	45	165
2019-09-02	WEEKEND/HOLIDAY	10	7	34	81	47	159
2019-09-04	WEEKDAY	10	6	33	70	31	121
2019-09-05	WEEKDAY	9	6	34	73	41	134
2019-09-06	WEEKDAY	9	6	24	70	35	128
2019-09-07	WEEKEND/HOLIDAY	14	7	31	104	42	175
2019-09-08	WEEKEND/HOLIDAY	14	7	35	126	22	168
2019-09-09	WEEKDAY	11	6	27	108	33	156
2019-09-10	WEEKDAY	15	8	35	141	43	209

<sup>34</sup> Mean and standard deviation values were rounded to the nearest whole number.

### **Comparison of PPV Levels to Analysis Threshold**

Table 16 summarizes PPV count data for the Devils Garden viewscape and suggests that current visitor exceeds the analysis threshold of 20 PPV about 10% of the time on weekdays and 16% of the time on weekend days and holidays.

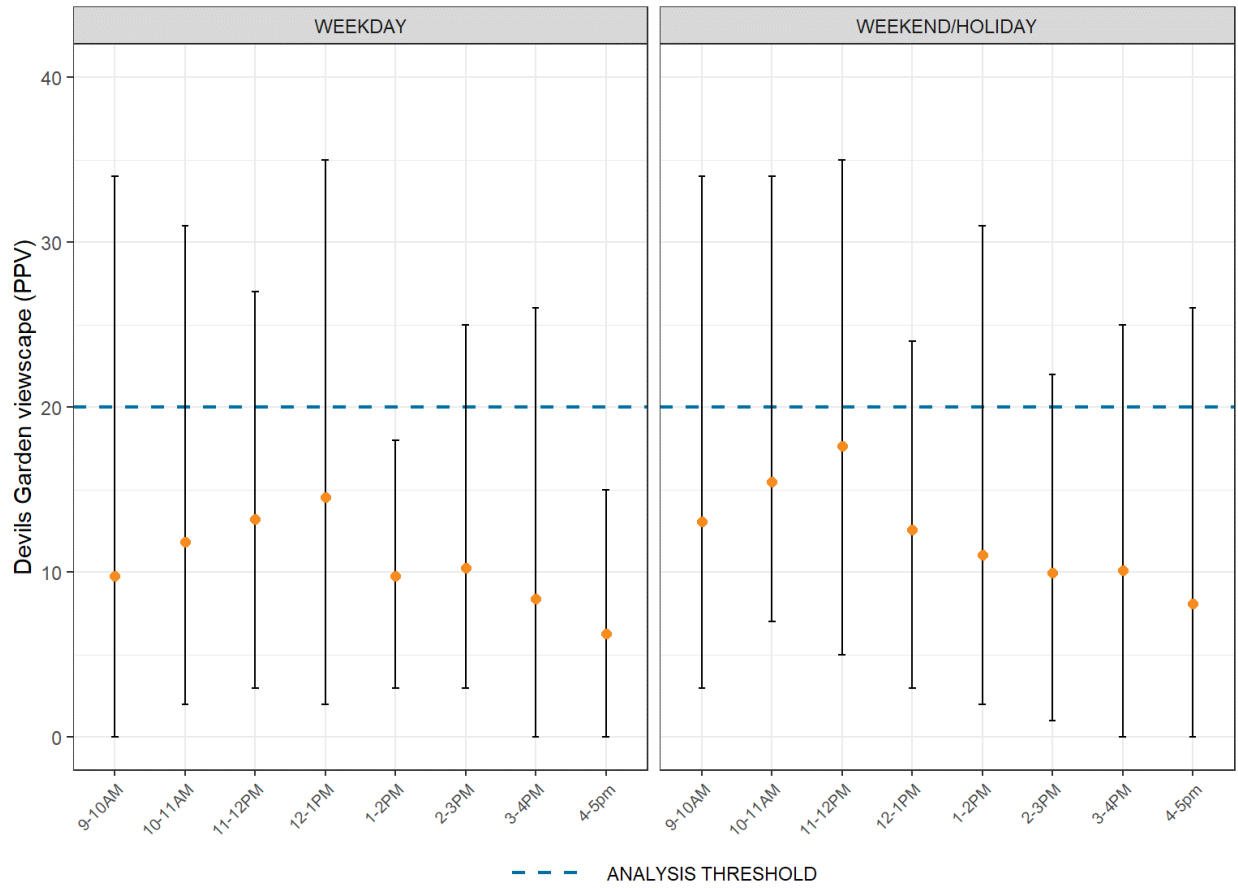
- On weekend days and holidays, 16% of all PPV counts recorded in the Devils Garden viewscape exceeded the analysis threshold of 20 PPV. On weekdays, 10% of the PPV counts in the Devils Garden viewscape exceeded the analysis threshold.
- The maximum PPV count at the Devils Garden viewscape exceeded the analysis threshold on every day PPV counts were conducted (Table 15).

**TABLE 16. PERCENTAGE OF PPV COUNTS EXCEEDING ANALYSIS THRESHOLD: DEVILS GARDEN**

DAY TYPE	ANALYSIS THRESHOLD (PPV)	TOTAL COUNTS	PERCENTAGE OF COUNTS EXCEEDING ANALYSIS THRESHOLD
Weekday	20	240	10%
Weekend/Holiday	20	236	16%

Statistical summaries of the range of PPV counts at Devils Garden, by hour of the day, are presented in Figure 46. The points represent mean hourly PPV values and the vertical lines represent the full range of PPV values observed, from the minimum value at the bottom of the vertical line to the maximum value at the top of the vertical line. These data suggest:

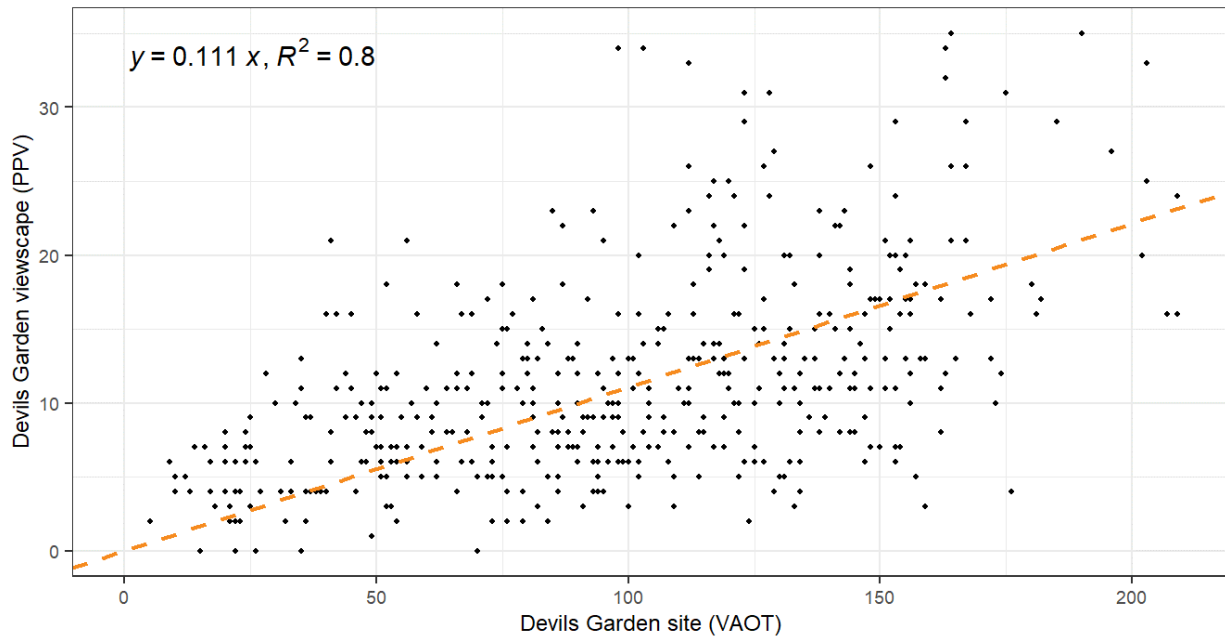
- On weekdays and on weekend days and holidays, hourly mean PPV remained below the analysis threshold of 20 PPV. Hourly maximum PPV counts were consistently above the 20 PPV most hours of the day on weekdays and on weekend days and holidays.
- PPV at Devils Garden ranged widely during the day on weekdays and on weekend days and holidays. On weekdays, the hourly minimum PPV values ranged from 0 to 3 PPV and hourly maximum values ranged from 15 to 35 PPV. On weekend days and holidays, hourly minimum PPV values ranged from 0 to 7 PPV and hourly maximum values ranged from 22 to 35 PPV.



**FIGURE 46. HOURLY AVERAGE, MINIMUM, AND MAXIMUM NUMBER OF PEOPLE-PER-VIEWSCAPE (PPV): DEVILS GARDEN**

### Regression Analysis

A regression analysis was conducted to estimate the statistical relationship between VAOT at Devils Garden and PPV in the Devils Garden viewscape (Figure 47). The purpose of the regression analysis was to derive an empirical basis to convert estimates of site VAOT counts from the park-owned traffic counter at Devils Garden to estimates of viewscape PPV counts. The resulting coefficient of the regression equation (0.111) suggests that, on average, for every 10 vehicles at Devils Garden at one time, there is one person in the Devils Garden viewscape.



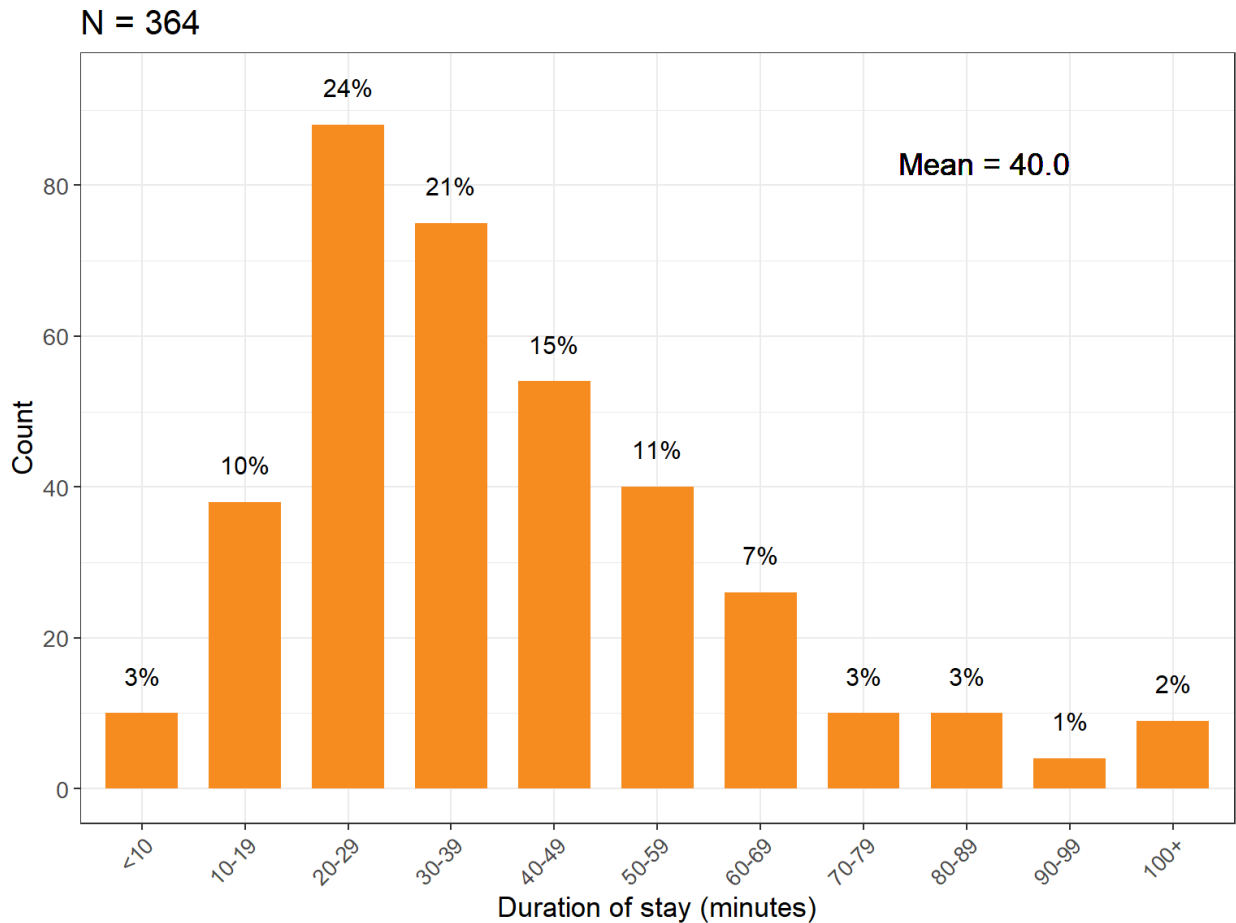
**FIGURE 47. SCATTERPLOT AND REGRESSION EQUATION: VAOT AT DEVILS GARDEN AND PPV IN THE DEVILS GARDEN VIEWSCAPE**

