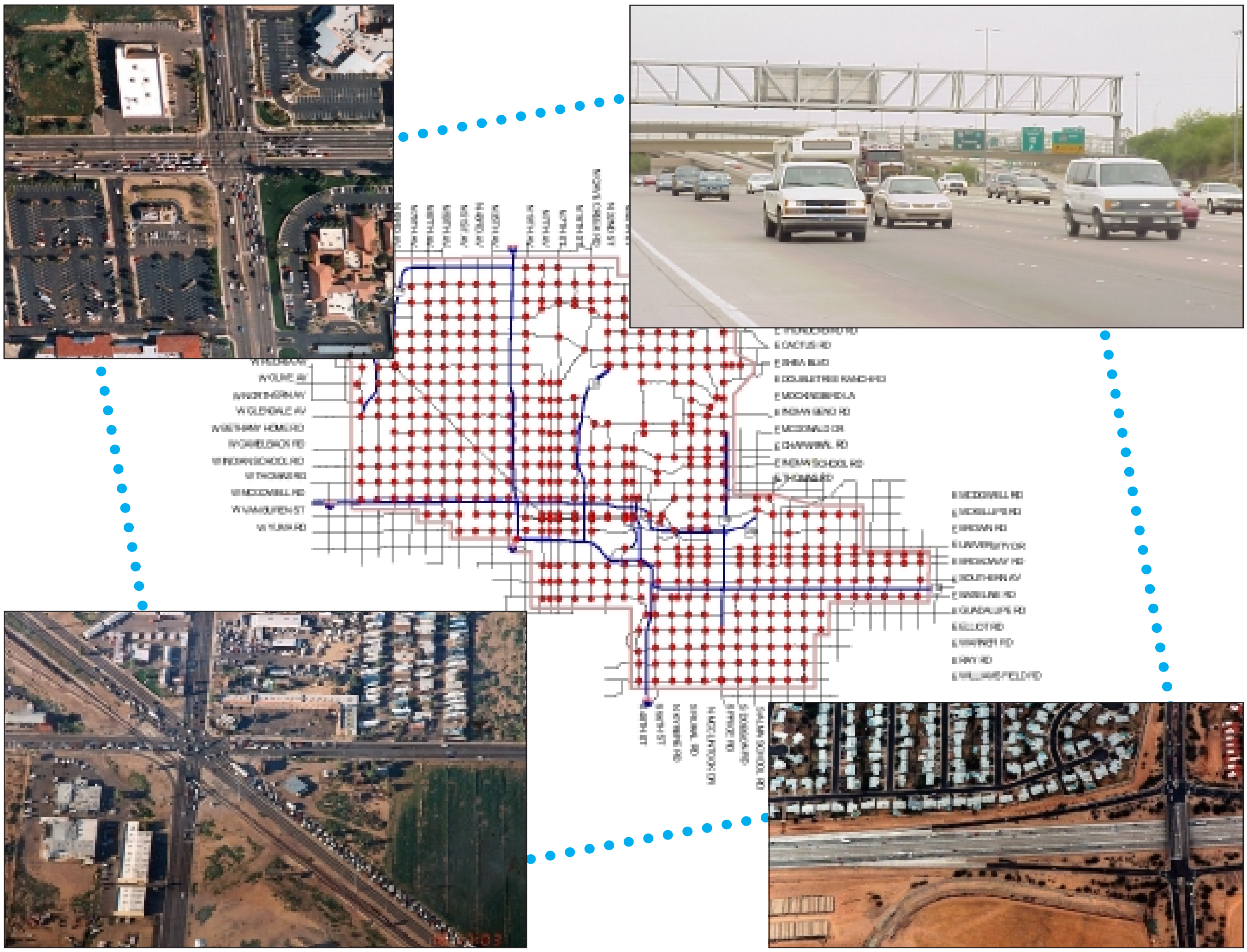
1998 MAG Regional Congestion Study



Final Report

September 2000

MARICOPA ASSOCIATION of GOVERNMENTS

Final Report

1998 MAG REGIONAL CONGESTION STUDY

Conducted for the Maricopa Association of Governments

By: Traffic Research & Analysis, Inc.
Skycomp Inc.
Mini/Micro Technology, Inc.
Heffernan & Associates
ATD, Northwest

September 29, 2000

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1. INTRODUCTION

The Maricopa Association of Governments (MAG) is the designated Metropolitan Planning Organization (MPO) for the Phoenix area. In this role, MAG serves as the central focus for a wide variety of transportation planning activities that encompass all modes of transportation. The agency coordinates and provides technical support to many regional planning studies. MAG is also an important source of transportation data used in various traffic engineering studies and roadway design projects undertaken by its member jurisdictions and private organizations. Consequently, MAG needs accurate and objective data in order to maintain both the validity and the credibility of the decisions that may be based on these studies.

A major study completed in 1991 provided MAG, for the first time, with an electronic database of detailed traffic information that could be used to measure the relative congestion at major intersections and on selected freeway segments throughout the Valley. These data were then used to identify those locations operating under, near, or over capacity in the fall of 1989 (when the data were collected). This study also included extensive evaluations of different data collection and analysis techniques to help MAG staff members determine the most accurate and cost-effective ways of monitoring congestion on a periodic basis.

The Phoenix area has changed dramatically since 1989. Phenomenal population growth, coupled with extensive freeway construction and other road building, has altered regional travel patterns significantly over the past ten years. Therefore, MAG felt it was time to conduct a major update of the traffic database in order to provide information on current levels of congestion.

STUDY OBJECTIVES

The overall purpose of the 1998 MAG Regional Congestion Study was to provide updated traffic data for the MAG transportation planning process. These data would be used to: (1) ensure that the travel demand forecast models created and maintained by MAG continue to provide a reasonable representation of current and future traffic conditions, (2) provide input to regional transportation planning studies, and (3) provide information needed for local traffic studies and roadway design projects. The study also provided an opportunity to expand the database to cover a larger geographic area and to include additional information (e.g., vehicle classification data) that would be useful to transportation planners and engineers. In addition, any changes in the severity and/or duration of peak-period traffic congestion might be identified by comparing the results of the 1998 study to the results reported in the earlier study.

STUDY TEAM MEMBERS

Due to the diverse nature of the data items to be collected and the importance of having such data be as accurate as possible, the 1998 Regional Congestion Study was conducted by a team of specialists, each selected for specific expertise in one or more of the technical areas needed to achieve the study objectives:

- *Traffic Research & Analysis, Inc. (TRA)* served as the Prime Consultant – taking responsibility for the overall administration, coordination, and management of the study. TRA also conducted all of the turning movement counts and most of the machine counts performed for this study.