### 3.8 STUDY SITE DWELL TIMES

This subsection of the report presents study site dwell times recorded with delay cards administered to visitor groups at the Windows, Delicate Arch, and Devils Garden. Means and frequency distributions of dwell times are presented in Figure 48 through Figure 51. The target population for these dwell times differ from those measured via GPS-based tracking. The delay card data represent site dwell times of those visitor groups at each study site who left their vehicles and walked past the delay card sampling location. In contrast, the GPS data represent site dwell times of all visitor groups at each study site who travel in a vehicle to the study site, whether or not they leave their vehicle when they are at the site. The delay card data suggest:

#### The Windows

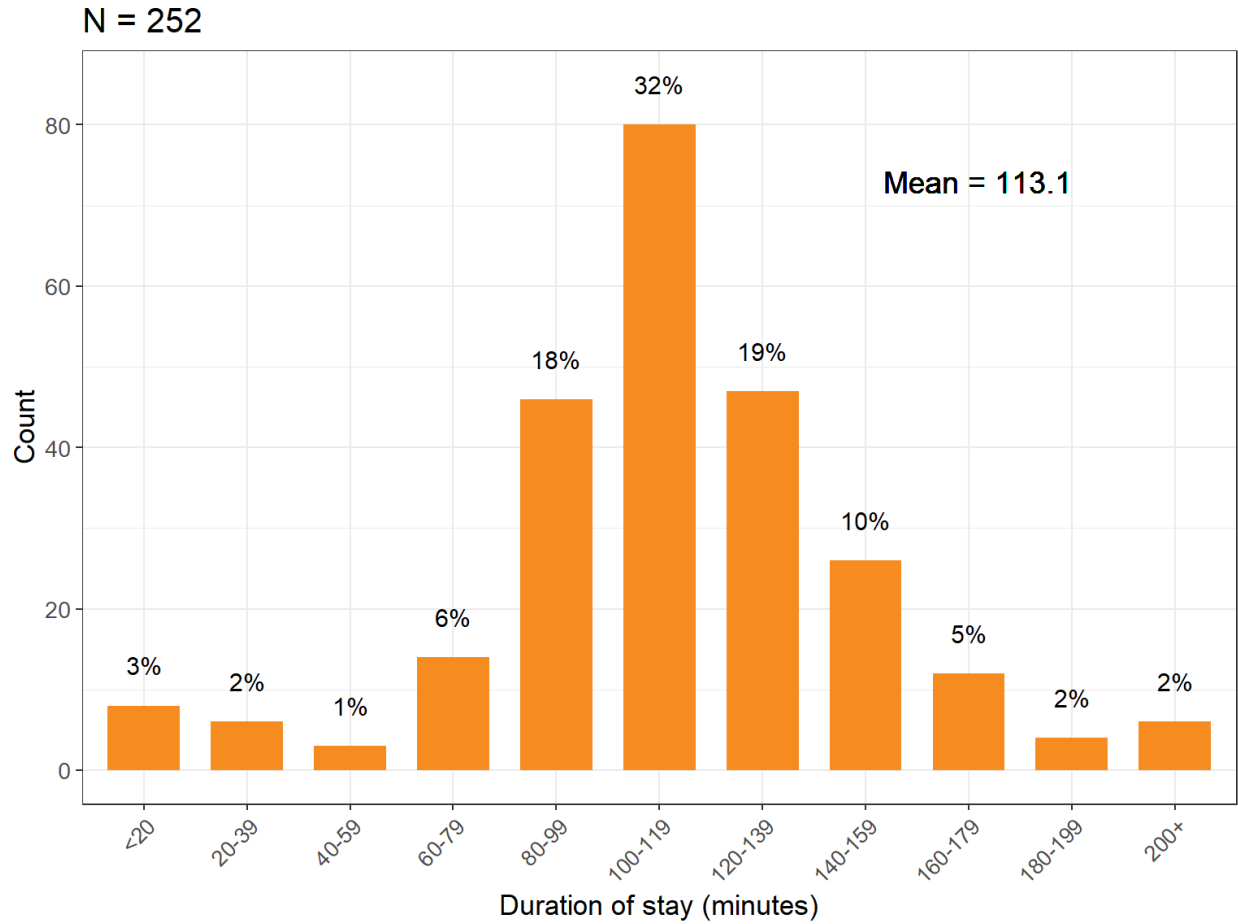
- On average, visitors who were administered a delay card at the Windows spent about 40 minutes there.
- The minimum duration of stay recorded at the Windows was two minutes and the maximum was just over two hours (132 minutes).
- The vast majority (84%) of visitors spent less than one hour at the Windows, and a majority (58%) spent less than 40 minutes there.



**FIGURE 48. FREQUENCY DISTRIBUTION OF DELAY CARD-BASED DWELL TIMES: THE WINDOWS**

### Delicate Arch

- On average, visitors who were administered a delay card at Delicate Arch spent just under 2 hours (113 minutes) there.
- The minimum duration of stay recorded at Delicate Arch was five minutes and the maximum was just over five hours (306 minutes).
- More than two-thirds (69%) of visitors spent between an hour and a half and two and a half hours at Delicate Arch. About one-third (38%) of visitors spent two or more hours at Delicate Arch.

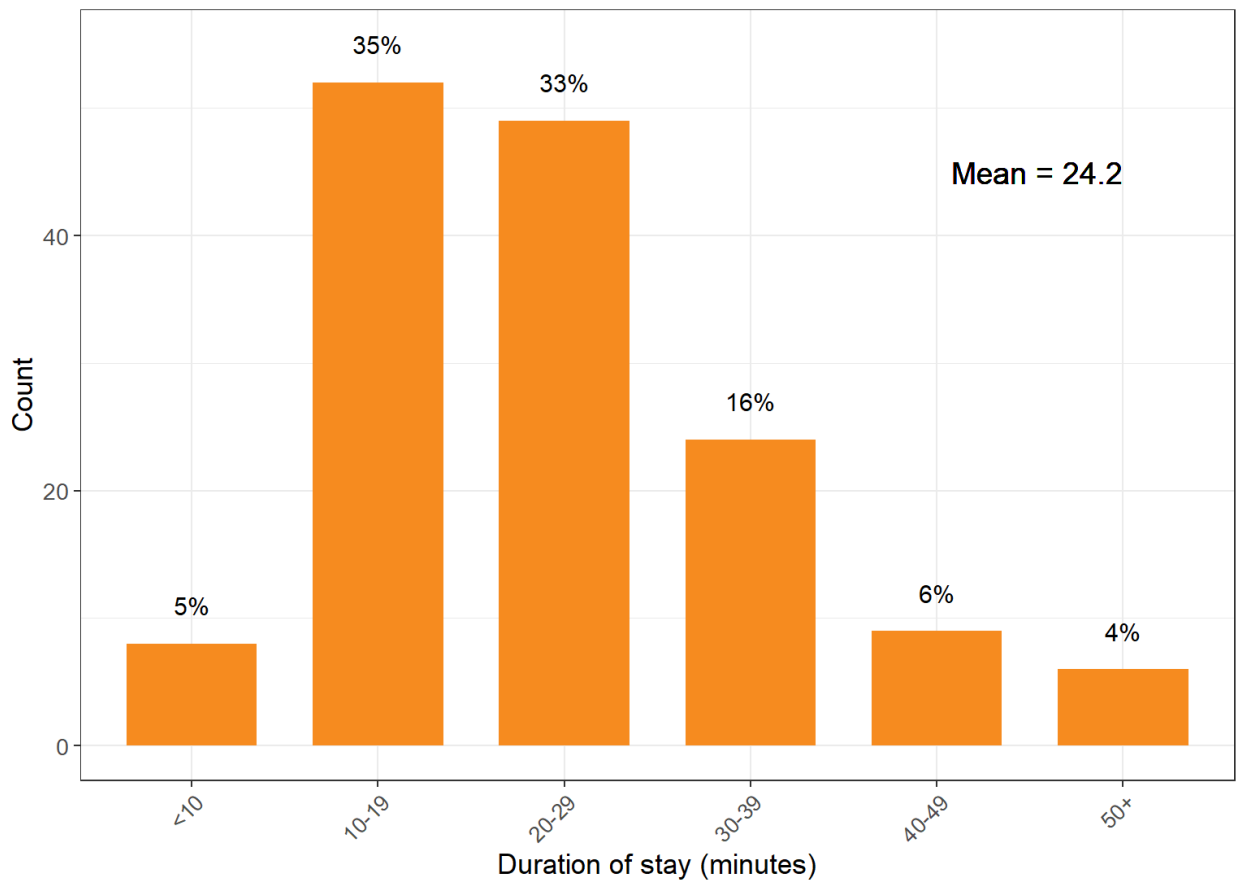


**FIGURE 49. FREQUENCY DISTRIBUTION OF DELAY CARD-BASED DWELL TIMES: DELICATE ARCH**

### Delicate Arch Viewscope<sup>35</sup>

- On average, visitors who were administered a delay card at Delicate Arch and hiked to the Delicate Arch viewscope spent an average of 24 minutes in the viewscope.
- The minimum duration of stay recorded at the Delicate Arch viewscope was two minutes and the maximum was 75 minutes.
- More than two-thirds (68%) of visitors who hiked to the Delicate Arch viewscope spent 10 to 29 minutes there. Very few (4%) of visitors spent 50 minutes or more there.

N = 148



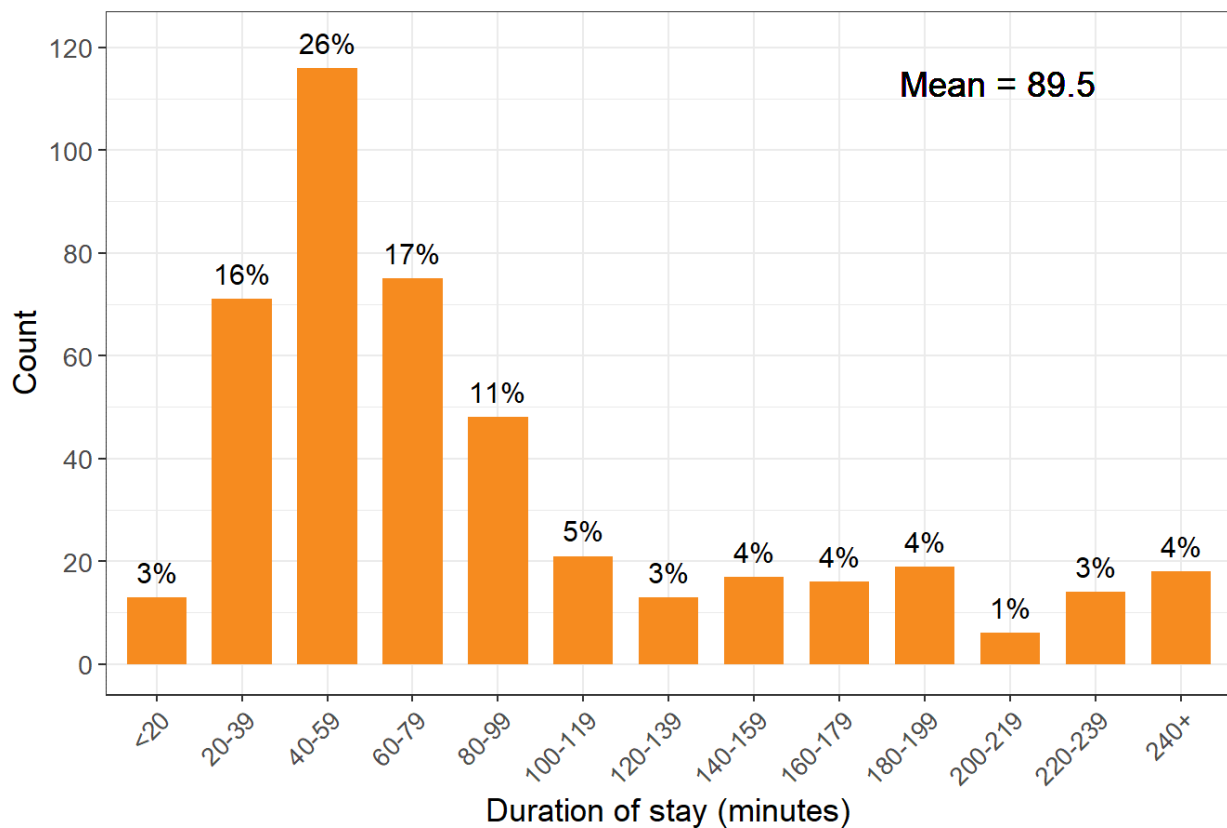
**FIGURE 50. FREQUENCY DISTRIBUTION OF DELAY CARD-BASED DWELL TIMES: DELICATE ARCH VIEWSCOPE**

<sup>35</sup> Visitor duration of stay in the Delicate Arch Viewscope is a portion of visitor duration of stay at the Delicate Arch site.

## Devils Garden

- On average, visitors who were administer a delay card at Devils Garden spent about an hour and a half there.
- The minimum duration of stay at Devils Garden was six minutes and the maximum was nearly seven hours (413 minutes).
- A little less than half (45%) of visitors spent less than an hour at Devils Garden, one-third (33%) of visitors spent one to two hours there, and about one-quarter (23%) of visitors spent two or more hours there.

**N = 447**



**FIGURE 51. FREQUENCY DISTRIBUTION OF DELAY CARD-BASED DWELL TIMES: DEVILS GARDEN**

## 4.0 STATISTICAL MODELING OF STUDY DATA

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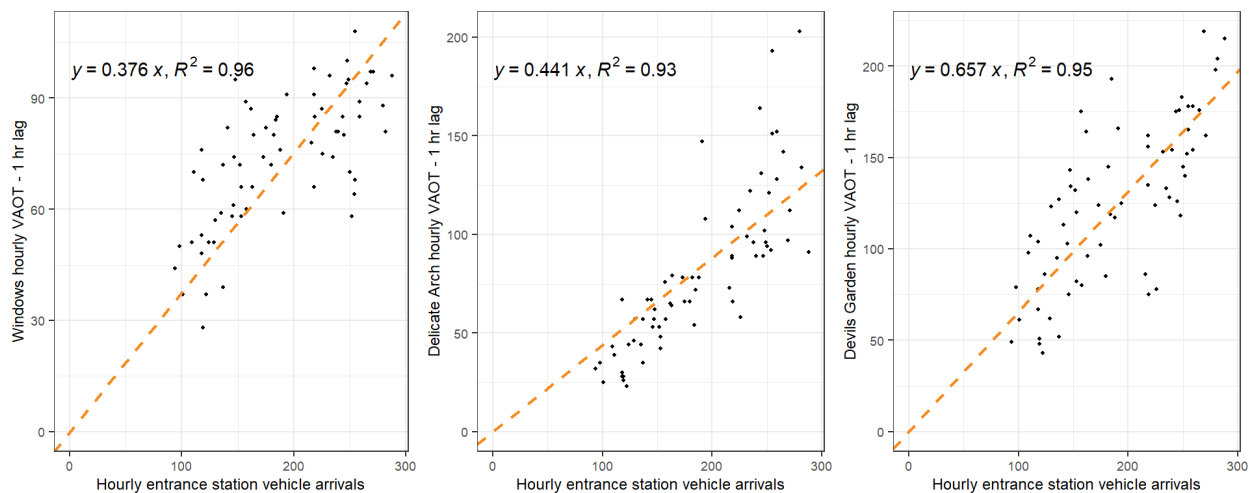
This subsection of the report presents the results of various regression analyses conducted to model relationships among the following transportation- and visitor use-related measures:

- Hourly entrance station vehicle arrivals and hourly site-level parking accumulation (VAOT), by study site.
- Hourly site-level vehicle arrivals and hourly site-level parking accumulation (VAOT), by study site.
- Hourly site-level vehicle arrivals and hourly site-level trail use arrivals, by study site.
- Hourly site-level parking accumulation (VAOT) and hourly site-level trail use arrivals, by study site.
- Hourly site-level trail use arrivals and hourly site-level mean PAOT/PPV in the viewscape, by study site.
- Hourly site-level trail use arrivals and hourly site-level maximum PAOT/PPV in the viewscape, by study site.
- Hourly entrance station vehicle arrivals and hourly site-level vehicle arrivals, by study site.
- Daily entrance station vehicle arrivals and daily site-level vehicle arrivals, by study site.

## 4.1 HOURLY ENTRANCE STATION VEHICLE ARRIVALS AND HOURLY SITE-LEVEL PARKING ACCUMULATION (VAOT), BY STUDY SITE

Regression results in Figure 52 suggest that between 9:00 a.m. and 4:00 p.m. there are strong statistical relationships between hourly entrance station vehicle arrivals and hourly site-level parking accumulation (VAOT) one hour later. The model results suggest for every 100 hourly vehicle arrivals at the entrance station there are:

- Approximately 38 cars parked at one time at the Windows in the following hour
- Approximately 44 cars parked at one time at Delicate Arch in the following hour
- Approximately 66 cars parked at one time at Devils Garden in the following hour

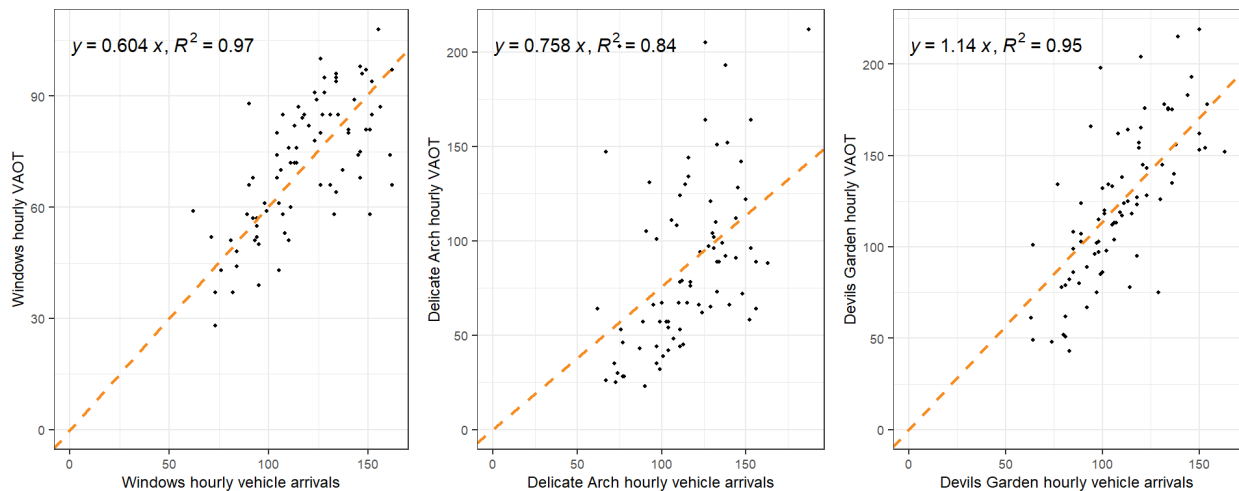


**FIGURE 52. HOURLY ENTRANCE STATION VEHICLE ARRIVALS AND HOURLY SITE-LEVEL PARKING ACCUMULATION (VAOT), BY STUDY SITE**

## 4.2 HOURLY SITE-LEVEL VEHICLE ARRIVALS AND HOURLY SITE-LEVEL PARKING ACCUMULATION (VAOT), BY STUDY SITE

Regression results in Figure 53 suggest there are strong statistical relationships between hourly site-level vehicle arrivals and hourly site-level parking accumulation (VAOT) between the hours of 9:00 a.m. and 4:00 p.m. The model results suggest that:

- For every 100 hourly vehicle arrivals at the Windows there are approximately 60 cars parked at one time during the hour.
- For every 100 hourly vehicle arrivals at Delicate Arch there are approximately 76 cars parked at one time during the hour.
- For every 100 hourly vehicle arrivals at Devils Garden there are approximately 114 cars parked at one time during the hour.