- *Skycomp Inc.* was responsible for all aerial photography and reduction of the data derived from this source. Skycomp also produced two CD-ROMs that are part of the study documentation.

- *Mini/Micro Technology, Inc. (M/MT)*, which specializes in systems and software engineering, was responsible for the database design and management.

- *Heffernan & Associates (H&A)* provided the traffic engineering expertise needed for specific work tasks, such as traffic estimation and interpretation of capacity analysis results. H&A also prepared the final report and documentation of the individual work tasks required to complete the study.

- *ATD, Northwest,* which provides video traffic surveys, was responsible for collecting and analyzing the vehicle classification data.

AVAILABLE DOCUMENTATION

This report provides a fairly comprehensive overview of the study methodology, findings, and conclusions. However, additional information may be found in the work papers prepared for individual study tasks. In particular, *Work Paper for Task #7: Database Report* (prepared by Mini/Micro Technology, Inc.) provides detailed documentation of the MAG database, including a complete description of its organizational structure and the data contained therein.

Two CD-ROMs, which contain information derived from the analysis of aerial photographs (conducted by Skycomp Inc.) are also available: *Photolog of Selected Highways in the Metropolitan Phoenix Planning Region* and *Traffic Quality in the Metropolitan Phoenix Planning Region.* The latter CD-ROM also contains a traffic count map *(1998 MAG Average Daily Traffic Map)* and four work papers prepared for this study *(Database Report, 1998 Vehicle Classification Report, Methodology to Calculate Signal Cycle Lengths,* and *Documentation for LOS Estimation Program)*, as well as a publication from the 1989 MAG Congestion Study entitled *Analysis of Traffic Congestion and Related Problems in the MAG Area: Documentation of Selected Traffic Characteristics*.

2. DATA COLLECTION ACTIVITIES

This chapter describes the different types of traffic data included in the MAG database and how they were collected during the 1998 Regional Congestion Study.

STUDY AREA

Exhibit 1 shows the study area, which was defined to include all parts of the Valley likely to be experiencing significant peak-hour congestion. The outermost limits of the study area are Beardsley Road on the north, Power Road on the east, Chandler Boulevard (Williams Field Road) on the south, and 107th Avenue on the west. This includes portions of Chandler, Gilbert, Glendale, Guadalupe, Mesa, Paradise Valley, Peoria, Phoenix, Scottsdale, Tempe, and unincorporated Maricopa County.

Major Intersections

A total of 669 "major intersections" were analyzed in this study (see Exhibit 2). This count includes 498 arterial intersections, 79 freeway diamond interchanges (with each diamond interchange counting as two separate intersections) and 13 freeway urban interchanges (with each urban interchange counting as a single intersection.)

Freeway Segments and Ramps

Approximately 231 directional miles of existing freeways were also analyzed. A total of 114 freeway segments (one-way links between adjacent interchanges) were defined for the purposes of this study; these segments were usually, although not always, about one mile long. The database also contained information for 26 free-flow ramps (where traffic exits a freeway and merges into traffic already on an arterial street, or another freeway, without stopping) and 86 diamond interchange on-ramps.