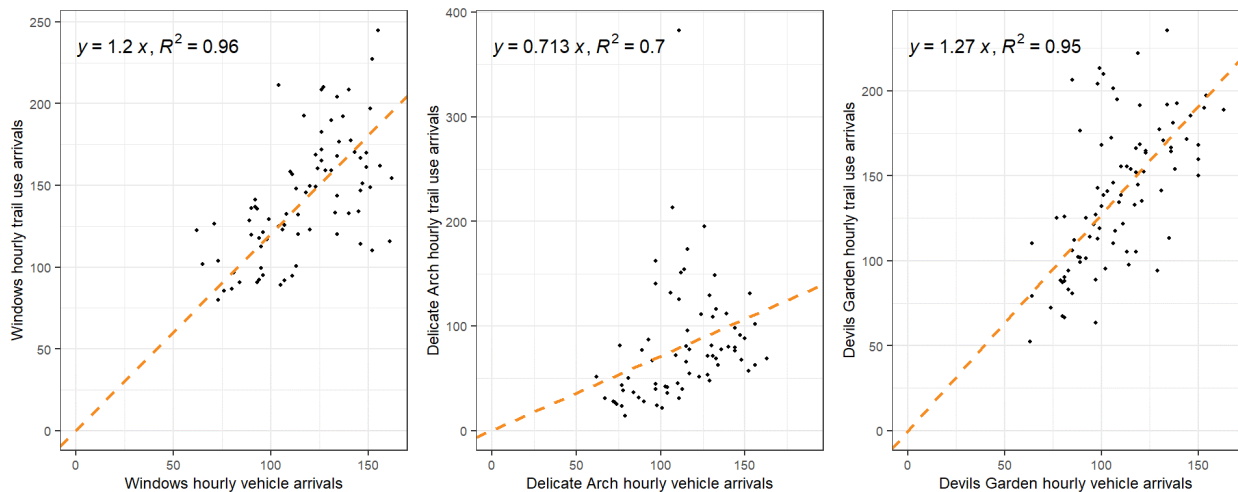


**FIGURE 53. HOURLY SITE-LEVEL VEHICLE ARRIVALS AND HOURLY SITE-LEVEL PARKING ACCUMULATION (VAOT), BY STUDY SITE**

### 4.3 HOURLY SITE-LEVEL VEHICLE ARRIVALS AND HOURLY SITE-LEVEL TRAIL USE ARRIVALS, BY STUDY SITE

Regression results in Figure 54 suggest there are strong statistical relationships between hourly site-level vehicle arrivals and hourly site-level trail use arrivals between the hours of 9:00 a.m. and 4:00 p.m. at the Windows and Devils Garden. A moderately strong statistical relationship exists at Delicate Arch; the relationship is attenuated, to some extent, by the fact that the road to Delicate Arch provides access to Delicate Arch and to the Delicate Arch Viewpoint. The model results suggest that:

- For every 100 hourly vehicle arrivals at the Windows there are approximately 120 trail use arrivals during the hour.
- For every 100 hourly vehicle arrivals at Delicate Arch there are approximately 71 trail use arrivals during the hour.
- For every 100 hourly vehicle arrivals at Devils Garden there are approximately 127 trail use arrivals during the hour.

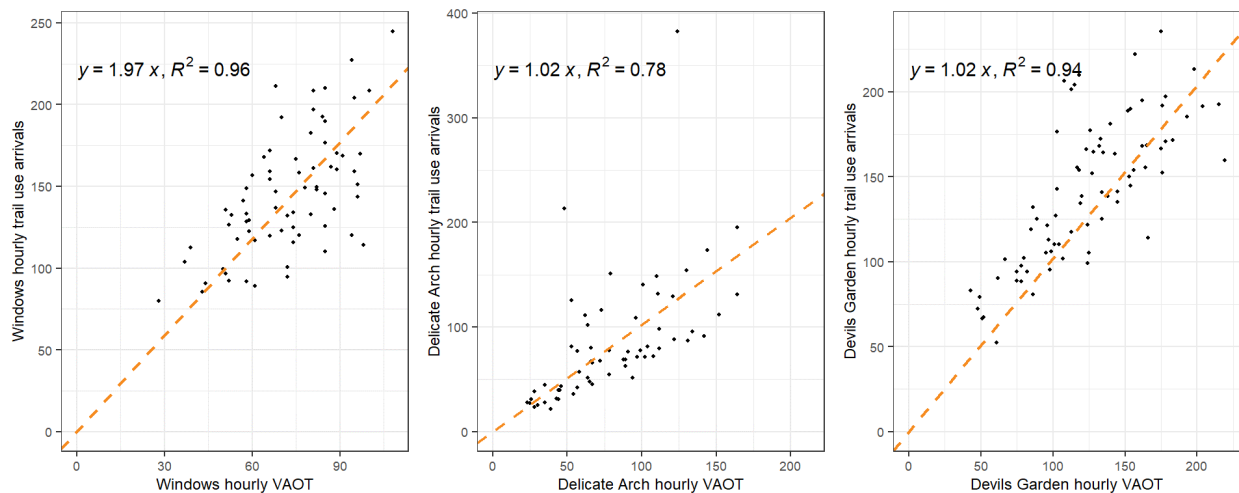


**FIGURE 54. HOURLY SITE-LEVEL VEHICLE ARRIVALS AND HOURLY SITE-LEVEL TRAIL USE ARRIVALS, BY STUDY SITE**

## 4.4 HOURLY SITE-LEVEL PARKING ACCUMULATION (VAOT) AND HOURLY SITE-LEVEL TRAIL USE ARRIVALS, BY STUDY SITE

Regression results in Figure 55 suggest there are strong statistical relationships between hourly site-level parking accumulation (VAOT) and hourly site-level trail use arrivals between the hours of 9:00 a.m. and 4:00 p.m. The model results suggest that:

- For every 100 vehicles parked at one time at the Windows there are approximately 197 trail use arrivals during the hour.
- For every 100 vehicles parked at one time at Delicate Arch there are approximately 102 trail use arrivals during the hour.
- For every 100 vehicles parked at one time at Devils Garden there are approximately 102 trail use arrivals during the hour.

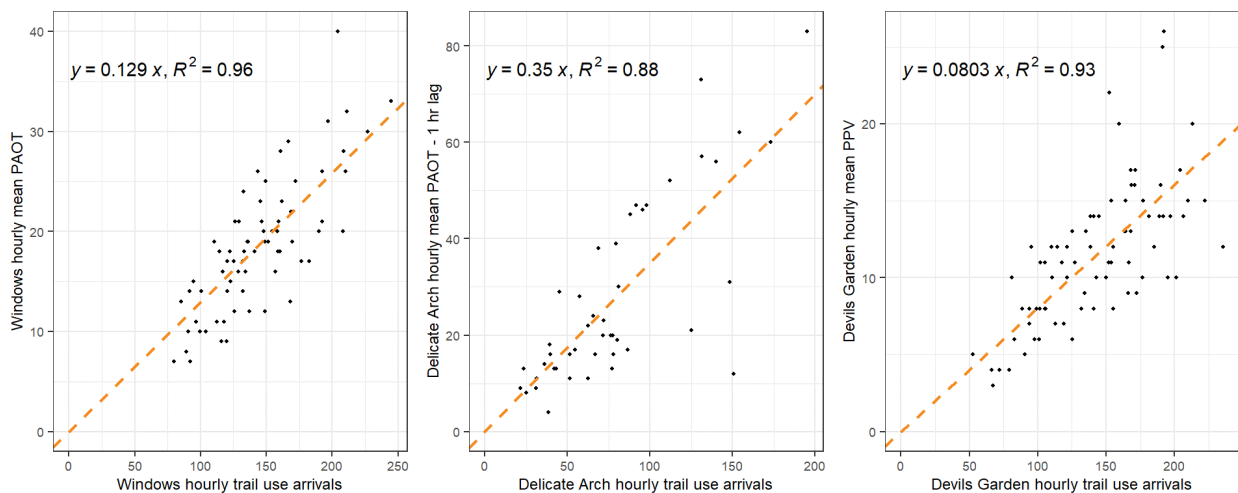


**FIGURE 55. HOURLY SITE-LEVEL PARKING ACCUMULATION (VAOT) AND HOURLY SITE-LEVEL TRAIL USE ARRIVALS, BY STUDY SITE**

## 4.5 HOURLY SITE-LEVEL TRAIL USE ARRIVALS AND HOURLY SITE-LEVEL MEAN PAOT/PPV IN THE VIEWSCAPE, BY STUDY SITE

Regression results in Figure 56 suggest there are strong statistical relationships between hourly site-level trail use arrivals and hourly site-level mean PAOT/PPV in the viewscape between the hours of 9:00 a.m. and 4:00 p.m. In the case of Delicate Arch, the best fitting model included a 1-hour lag between trail use arrivals and mean PAOT in the viewscape. The model results suggest:

- For every 100 hourly trail use arrivals at the Windows there are an average of 13 PAOT in the viewscape during the hour.
- For every 100 hourly trail use arrivals at Delicate Arch there are an average of 35 PAOT in the viewscape one hour later.
- For every 100 hourly trail use arrivals at Devils Garden there are an average of 8 PPV in the viewscape during the hour.

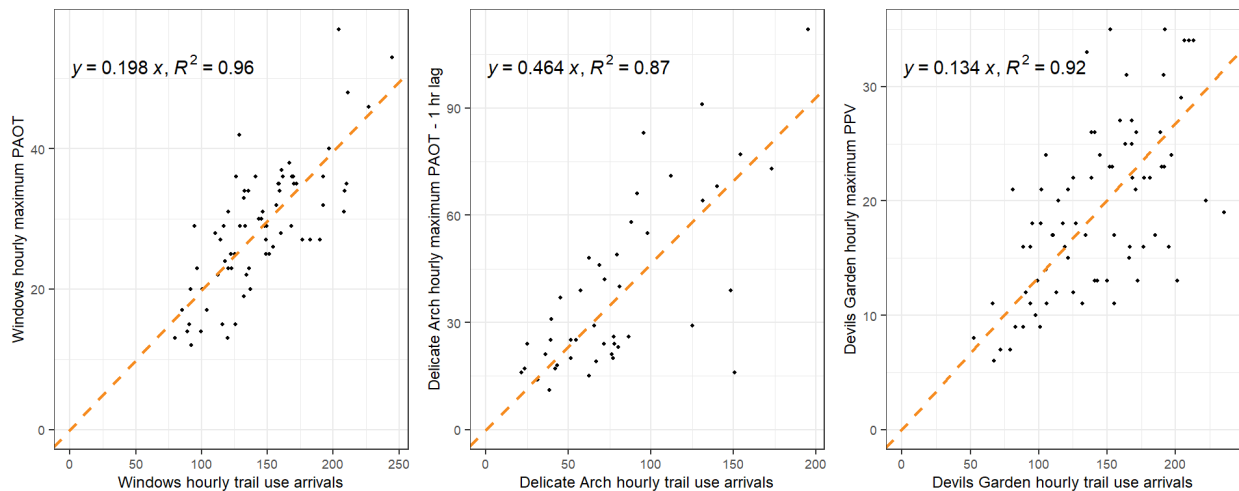


**FIGURE 56. HOURLY SITE-LEVEL TRAIL USE ARRIVALS AND HOURLY SITE-LEVEL MEAN PAOT/PPV IN THE VIEWSCAPE, BY STUDY SITE**

## 4.6 HOURLY SITE-LEVEL TRAIL USE ARRIVALS AND HOURLY SITE-LEVEL MAXIMUM PAOT/PPV IN THE VIEWSCAPE, BY STUDY SITE

Regression results in Figure 57 suggest there are strong statistical relationships between hourly site-level trail use arrivals and hourly site-level maximum PAOT/PPV in the viewscape between the hours of 9:00 a.m. and 4:00 p.m. In the case of Delicate Arch, the best fitting model included a 1-hour lag between trail use arrivals and mean PAOT in the viewscape. The model results suggest:

- For every 100 hourly trail use arrivals at the Windows there is an hourly maximum of 20 PAOT in the viewscape during the hour.
- For every 100 hourly trail use arrivals at Delicate Arch there is an hourly maximum of 46 PAOT in the viewscape one hour later.
- For every 100 hourly trail use arrivals at Devils Garden there is an hourly maximum of 13 PPV in the viewscape during the hour.

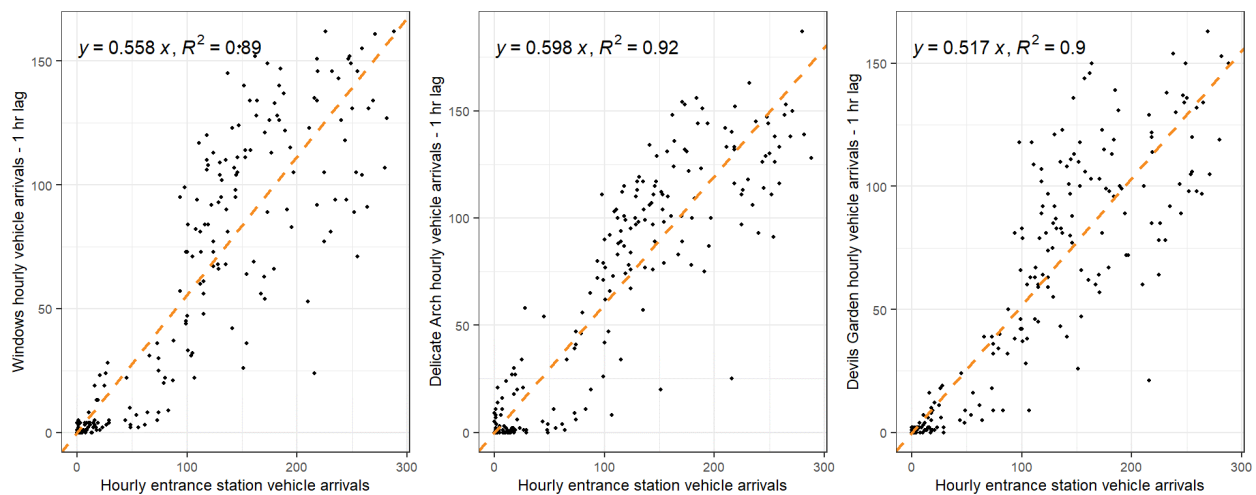


**FIGURE 57. HOURLY SITE-LEVEL TRAIL USE ARRIVALS AND HOURLY SITE-LEVEL MAXIMUM PAOT/PPV IN THE VIEWSCAPE, BY STUDY SITE**

## 4.7 HOURLY ENTRANCE STATION VEHICLE ARRIVALS AND HOURLY SITE-LEVEL VEHICLE ARRIVALS, BY STUDY SITE

Regression results in Figure 58 suggest that between the hours of 9:00 a.m. and 4:00 p.m. there are strong statistical relationships between hourly entrance station vehicle arrivals and hourly site-level vehicle arrivals one hour later. The model results suggest for every 100 hourly vehicle arrivals at the entrance station there are:

- Approximately 56 vehicle arrivals at the Windows in the following hour.
- Approximately 60 vehicle arrivals at Delicate Arch in the following hour.
- Approximately 52 vehicle arrivals at Devils Garden in the following hour.

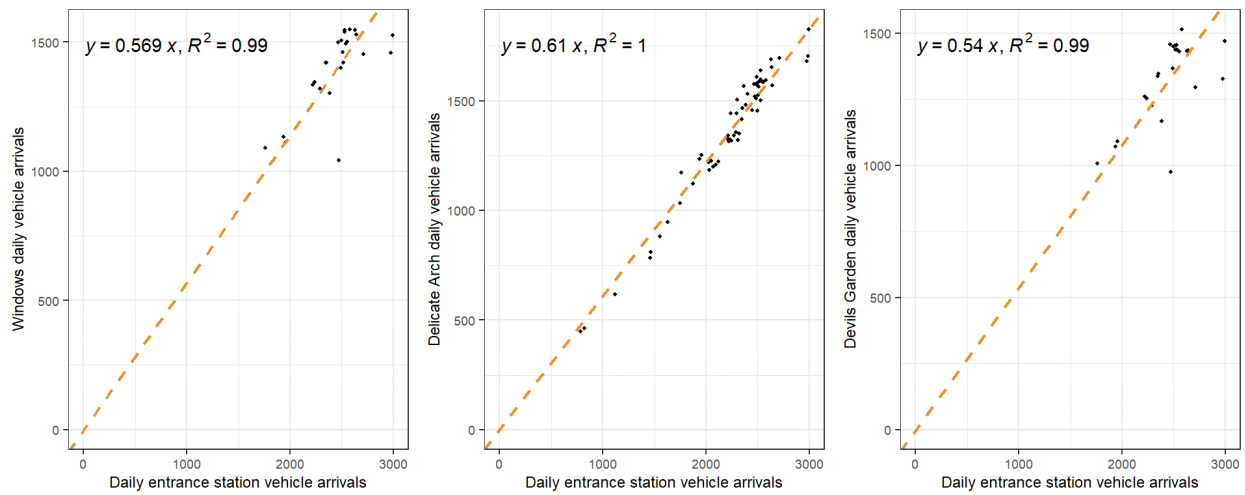


**FIGURE 58. HOURLY ENTRANCE STATION VEHICLE ARRIVALS AND HOURLY SITE-LEVEL VEHICLE ARRIVALS, BY STUDY SITE**

## 4.8 DAILY ENTRANCE STATION VEHICLE ARRIVALS AND DAILY SITE-LEVEL VEHICLE ARRIVALS, BY STUDY SITE

Regression results in Figure 59 suggest that there are strong statistical relationships between daily entrance station vehicle arrivals and daily site-level vehicle arrivals. The model results suggest for every 100 daily vehicle arrivals at the entrance station there are:

- Approximately 57 daily vehicle arrivals at the Windows.
- Approximately 61 daily vehicle arrivals at Delicate Arch.
- Approximately 54 daily vehicle arrivals at Devils Garden.



**FIGURE 59. DAILY ENTRANCE STATION VEHICLE ARRIVALS AND DAILY SITE-LEVEL VEHICLE ARRIVALS, BY STUDY SITE**

## 5.0 SIMULATION MODELING

A simulation model of parkwide vehicle volumes and patterns and study site-level parking and visitor use conditions was developed as a key component of the Arches Visitor Use, Access, and Experience Study. The specific purpose of the simulation model developed for this study are to provide:

- Precise, quantitative information about parkwide vehicle traffic volumes and patterns and study site-level parking conditions, visitor use levels, and crowding conditions at the Windows, Delicate Arch, and Devils Garden during typically busy peak season days (referred to hereafter as “baseline conditions”).
- Scientifically rigorous estimates of the maximum number of visitors that can be accommodated per day in ARCH without exceeding potential parking- and crowding-related capacities.
- Data-driven insights into the efficacy of visitor use and transportation congestion management scenarios to achieve desired conditions in the park.

This section of the report is organized into subsections that present: 1) an overview of the simulation model; 2) model input data analysis methods and results; 3) model algorithm and programming; 4) baseline simulation analysis methods and results; and 5) model validation methods and results. At the time when this report was prepared, NPS had not yet identified the management scenarios for analysis with the simulation model. Therefore, methods and results of the management scenarios analyses will be provided in an addendum to this report later.

### 5.1 METHODS

#### Model Overview

As noted, the Arches Visitor Use Model is parkwide in scope, with points of focus at the Windows, Delicate Arch, and Devils Garden (see Figure 1 and Section 2.1 Study Area). Daily private and commercial vehicle arrivals at the park entrance station and daily private vehicle arrivals into the park from Salt Valley Road and Willow Springs Road provide the basis for programming the Arches Visitor Use Model and conducting simulations with the model. The study sites are points of focus for estimating parking demand, visitor use, and parking- and crowding-related capacities with the computer simulation model.

The following data served as the primary sources of inputs for the Arches Visitor Use Model developed for this study:

- Vehicle arrival counts at the entrance station, Salt Valley Road, and Willow Springs Road.
- GPS route tracking.
- People-at-one-time (PAOT) counts at the Windows and Delicate Arch viewscapes and people-per-viewescape (PPV) counts at the Devils Garden viewescape.

## Arches National Park

- Vehicles-at-one-time (VAOT) estimates from the park-owned traffic counters at each of the three study sites.

The methods used to collect these data are described in detail in Section 2.2 of this report and descriptive summaries of these data are presented in Section 3.0.

### Model Input Analysis

The transportation and visitor use data collected during the 2019 study were analyzed to develop the model inputs needed to program the Arches Visitor Use Model and to conduct model simulations. The methods and results of these analyses are summarized in this subsection of the report.

#### *Daily and Hourly Private Vehicle Arrivals*

Hourly private vehicle arrivals specified in the simulation model were derived from traffic counters installed at the entrance station and on Salt Valley Road and Willow Springs Road. Hourly private vehicle arrivals from all weekend days and holidays during the sampling period and from each of the three park entrances were averaged to represent the hourly private vehicle arrival schedule for baseline conditions. The average hourly private vehicle arrival schedules for all three park access points are presented in Table 17 and were used to calculate and program the model with the hourly proportion of daily arrivals, by entrance location and hour of the day. The design day volume of inbound traffic reported in the Design Day Analysis section was used to simulate baseline transportation and visitor use conditions, with hourly arrivals generated according to the hourly arrival proportions noted.

**TABLE 17. AVERAGE HOURLY AND DAILY PRIVATE VEHICLE ARRIVALS, BY POINT OF ACCESS TO ARCHES NATIONAL PARK (WEEKEND DAYS AND HOLIDAYS)**

HOURLY	ENTRANCE STATION	SALT VALLEY ROAD	WILLOW SPRINGS ROAD
12:00 a.m.–1:00 a.m.	3	0	0
1:00 a.m.–2:00 a.m.	2	0	0
2:00 a.m.–3:00 a.m.	1	0	0
3:00 a.m.–4:00 a.m.	2	0	0
4:00 a.m.–5:00 a.m.	6	0	0
5:00 a.m.–6:00 a.m.	31	0	0
6:00 a.m.–7:00 a.m.	77	0	0
7:00 a.m.–8:00 a.m.	172	0	0
8:00 a.m.–9:00 a.m.	229	0	2
9:00 a.m.–10:00 a.m.	253	2	0
10:00 a.m.–11:00 a.m.	238	2	0
11:00 a.m.–12:00 p.m.	216	5	3
12:00 p.m.–1:00 p.m.	189	5	2
1:00 p.m.–2:00 p.m.	172	1	2
2:00 p.m.–3:00 p.m.	162	1	0
3:00 p.m.–4:00 p.m.	162	4	1

HOUR	ENTRANCE STATION	SALT VALLEY ROAD	WILLOW SPRINGS ROAD
4:00 p.m.–5:00 p.m.	150	5	2
5:00 p.m.–6:00 p.m.	128	2	0
6:00 p.m.–7:00 p.m.	112	3	0
7:00 p.m.–8:00 p.m.	80	1	0
8:00 p.m.–9:00 p.m.	38	3	0
9:00 p.m.–10:00 p.m.	19	0	0
10:00 p.m.–11:00 p.m.	12	1	0
11:00 p.m.–12:00 a.m.	5	0	0
<b>Total Daily Vehicle Arrivals</b>	<b>2457</b>	<b>34</b>	<b>12</b>

### ***Daily and Hourly Commercial Vehicle Arrivals***

Park-staff estimates of daily commercial vehicle arrivals at the entrance station, along with direct observation counts of the number of commercial vehicles in the entrance station queue, were used to inform hourly and daily commercial vehicle arrival schedules for both minibuses and coach buses (see Table 18). The park-staff estimates of commercial vehicle arrivals were used to inform the average daily number of commercial vehicles arrivals via the entrance station. The direct observation entrance station queue data were used to program total daily arrivals into hourly arrival bins. The model was programmed to generate a total of 12 simulated commercial vehicles of two types at the entrance station during each simulation run: two minibuses and 10 coach buses. These simulated commercial vehicles were programmed to arrive between the hours of 7:00 a.m. and 5:00 p.m. No simulated commercial vehicles were generated at Salt Valley Road or Willow Springs Road.