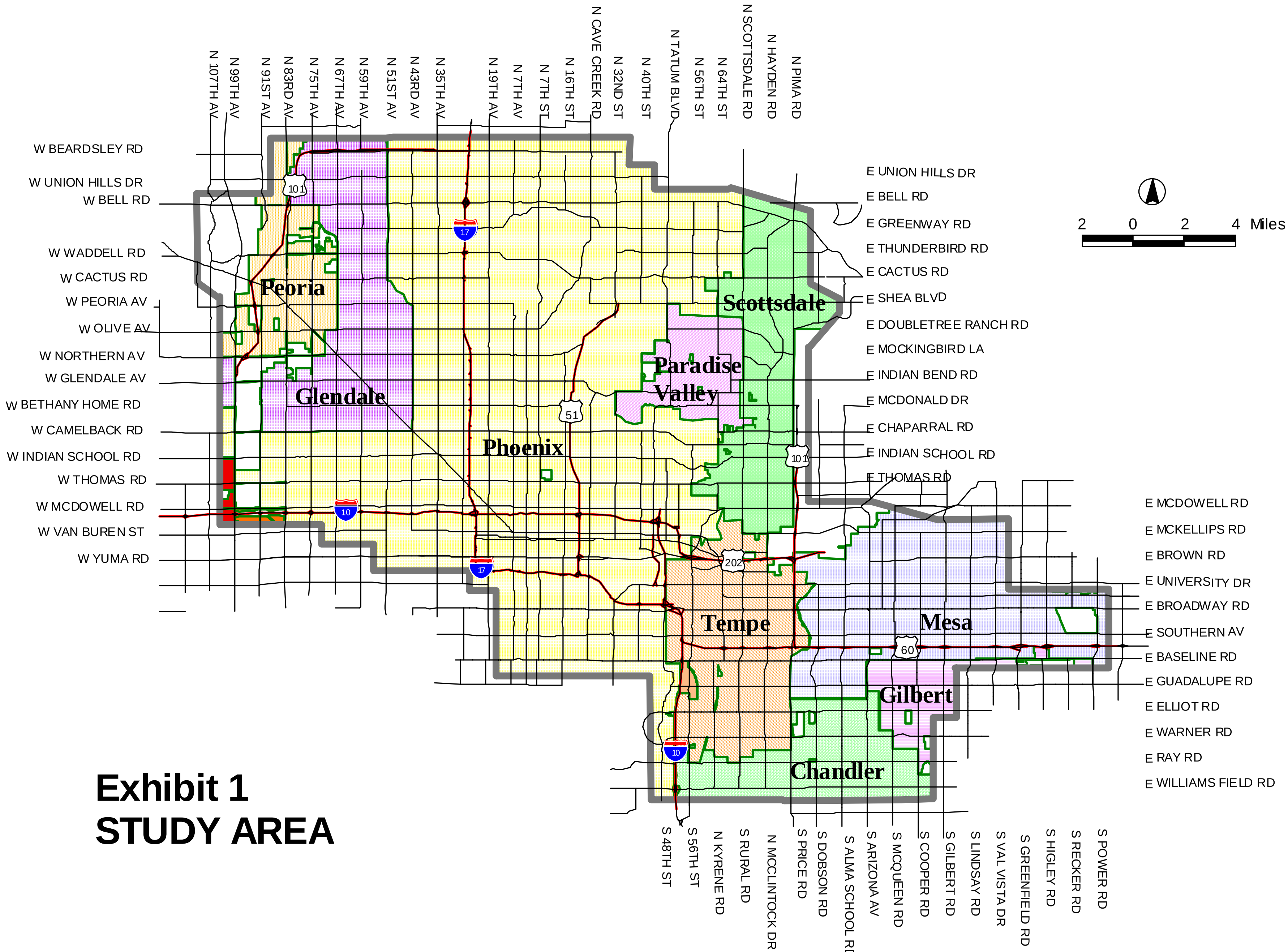


Exhibit 1
STUDY AREA

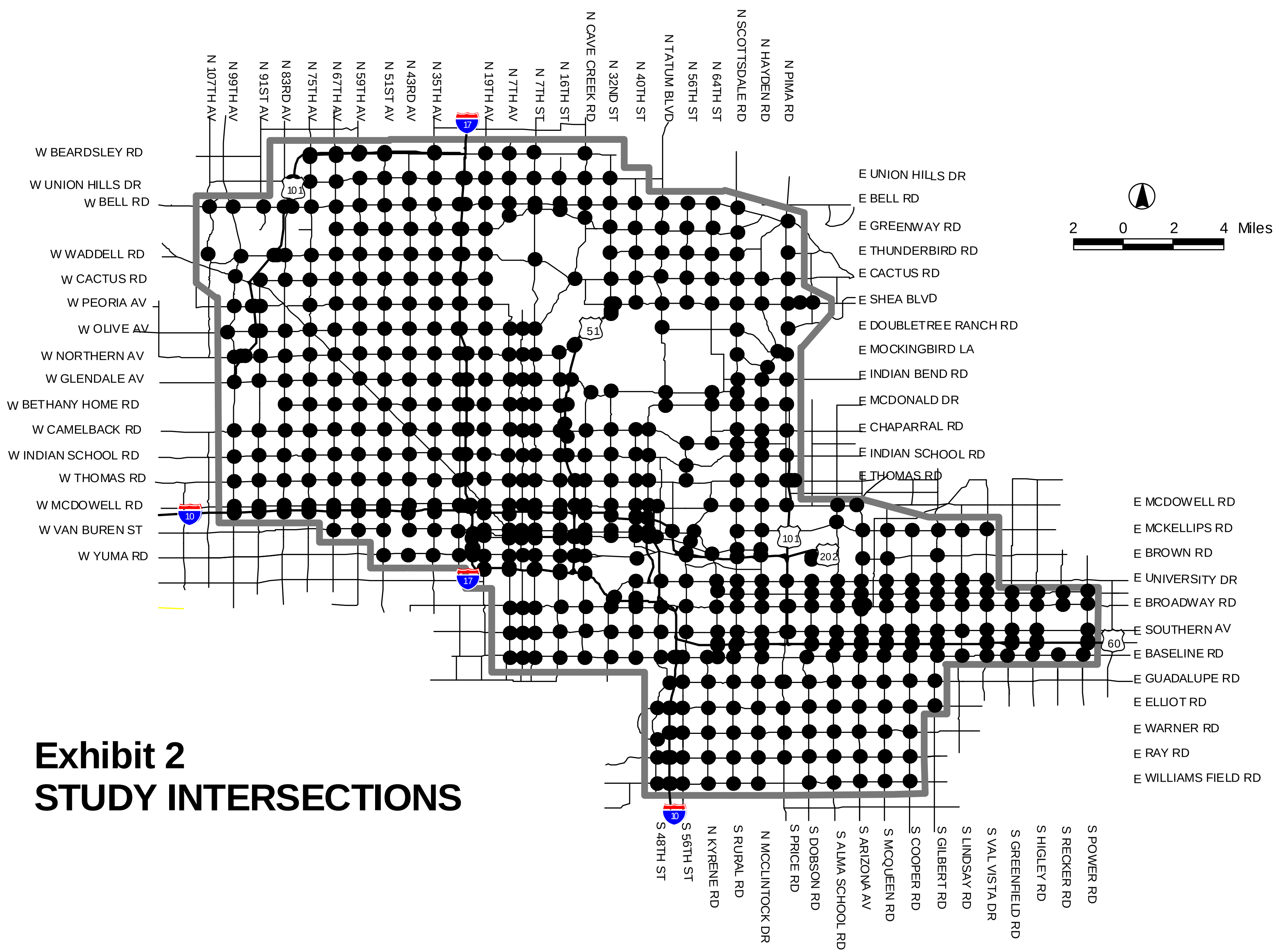


Exhibit 2
STUDY INTERSECTIONS

TRAFFIC VOLUME DATA

Two types of traffic volume data were collected during the 1998 Regional Congestion Study. Machine counts were used to collect 24-hour (or more) traffic volumes on selected intersection approaches, freeway ramps, and mainline freeway segments. These were supplemented by manual turning movement counts conducted at selected intersections during AM and PM peak periods.

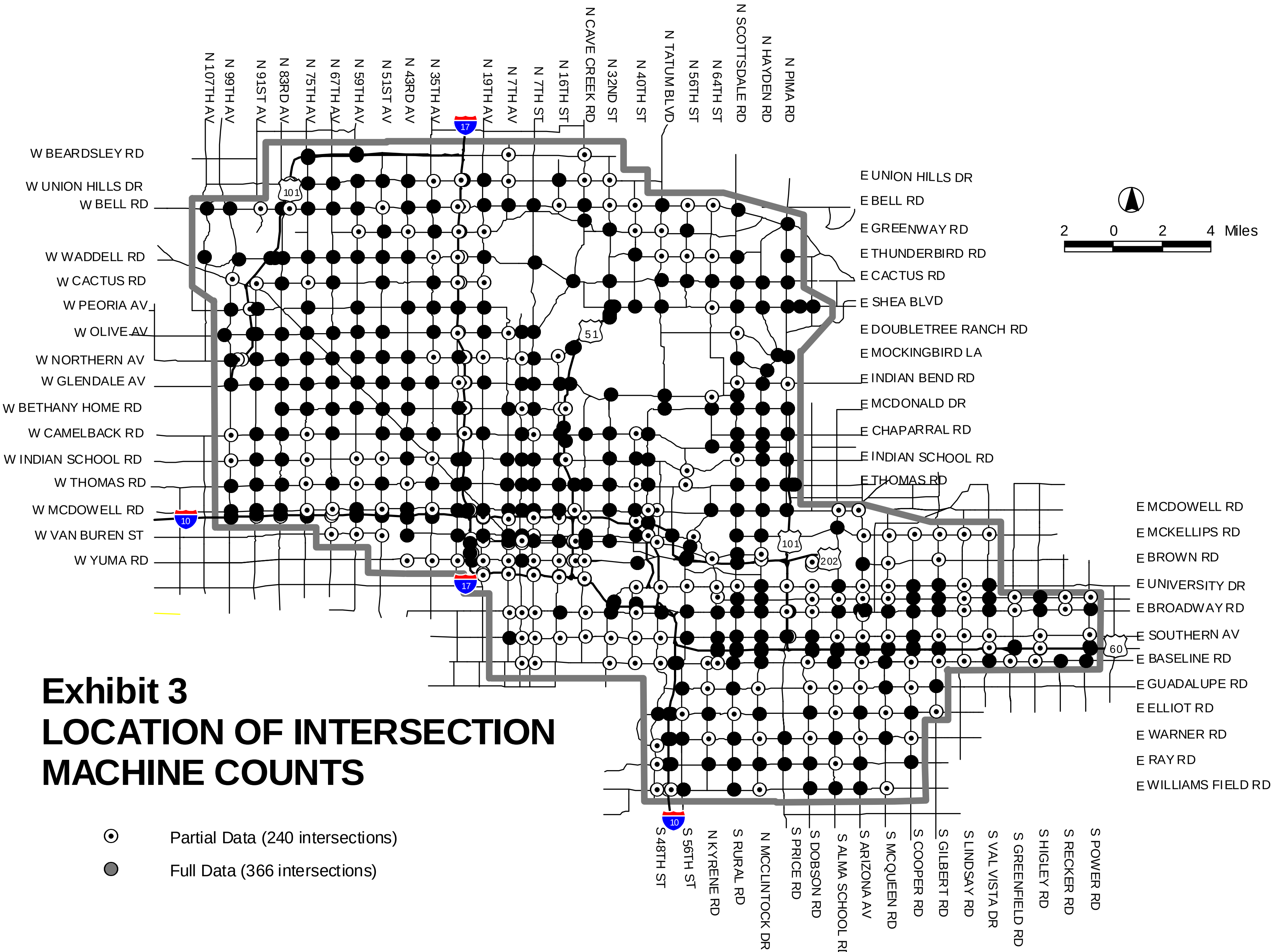
Machine Counts

The cooperative efforts of MAG and several of its member agencies made it possible to greatly expand the number of new machine counts that could be added to the MAG database. The Cities of Scottsdale and Phoenix, as well as Maricopa County, routinely conduct traffic counts using their own personnel and equipment, and these agencies agreed to provide the results to MAG. Four other cities – Chandler, Gilbert, Glendale, and Peoria – had already contracted individually with the Prime Consultant (TRA) to collect traffic data within their jurisdictions. Three agencies – Mesa, Tempe, and the Arizona Department of Transportation (ADOT) – do both; they collect some data themselves and contract with TRA for other counts. By coordinating all of the counts available from these myriad sources, duplicate data collection efforts were avoided. Also, TRA was often able to piggyback onto already scheduled counts and reduce its overall data collection costs. These cost savings allowed the available MAG funding to cover more count locations.

Exhibit 3 shows the locations of the 606 intersections where mechanical counters were placed to collect traffic volume data. At 366 intersections, traffic counts were conducted on all approaches. However, at the remaining 240 intersections, non-MAG funding was used to collect the data and traffic counts were available for only some of the intersection approaches.

Machine counts were collected at 1,962 intersection approaches between January 1997 through March 1999, with approximately 60 percent (1,152 counts) occurring during the October 1997 – May 1998 time period. Most of the counts conducted by TRA covered 48 consecutive hours (recorded by 15-minute intervals) and were taken on weekdays (but not earlier than noon on Mondays and not later than noon on Fridays). The City of Phoenix provided 48-hour machine

Exhibit 3
LOCATION OF INTERSECTION MACHINE COUNTS



counts for 117 locations – 19 intersection approach counts and 98 mid-block counts – while the City of Scottsdale provided them for 118 intersection approaches. All of these counts were also taken on weekdays (Monday through Friday). Some counts funded by Mesa, Gilbert, Chandler, and Peoria covered only a 24-hour period (recorded at 15-minute intervals) and were collected on Tuesdays, Wednesdays, and Thursdays only.

All of the machine counts taken on arterial streets utilized pneumatic road tube detectors. However, freeway volume data were collected by TRA using permanently installed loop detectors or were obtained directly from ADOT's Freeway Management System (FMS) database.

Several quality control checks were utilized to ensure the accuracy of the count data. TRA's field technicians performed verification tests in the field when the machines were set up, and again when they were taken down, to make certain that the machines were working properly. A technician also made a manual check after the data for each count was downloaded and printed out, searching for inconsistencies or unusually large variations between intervals. After the counts were delivered to MAG, MAG staff used a count viewer program, developed by M/MT for this study, to look for inconsistencies between AM and PM peak periods.

After these checks were made, any volume data that were identified as being inconsistent with overall travel patterns or otherwise "suspicious" were cropped out – provided that at least 24 consecutive hours of "good" data still remained after the deletion. If this was not the case, the count was redone and the new data replaced the questionable data in the MAG database.

Turning Movement Counts

TRA staff conducted manual turning movement counts at 229 intersections (see Exhibit 4). These counts were conducted during the AM and PM peak periods (7:00 – 9:00 AM and 4:00 – 6:00 PM). As with the machine counts, no turning movement counts were taken on Monday mornings or Friday afternoons. Nearly all of these counts were collected between October 1997 and March 1998, although a few recounts were taken later.