**TABLE 18. HOURLY AND DAILY ENTRANCE STATION COMMERCIAL VEHICLE ARRIVALS, BY TYPE**

HOUR	MINIBUS	COACH
12:00 a.m.–1:00 a.m.	0	0
1:00 a.m.–2:00 a.m.	0	0
2:00 a.m.–3:00 a.m.	0	0
3:00 a.m.–4:00 a.m.	0	0
4:00 a.m.–5:00 a.m.	0	0
5:00 a.m.–6:00 a.m.	0	0
6:00 a.m.–7:00 a.m.	0	0
7:00 a.m.–8:00 a.m.	0	1
8:00 a.m.–9:00 a.m.	1	1
9:00 a.m.–10:00 a.m.	1	1
10:00 a.m.–11:00 a.m.	0	1
11:00 a.m.–12:00 p.m.	0	1
12:00 p.m.–1:00 p.m.	0	1
1:00 p.m.–2:00 p.m.	0	1

HOUR	MINIBUS	COACH
2:00 p.m.–3:00 p.m.	0	1
3:00 p.m.–4:00 p.m.	0	1
4:00 p.m.–5:00 p.m.	0	1
5:00 p.m.–6:00 p.m.	0	0
6:00 p.m.–7:00 p.m.	0	0
7:00 p.m.–8:00 p.m.	0	0
8:00 p.m.–9:00 p.m.	0	0
9:00 p.m.–10:00 p.m.	0	0
10:00 p.m.–11:00 p.m.	0	0
11:00 p.m.–12:00 a.m.	0	0
<b>Total Daily Vehicle Arrivals</b>	<b>2</b>	<b>10</b>

**Visitor Group Size**

The frequency distribution of group sizes for simulated vehicles in the model was derived from analysis of the GPS administration contact log data. The group size frequency distributions in Table 19, Table 20, and Table 21 were programmed into the model to assign group sizes to simulated vehicles according to vehicle type.

**TABLE 19. FREQUENCY DISTRIBUTION OF VISITOR GROUP SIZES: PRIVATE VEHICLES**

GROUP SIZE	COUNT	PERCENT
1	52	9%
2	402	66%
3	56	9%
4	62	10%
5	24	4%
6	10	2%
7	2	<1%
8	4	1%
<b>Total</b>	<b>612</b>	<b>100%</b>

**TABLE 20. FREQUENCY DISTRIBUTION OF VISITOR GROUP SIZES: COMMERCIAL MINIBUSES**

<b>GROUP SIZE</b>	<b>COUNT</b>	<b>PERCENT</b>
2	1	5%
5	1	5%
6	1	5%
8	1	5%
12	1	5%
13	1	5%
16	2	11%
17	1	5%
19	2	11%
20	2	11%
21	4	21%
25	2	11%
<b>Total</b>	<b>19</b>	<b>100%</b>

**TABLE 21. FREQUENCY DISTRIBUTION OF VISITOR GROUP SIZES: COMMERCIAL COACH BUSES**

<b>GROUP SIZE</b>	<b>COUNT</b>	<b>PERCENT</b>
26	3	10%
27	2	7%
29	1	3%
30	1	3%
33	1	3%
35	2	7%
37	3	10%
38	2	7%
39	2	7%
40	1	3%
43	1	3%
44	1	3%
45	1	3%
46	3	10%
47	1	3%
53	2	7%
54	2	7%
<b>Total</b>	<b>29</b>	<b>100%</b>

**Visitor Travel Routes**

As noted in Section 3.4, vehicle travel routes were derived from the GPS route tracking data and were classified as one of four route profiles based on the number of study sites traveled to along the GPS route. Separate route profile frequency distributions were programmed into the model to assign a route profile to each simulated private vehicle, depending on arrival time (Table 22, Table 23). The route profile frequency distribution for commercial vehicles presented in Table 24 was programmed into the model to assign a route profile to each simulated commercial vehicle, regardless of arrival time.

**TABLE 22. FREQUENCY DISTRIBUTION OF PRIVATE VEHICLE ROUTE PROFILES FOR VEHICLES ARRIVING BEFORE NOON**

PROFILE	COUNT	PERCENT
All three study sites	111	42%
Two of the three study sites	78	29%
One of the three study sites	68	26%
None of the three study sites	8	3%
<b>Total</b>	<b>265</b>	<b>100%</b>

**TABLE 23. FREQUENCY DISTRIBUTION OF PRIVATE VEHICLE ROUTE PROFILES FOR VEHICLES ARRIVING AT NOON OR LATER**

PROFILE	COUNT	PERCENT
All three study sites	55	28%
Two of the three study sites	68	34%
One of the three study sites	64	32%
None of the three study sites	11	6%
<b>Total</b>	<b>198</b>	<b>100%</b>

**TABLE 24. FREQUENCY DISTRIBUTION OF COMMERCIAL VEHICLE ROUTE PROFILES**

PROFILE	COUNT	PERCENT
All three study sites	3	8%
Two of the three study sites	20	50%
One of the three study sites	16	40%
None of the three study sites	1	3%
<b>Total</b>	<b>40</b>	<b>101%</b>

The GPS route tracking data were analyzed to estimate the distribution of travel routes, by route profile and vehicle type, for vehicles that entered the park via the entrance station. The travel route distributions reported in Table 7 and Table 8 were used to assign travel routes to simulated visitor groups arriving at the entrance station, by route profile and vehicle type. GPS tracking units were not administered to vehicles entering the park from Salt Valley Road and Willow Springs Road, so professional judgment was used to specify travel route distributions for the low volume of simulated vehicles entering via each of the park’s secondary roads. For simulated private vehicles that entered the park from Salt Valley Road, the majority of vehicles (60%) were assigned to only travel along Salt Valley Road, one-quarter were assigned to travel

to Devils Garden and then exit via Salt Valley Road, and the remaining 15% of vehicles traveled to Devils Garden, then to Delicate Arch or the Windows before exiting the park via the entrance station. All simulated private vehicles that entered the park from Willow Springs Road were assigned to travel only along Willow Springs Road.

GPS route tracking data collection began at 8:00 a.m. on each sampling day, and therefore cannot be assumed to represent travel routes prior to that time. For example, parking accumulation data suggest that there may be a substantially larger proportion of vehicles at Delicate Arch than the other two study sites during the early morning hours than is reflected in the GPS-based route distributions for the sampling hours. As such, route profile and travel route assignments for simulated vehicles arriving earlier than 9:00 a.m. were calibrated based on a comparison of entrance station vehicle arrivals and site-level parking lot accumulation.

### ***Travel Times and Site Dwell Times***

As noted, the GPS route tracking data were analyzed to estimate mean travel times on road segments and site dwell times. The means and corresponding standard deviations for vehicle travel times on road segments were used to specify lognormal distributions in the Arches Visitor Use Model to assign travel times to simulated vehicles. Similarly, site dwell time means and corresponding standard deviations were used to specify lognormal distributions in the model to assign site dwell times to simulated vehicles, as a function of park arrival time, route profile, and vehicle type. Park-staff estimates of entrance station transaction time parameters were calibrated and used to specify lognormal distributions in the model to assign transaction times to simulated private and commercial vehicles entering the park via the entrance station.

## **Model Algorithm and Programming**

The results of the model input analyses described in the preceding subsections were used to develop the Arches Visitor Use Model. The model was developed using ExtendSim, a discrete-event systems simulation software, and was programmed to:

- Estimate parkwide and site-level baseline transportation and visitor use conditions based on daily parkwide vehicle arrivals.
- Estimate parking- and crowding-related capacities for ARCH.
- Analyze the efficacy of visitor use and transportation congestion management scenarios to achieve desired conditions in the park.

## Arches National Park

The sequence of processes that occurs within the Arches Visitor Use Model is as follows:

- Simulated private vehicles are generated at the three points of access to Arches National Park, according to hourly arrival schedules derived from traffic counters (Table 17).
- Simulated commercial minibus and coach bus vehicles are generated at the entrance station, according to hourly arrival schedules derived from park-staff estimates and the entrance station queue counts recorded in this study (Table 18).
- Simulated private and commercial vehicles are attributed with group sizes (Table 19, Table 20, Table 21), route profiles (Table 22, Table 23, Table 24), travel routes (Table 7 and Table 8), road segment travel times, and site dwell times based on frequency distributions and parameters derived from the GPS route tracking analyses.
- The model is programmed to “hold” vehicles generated at the entrance station in the entrance station transaction booth for varying transaction times assigned based on vehicle type. This, in turn, can cause a queue to form at the entrance station during busy times within model simulations.
- The model monitors and records simulated entrance station vehicle queue length every 30 seconds of each simulated day.
- Simulated vehicles are routed through the park according to their assigned travel routes. As simulated vehicles travel the course of their route, the model is programmed to “hold” simulated visitor groups along travel corridors according to their assigned travel times between destinations.
- At the Windows, Delicate Arch, and Devils Garden, the model is programmed to “hold” simulated vehicles and visitors for amounts of time based on their assigned site-specific dwell times.
- The model monitors and records simulated parking- and crowding-related conditions (i.e., VAOT and PAOT/PPV) at the Windows, Delicate Arch, and Devils Garden, every five minutes of each simulated day.
- Simulated vehicles are routed to exit the park when their simulated travel routes are completed.

These modeling processes are stochastic, meaning the outcomes vary with each replication of the model. Thus, mean values of outcome variables of interest are computed based on the results of multiple replications of the model. Outputs from the Arches Visitor Use Model were computed by averaging the results of 300 replications of the model.

## 5.2 SIMULATION ANALYSIS OF VISITOR USE AND CAPACITIES

The Arches Visitor Use Model was used to simulate baseline transportation and visitor use conditions. Results from these simulation runs were used to assess whether 2019 peak season levels of visitation exceed striped parking capacities or potential crowding-related thresholds at the Windows, Delicate Arch, and Devils Garden. The crowding-related thresholds used in the baseline simulation analysis are derived from the results of visitor surveys conducted in the park in 1993<sup>36</sup> and specified in the park's 1995 Visitor Experience and Resource Protection Implementation Plan. The site-specific thresholds specified for baseline simulation results and analysis (referred to in this section as "Analysis Thresholds") are as follows:

### **The Windows**

*VAOT in the Windows parking lot does not exceed the "effective capacity" of the lot (defined as 90% of striped capacity of the lot) more than 1% of the time throughout the day, from 4:00 a.m. to 12:00 a.m.*

*PAOT in the Windows viewscape does not exceed 20 for more than 20% of the time per day, from 4:00 a.m. to 12:00 a.m.*

### **Delicate Arch**

*VAOT in the Delicate Arch parking lot does not exceed the "effective capacity" of the lot (defined as 90% of the striped capacity of the lot) more than 1% of the time throughout the day, from 4:00 a.m. to 12:00 a.m.*

*PAOT in the Delicate Arch viewscape does not exceed 30 for more than 20% of the time per day, from 4:00 a.m. to 12:00 a.m.*

### **Devils Garden**

*VAOT in the Devils Garden parking lot does not exceed the "effective capacity" of the lot (defined as 90% of the striped capacity of the lot) more than 1% of the time throughout the day, from 4:00 a.m. to 12:00 a.m.*

*PPV in the Devils Garden viewscape does not exceed 20 for more than 10% of the time per day, from 4:00 a.m. to 12:00 a.m.*

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<sup>36</sup> The 1993 survey results are presented in a 1994 report entitled *Indicators and Standards of Quality for the Visitor Experience at Arches National Park: Phase II Research*. A range of other potential crowding-related thresholds based on results of visitor surveys conducted in the park in 1997 are reported with the baseline results for points of reference.