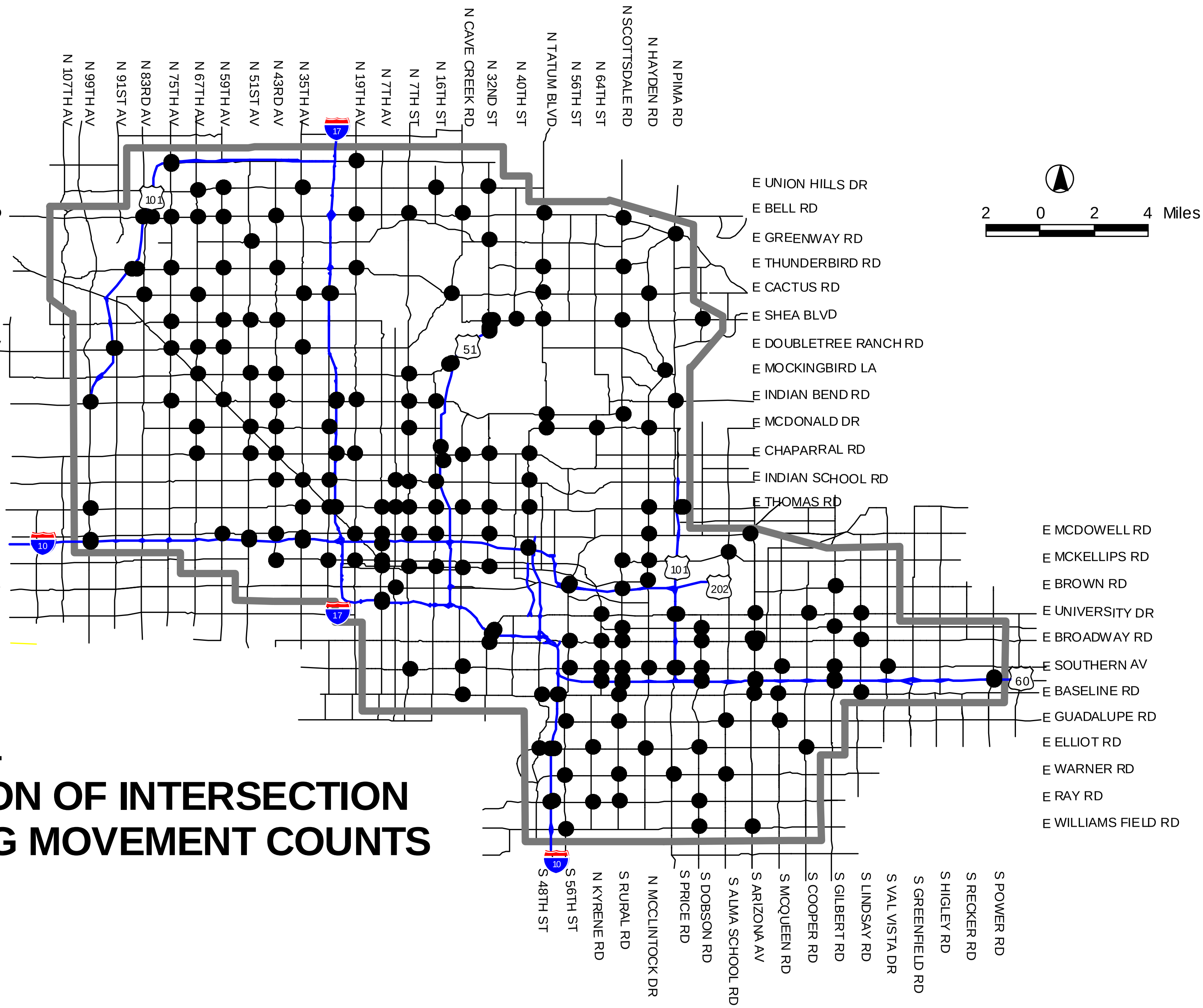


Exhibit 4
LOCATION OF INTERSECTION TURNING MOVEMENT COUNTS

Whenever possible, turning movement counts were conducted at the same time as the corresponding machine counts so that the two results could be checked against each other to identify any inconsistencies or other discrepancies as part of the quality control process.

AERIAL PHOTOGRAPHY

Skycomp Inc. was responsible for obtaining aerial photographs of peak-period traffic conditions in the study area. Because the level of traffic congestion at a particular location can vary considerably over a two-hour time period (7:00 – 9:00 AM in the morning or 4:00 – 6:00 PM in the evening), a large number of photographs – usually 48 – had to be taken at regular intervals for each study location. All survey flights were conducted in March - June of 1998.

Five flight patterns were devised to cover the entire study area (see Exhibit 5). Four of these were "racetrack" tours, whereby the airplane would fly from west to east above an arterial street, reverse course at the east end, and fly back along another arterial street two miles south of the original one. This 20-minute flight pattern would then be repeated six times during each two-hour flight. Therefore, in order to generate 48 photographs, each flight had to be repeated for four morning and four evening survey periods. The fifth flight pattern – Tour E – covered a more limited area and required just ten minutes for a round trip. Twelve photographs could be obtained during each two-hour flight, so it only had to be flown twice in the morning and twice in the evening.

In some cases, scheduled flights had to be cut short due to the formation of clouds that obscured the photographer's view. Supplemental flights were then added at a later date to obtain any missing data.

A series of color photographs (4" x 6"), with a time-of-day stamp included in the lower right-hand corner, were produced and sorted by location. These were then used for determining vehicle queue lengths at major intersections and vehicle densities on freeway segments, as discussed in Chapter 3.

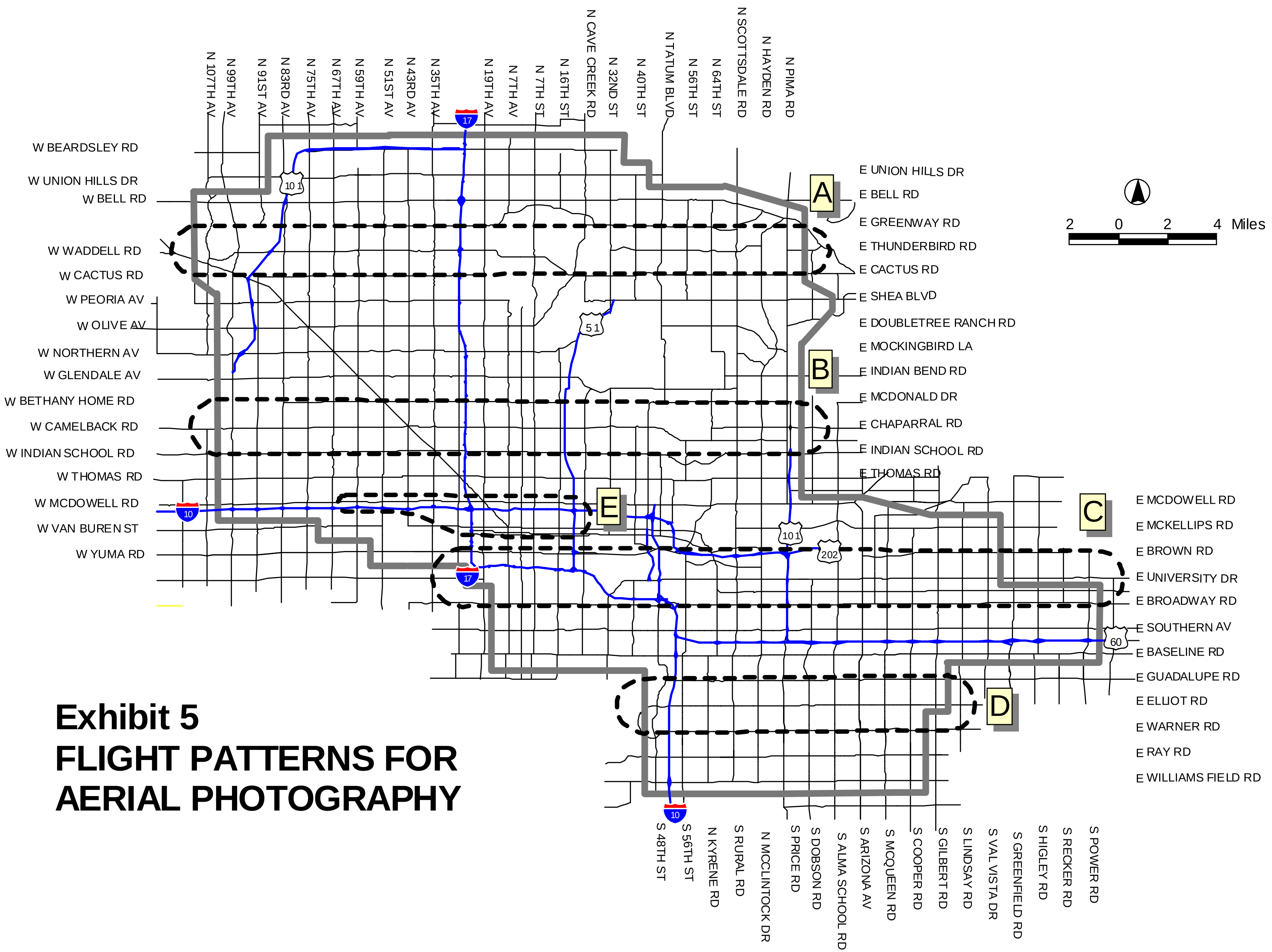
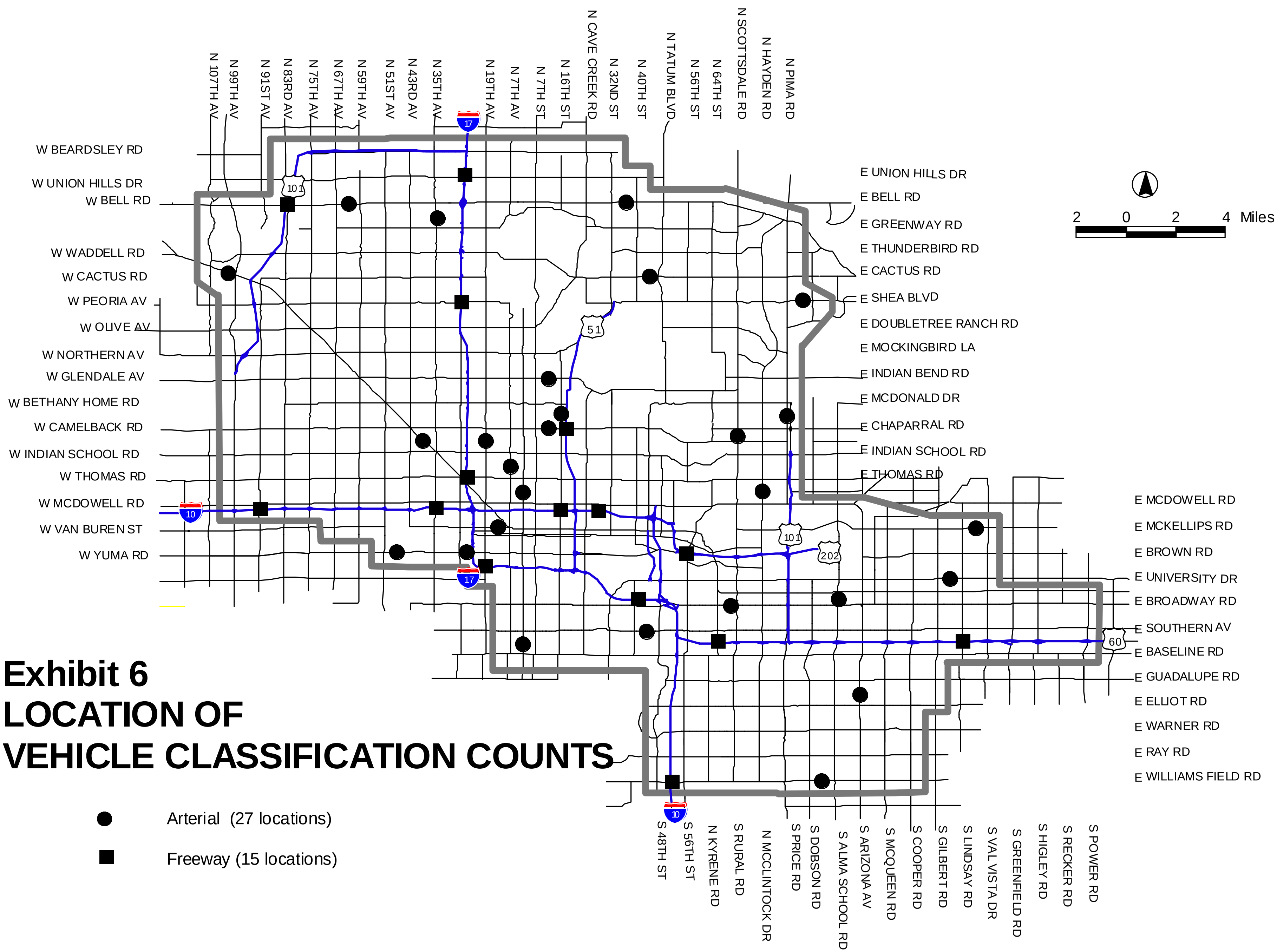


Exhibit 5
FLIGHT PATTERNS FOR AERIAL PHOTOGRAPHY

Exhibit 6
LOCATION OF VEHICLE CLASSIFICATION COUNTS



● Arterial (27 locations)

■ Freeway (15 locations)

VEHICLE CLASSIFICATION DATA

Vehicle classification data were collected for selected locations on arterial streets and freeways (see Exhibit 6). These locations were chosen to provide representative data for the study area. Fifteen of the survey sites involved freeways, while 27 sites were on arterial streets.