## **Simulation Results: Current Visitor Use Conditions**

Simulation results of baseline transportation and visitor use conditions are presented in this subsection. These results include site-level estimates of VAOT and PAOT/PPV in the viewscape at each of the three study sites, by time of day. The results also include model estimates of the percentage of time the analysis thresholds for VAOT and PAOT/PPV are exceeded under baseline conditions. As noted, the simulation analysis results are average values from 300 replications of the model for each set of results.

### ***VAOT and PAOT at the Windows***

Mean VAOT at the Windows and mean PAOT in the Windows viewscape, by time of day for the baseline conditions are plotted in Figure 60. The solid horizontal lines in Figure 60 represent the effective capacity of the Windows parking lot (90% of the striped parking capacity) and the PAOT level for the crowding-related analysis threshold. The dashed horizontal lines represent the other visitor survey-based thresholds noted.

The results of the simulations suggest VAOT at the Windows exceeds the effective capacity of the parking lot approximately 25% of the time during the 4:00 a.m. – 12:00 a.m. period. In addition, mean PAOT in the Windows viewscape exceeds the analysis threshold level of 20 PAOT approximately 19% of the time during the 4:00 a.m. – 12:00 a.m. period. These results suggest baseline levels of visitor use in ARCH cause potentially unacceptable parking shortages, vehicle congestion, and visitor crowding at the Windows.

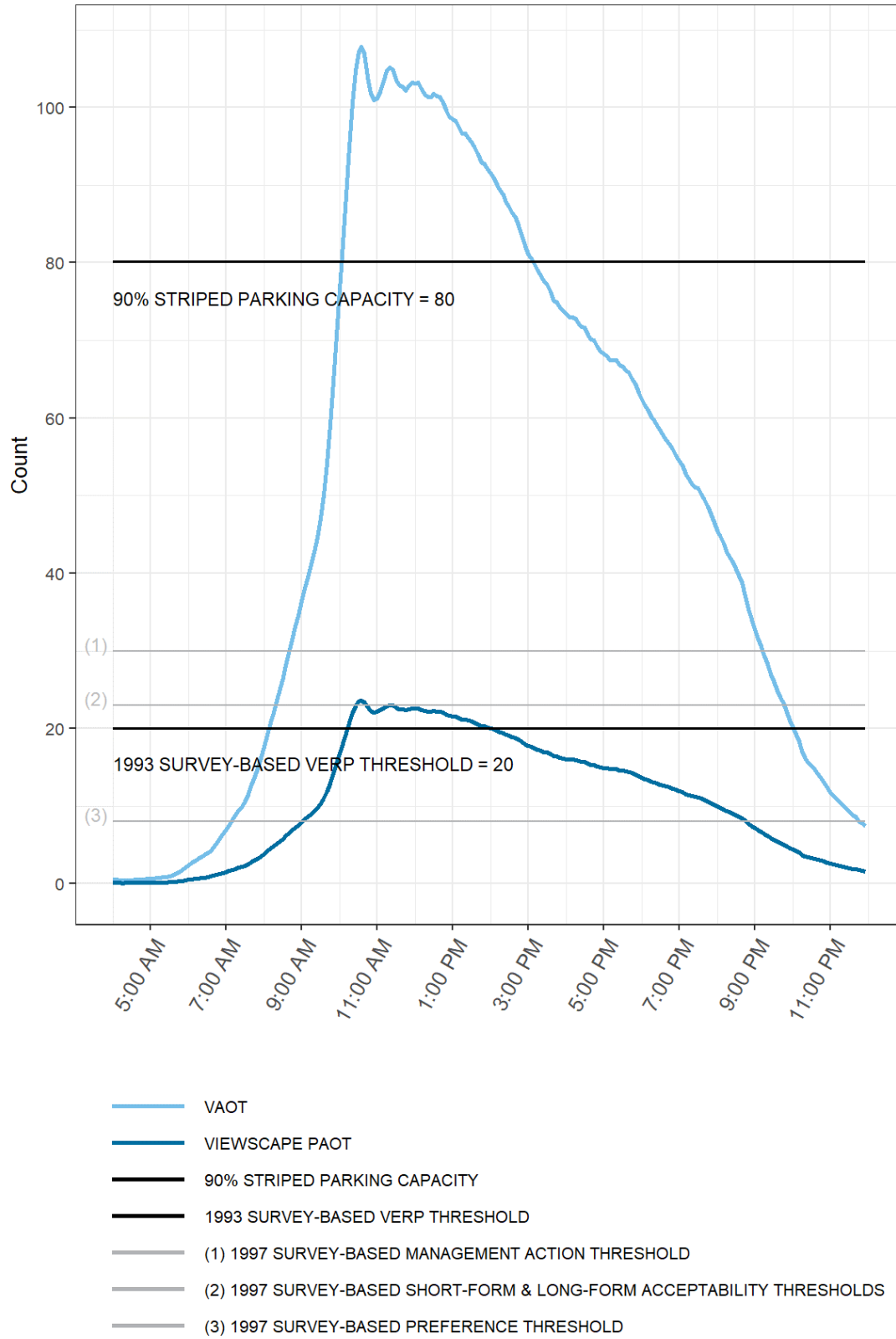


FIGURE 60. BASELINE SIMULATION RESULTS: THE WINDOWS

### ***VAOT and PAOT at Delicate Arch***

Mean VAOT at Delicate Arch and mean PAOT in the Delicate Arch viewscape, by time of day for the baseline conditions are plotted in Figure 61. The solid horizontal lines in Figure 61 represent the “effective capacity” of the Delicate Arch main and overflow parking lots (90% of the striped parking capacity) and the PAOT level for the crowding-related analysis threshold. The dashed horizontal lines represent the other visitor survey-based thresholds noted.

The results of the simulations suggest VAOT at Delicate Arch exceeds the effective capacity of the main and overflow parking lots approximately 6% of the time during the 4:00 a.m. – 12:00 a.m. period. Mean PAOT in the Delicate Arch viewscape exceeds the analysis threshold level of 30 PAOT approximately 34% of the time during the 4:00 a.m. – 12:00 a.m. period. At its peak, mean PAOT in the Delicate Arch viewscape is estimated to be approximately three times the analysis threshold level. These results suggest that baseline levels of visitor use in ARCH and the extent of parking capacity provided at Delicate Arch cause potentially unacceptable and pronounced visitor crowding at Delicate Arch.

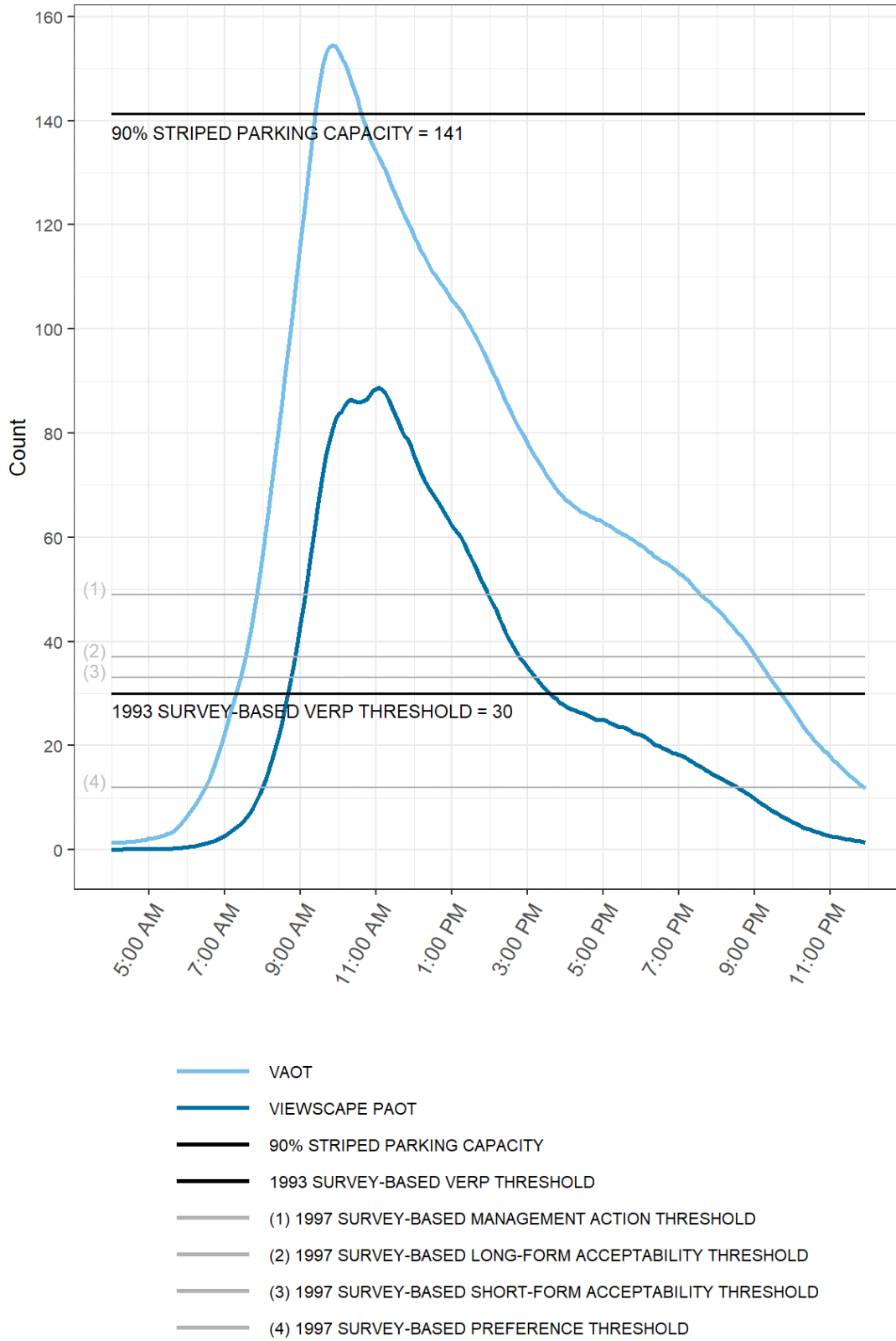


FIGURE 61. BASELINE SIMULATION RESULTS: DELICATE ARCH

### ***VAOT and PPV at Devils Garden***

Mean VAOT at Devils Garden and mean PPV in the Devils Garden viewscape, by time of day for the baseline conditions are plotted in Figure 62. The solid horizontal lines in Figure 62 represent the effective capacity of the Devils Garden parking lot (90% of the striped parking capacity) and the PPV level for the crowding-related analysis threshold. The dashed horizontal lines represent the other visitor survey-based thresholds noted.