ATD, Northwest used video surveillance to collect vehicle classification data on the freeways. Video cameras were set up to observe all lanes of travel for each direction at a particular survey site. The cameras recorded traffic for approximately 22 hours (roughly 2:00 AM until 12:00 AM), although only data from the 2:00 AM – 10:00 PM time frame (20 hours) were actually used in this study. For each hour of videotape, technicians would classify all vehicles observed traveling past the camera during a single fifteen-minute time period; this produced a total of five hours' worth of actual data for each direction of travel at the 15 freeway sites. Each vehicle was placed into one of ten different categories for vehicle type, and the results were tabulated. All of the freeway classification data were collected on weekdays in mid-April of 1998.

Mechanical traffic counters, with pneumatic pressure tubes, were used to collect vehicle classification data on arterial streets. These counts were conducted by the Maricopa County Department of Transportation (MCDOT) between March 11 and June 17, 1998. Data were recorded for each direction of travel over a 24-hour period (by 15-minute intervals). Data were only collected on weekdays. These counts were conducted in accordance with standard procedures published by the Federal Highway Administration, which classifies traffic into 13 different vehicle types.

In order to make the data more useful to MAG, a simplified vehicle classification scheme was developed for reporting the results of this study. It included eight broad vehicle types:

Category	Vehicle Type
1	Motorcycle
2	Passenger car
3	Pick-up truck, van, sport utility vehicle
4	Buses
5	Single-unit truck, recreational vehicle
6	Three-axle truck
7	Single-trailer truck
8	Multi-trailer truck

OTHER INTERSECTION DATA

Two other types of data were entered into the database for each study intersection. Information about signal timing and lane configurations are both required as input to the intersection capacity analyses under the procedures established by the *Highway Capacity Manual* and used in this study.

Geometric Data

Field surveys were conducted in order to collect information regarding the number of traffic lanes on each approach of a study intersection, as well as the particular turning movements (left, straight, or right) permitted from each lane. TRA personnel provided a sketch containing this information for each of the 229 intersections where they conducted turning movement counts. H&A collected the geometric data for another 383 intersections, while MAG staff was responsible for the remaining intersections. All geometric data were collected between October 1997 and May 1998, and are representative of existing conditions at that time.

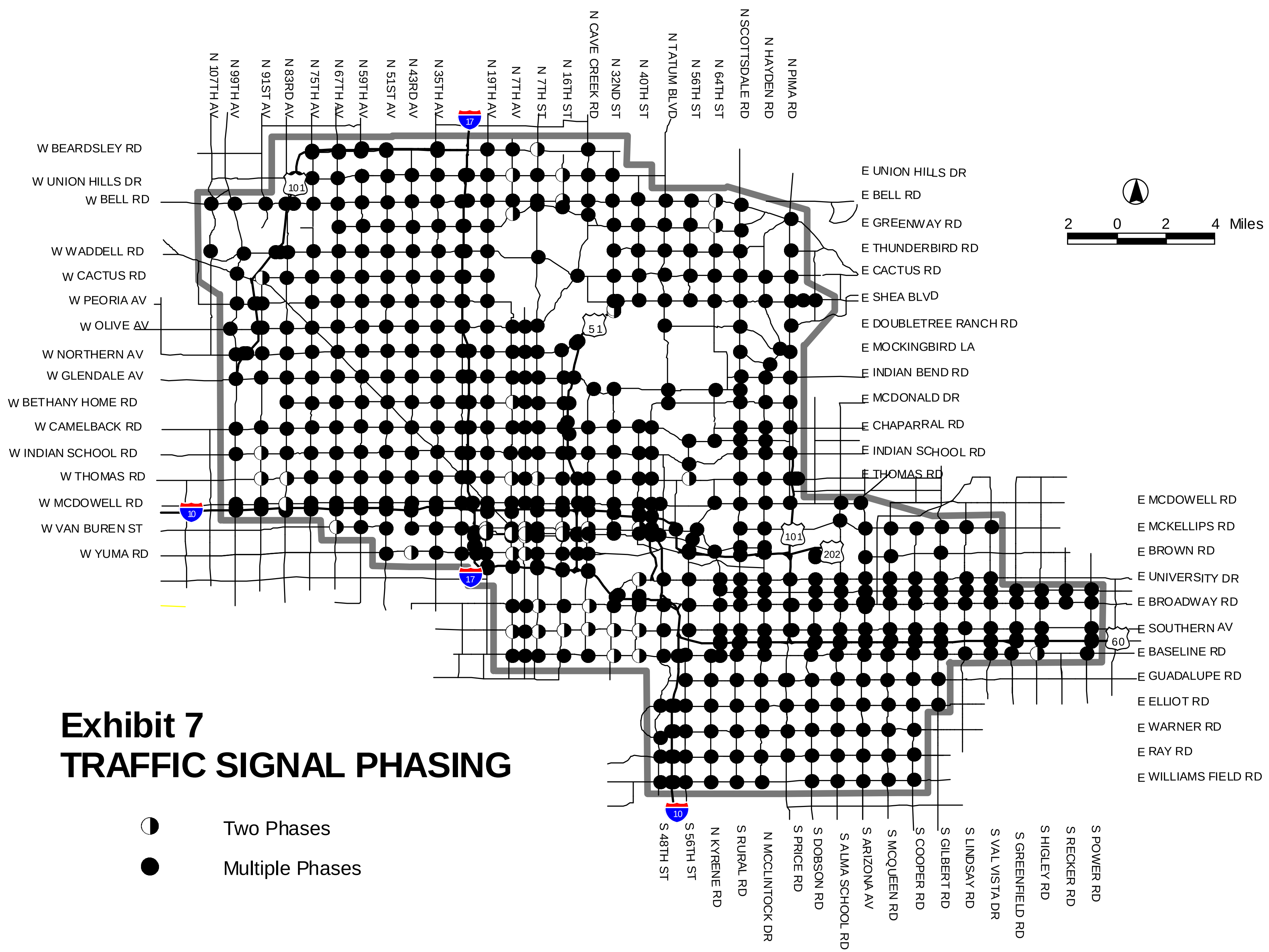
Geometric data were entered into the MAG database by H&A. As this was being done, the data were checked for both completeness and reasonableness; comparisons were also made to the lane configurations noted for that particular intersection in 1989. This quality control check generated a list of all geometric data that were missing or appeared questionable. Follow-up field checks were then conducted in order to verify the data for these specific locations.