The results of the simulations suggest VAOT at Devils Garden exceeds the effective capacity of the parking lot approximately 12% of the time during the 4:00 a.m. – 12:00 a.m. period. Mean PPV in the Devils Garden viewscape exceeds the analysis threshold level of 20 PPV approximately 5% of the time during the 4:00 a.m. – 12:00 a.m. period. These results suggest current levels of visitor use in ARCH cause short periods of unacceptable parking conditions and crowding at Devils Garden during the peak of the visitor use day.

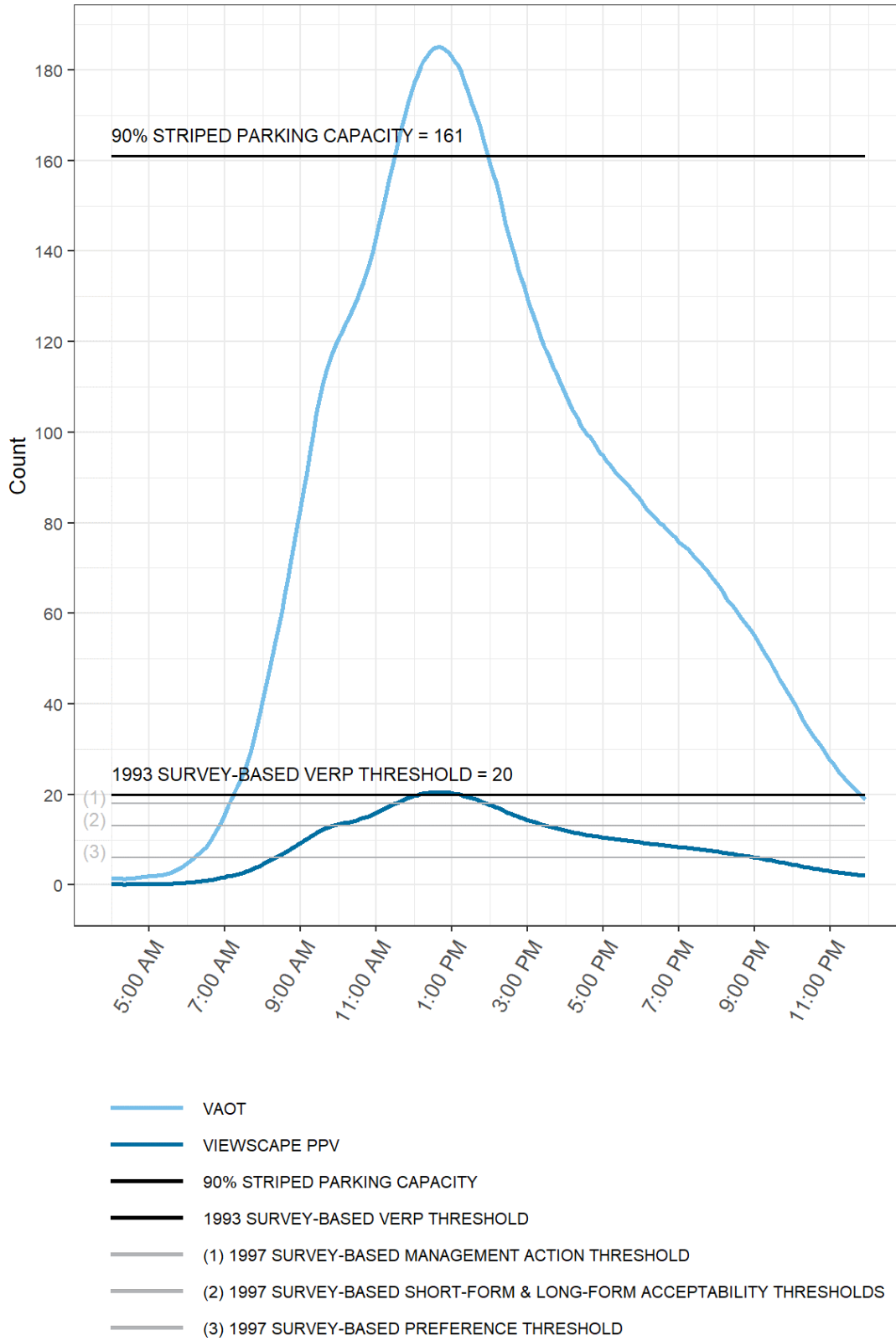


FIGURE 62. BASELINE SIMULATION RESULTS: DEVILS GARDEN

## 5.3 MODEL VALIDATION

Model validation is defined as “the process of determining whether a simulation model is an accurate representation of a system, for particular objectives of the study” (Law and Kelton 2000). In this project, a series of simulations was conducted with the Arches Visitor Use Model to assess the validity of the simulation model estimates and results. Specifically, estimates from the Arches Visitor Use Model for the indicators of interest in this project (VAOT and PAOT/PPV at the Windows, Delicate Arch, and Devils Garden, and entrance station vehicle queue length) were validated against on-the-ground data collected in Arches National Park during the late summer and early fall season of 2019. Results of the model validation are presented in this sub-section.

### VAOT

As noted in Section 2.2, both direct observation counts and park-owned traffic counter data were collected during the 2019 sampling period to measure parking accumulation and calculate VAOT at each study site. The direct observation counts represent counts of the number of vehicles parked in the parking lot at one time (i.e., parking accumulation). The traffic counter data represent counts of the number of vehicles parked, plus the number of vehicles circulating through the parking area, and is a direct corollary to the model estimates of VAOT<sup>37</sup>. These data, coupled together, provide a basis to assess the validity of the Arches Visitor Use Model. Specifically, a series of simulations was conducted with the model programmed to separately simulate the vehicle volume for nine dates of the sampling period<sup>38</sup>. The VAOT estimates from 300 replications of the model for each simulated date were compared to the corresponding VAOT data collected through direct observation counts and traffic counter counts at each of the three study sites.

The direct observation counts (labeled as “VAOT – OBSERVED”) and traffic counts (labeled as “VAOT – TRAFFIC COUNTER”) in the scatterplots presented in Appendix I, Appendix J, and Appendix K closely overlap with the corresponding model estimates of VAOT (labeled as “VAOT – MODELED”) at all sites, suggesting the model estimates of VAOT are in the same range as on-the-ground observations of VAOT. These results provide a high degree of confidence in the validity of the VAOT estimates from the Arches Visitor Use Model presented in this report.

### PAOT/PPV

As noted in Section 2.2, direct observation counts were collected during the 2019 sampling period to measure PAOT/PPV in each study site’s viewscape. These data provide a basis to assess the validity of the Arches Visitor Use Model. Specifically, a series of simulations was conducted with the model programmed to separately simulate the visitor volume for nine dates

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<sup>37</sup> VAOT estimates based on the park-owned traffic counter data should theoretically always be greater than the observed parking counts but are lower in some cases due to measurement error in the traffic counter data. This was a consideration in how we interpreted the results of the validation plots.

<sup>38</sup> Data from September 10, 2019 were excluded from model validation for VAOT because of data gaps due to thunderstorms in the park on that date.

of the sampling period<sup>39</sup>. The PAOT/PPV estimates from 300 replications of the model for each simulated date were compared to the corresponding viewscape PAOT/PPV data collected through direct observation counts at each of the three study sites.

The direct observation counts for the Windows viewscape (labeled as “PAOT – OBSERVED”) in the scatterplots presented in Appendix L suggest that PAOT in the viewscape can be highly variable, even from moment to moment at times. Despite this, the observation data generally overlap very closely with the corresponding model estimates of PAOT (labeled as “PAOT – MODELED”) when the variability of the observation data are relatively low. In cases where the observation data are highly variable, the corresponding model estimates generally pass through the center of the data scatter. These results suggest the model estimates of PAOT in the Windows viewscape are valid representations of on-the-ground conditions during periods of low to moderate variability in PAOT and valid representations of central tendencies for periods of high variability in on-the-ground conditions.

The direct observation counts for the Delicate Arch viewscape (labeled as “PAOT – OBSERVED”) in the scatterplots presented in Appendix M closely overlap with the corresponding model estimates of PAOT (labeled as “PAOT – MODELED”), for the most part. In a few cases, the model appears to overestimate PAOT to some degree during the 11:00 a.m. hour. However, this occurs in only a subset of the validation plots. These results suggest the model estimates of PAOT in the Delicate Arch viewpoint are valid representations of on-the-ground conditions, but may overestimate PAOT to some degree during the late morning and early afternoon hours under some conditions (e.g., the effects of lightning storms and similar weather events on PAOT may not be well represented by the model).

The direct observation counts for the Devils Garden viewscape (labeled as “PPV – OBSERVED”) in the scatterplots presented in Appendix N suggest that PPV in the viewscape is highly variable, even from moment to moment at times. This is to be expected, given the focus of the viewpoint on a section of trail where visitors flow through the space, rather than a destination where visitors congregate. Consequently, the observation data tend to “scatter across” rather than overlap closely with the corresponding model estimates of PPV (labeled as “PPV – MODELED”). That said, the model estimates generally pass through the center of the corresponding scatters of observation data. These results suggest the model estimates of PPV in the Devils Garden viewscape are valid representations of central tendencies for the high variable on-the-ground conditions.

## Entrance Station Vehicle Queue Counts

As noted in Section 2.2, hourly direct observation counts of entrance station vehicle queue length were collected during the 2019 sampling period. These data provide a basis to assess the validity of the Arches Visitor Use Model. Specifically, a series of simulations was conducted with the model programmed to separately simulate the visitor volume for eight dates of the

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<sup>39</sup> Data from September 10, 2019 were excluded from model validation for PAOT/PPV because of data gaps due to thunderstorms in the park on that date.

## Arches National Park

sampling period<sup>40</sup>. Entrance station vehicle queue length estimates recorded every 30 seconds from 300 replications of the model for each simulated date were compared to the corresponding entrance station queue length count data collected via direct observation counts.

Direct observation counts of queue length were recorded once per hour each sampling day, resulting in a total of eight observations per sampling day (as summarized in Section 3.1). As such, sampling error is high for the on-the-ground queue counts. For this reason, model estimates of entrance station vehicle queue length were validated against both the average and the maximum observed queue length counts.

The direct observation counts (labeled as “WEEKDAY” and “WEEKEND/HOLIDAY”) in the scatterplot presented in Appendix O overlap with the corresponding model estimates of entrance station vehicle queue length (labeled as “QUEUE LENGTH – SIMULATED”), suggesting the model estimates of entrance station vehicle queue length are in the same range as on-the-ground observations of entrance station vehicle queue length. However, the validation plot suggests mean queue length estimates from the model may underestimate queue lengths to some degree or the observation data may differ from model means due to high sampling error in the observation data. In either case, these results suggest that the queue length at the entrance station may be more stochastic and dynamic than is suitable to characterize with measures of central tendency of the simulation model outputs. Instead, it may be more suitable to report ranges and distributions of queue lengths from the simulation model results, which appear from the validation results to coincide with the range and distribution of queue lengths observed on the ground.

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<sup>40</sup> Data from September 1, 2019 were excluded from model validation for entrance station vehicle queue counts because the entrance station was closed for a period of time on that date to manage congestion in the park. Data from September 10, 2019 were excluded from model validation for entrance station vehicle queue counts because of data gaps due to thunderstorms in the park on that date.

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