Signal Timing Data

In 1998, all but four of the 669 study intersections operated under traffic signal control. The four unsignalized major intersections were: 99th Avenue/Thomas Road, Invergordon Road/ McDonald Drive, Pointe Parkway/Guadalupe Road, and Recker Road/Baseline Road. As shown in Exhibit 7, two-phase signals can be found at 45 locations, but multi-phase signals are far more common at major intersections.

MAG obtained signal timing data for each signalized intersection directly from the jurisdiction having responsibility for that particular location. The number of signal phases and the total cycle length for the AM and PM peak periods were entered into the MAG database. If an intersection had a fully-actuated signal, a nominal cycle length was calculated using a methodology based on intersection configuration and traffic volumes. This methodology is documented in more detail in a separate work paper prepared for this study.

Exhibit 7
TRAFFIC SIGNAL PHASING



3. DATA REDUCTION AND ANALYSIS PROCEDURES

Much of the raw data had to be reduced, processed, or otherwise manipulated, in order to produce the information necessary to achieve the study objectives. This chapter describes how the various data items identified in Chapter 2 were subsequently used during this study.

USING DATA FROM THE TRAFFIC COUNTS

All machine counts recorded traffic volumes by 15-minute intervals. In most cases, such data were collected over a period of two or three days. In order to generate a single value for each 15-minute period, the average of all available counts for that particular time period was calculated. The sum of these average values for all 15-minute periods then became the daily (24-hour) count used in this study for each freeway segment and intersection approach.

The AM peak hour for each freeway segment was identified by determining the highest sum of four consecutive 15-minute volumes occurring between 7:00 and 9:00 AM. The PM peak hour was identified in a like manner by looking at the volumes recorded between 4:00 and 6:00 PM. For major intersections, the AM and PM peak hours were determined by summing the traffic volumes on all approaches to find the maximum total hourly volumes during the 7:00 – 9:00 AM and 4:00 – 6:00 PM time periods.

After defining the AM and PM peak hours, peak hour factors (PHF) were calculated for each freeway segment and each intersection approach for which traffic counts were available. This was done by multiplying the peak 15-minute volume for the peak hour by four and then dividing this product into the total hourly volume. Peak hour factors are a measure of short-term fluctuations in traffic flows during the peak hours. Although peak hour factors can range between 0.25 and 1.00, they will most commonly fall into the 0.80 - 0.95 range on high-volume intersection approaches.

Because the traffic volume data were collected over an extended period of time, a seasonal adjustment factor was applied to each count in order to normalize the effects of taking counts at different times of the year. The freeway adjustment factors were developed from 1999 Freeway Management System data that were provided by the Arizona Department of Transportation. The arterial factors were based on a composite of monthly adjustment factors provided by MAG member agencies. These monthly factors were supplied by MAG for use in this study:

Month of Traffic Count	Adjustment Factor	
	Arterial	Freeway
January	1.02	1.03
February	0.97	0.97
March	0.97	0.95
April	0.97	0.95
May	1.01	1.00
June	1.02	0.99
July	1.06	1.01
August	1.04	1.03
September	1.01	1.04
October	0.98	0.99
November	0.98	1.03
December	0.96	1.01

ESTIMATING INTERSECTION APPROACH VOLUMES

Due to budget limitations, extensive traffic counts could not be conducted at all major intersections. Therefore, peak hour traffic volumes had to be estimated at locations where count data were not available.

At some intersections, machine counts were available for one or more of the approaches, and these data could be used to determine the peak hour. Where it was necessary to estimate the AM and PM peak hours, this was generally done by averaging the peak hours observed at surrounding intersections for which actual counts were available.

For those locations where no approach volumes were available, the AM and PM peak hour volumes had to be estimated. These estimates were generally based on data collected at nearby intersections. Using MAG node numbers, a spreadsheet listing all intersection approaches and exits in sequential order (by direction of travel) was created. First, all peak-hour entry and exit volumes already in the database – taken from either machine counts or turning movement counts – were entered into this spreadsheet. Next, a preliminary estimate of each missing volume was made, using a straight-line interpolation between available data points, and put into the spreadsheet. All of the hourly volumes (both actual and estimated) were then plotted on large maps and checked for reasonableness and consistency. The entire procedure was done twice – once for the AM peak hour and once for the PM peak hour.

ESTIMATING INTERSECTION TURNING MOVEMENTS

Due to the enormous labor costs involved in conducting manual turning movement counts, such counts could be conducted at only 229 intersections. Therefore, peak-hour turning movements had to be estimated for the remaining 440 intersections in the study area.

A matrix balancing algorithm was used to produce estimated turning movements from the hourly approach and exit volumes (actual or estimated). Seed values of 10% left turns, 75% straight, and 15% right turns were used initially for most intersections. However, at locations where the through movement was expected to be relatively small (for example, at freeway exit ramps), the seed values were 40% left turns, 20% straight, and 40% right turns. These values generally represent the average conditions observed at a sampling of locations where actual turning movement counts were available. The algorithm then applied an iterative process to balance inbound and outbound flows on each leg of the intersection and throughout the study area in order to produce estimates of the peak-hour turning movements at all intersections where actual counts were not conducted.

DETERMINING QUEUE LENGTHS AND VEHICLE DENSITIES

The aerial photos taken by Skycomp Inc. were used to determine both queue lengths at major intersections and vehicle densities on freeway segments. This information was then used to develop estimates of the relative amount of congestion (i.e., levels of service) occurring throughout the study area during the AM and PM peak periods.

Queue Lengths at Major Intersections

After being sorted by location, the time-stamped aerial photographs were used to determine the number of queued vehicles on each approach of a particular signalized intersection. At locations where one or more exclusive left-turn lanes were provided, left-turning vehicles on that approach were counted separately from vehicles turning right or traveling straight through the intersection.

Because the precise moment of an aerial photograph can occur at any point in the signal cycle, vehicles within queues could be moving or stopped at that instant. Therefore, rules had to be established in order to ensure consistency in defining queue lengths. Each queue count involved three steps – identifying the head of the queue, identifying the tail of the queue, and counting all the vehicles in between these two points. The following rules were adopted to help the technicians correctly interpret the aerial data for this study:

1. *Identifying the head of the queue*. Starting at the white stop bar, work upstream to find the first queued vehicle in any of the lanes available for that particular traffic movement. (A queued vehicle is defined as any vehicle within one car length of another.) This vehicle is then marked as the head of the queue and a line is drawn across all applicable lanes on the aerial photograph.

2. *Identifying the tail of the queue*. Starting at a point upstream of all queued vehicles, work forward (downstream) until finding the last queued vehicle in any lane available for that particular traffic movement. This vehicle is then identified as the tail of the queue and a line is drawn across all applicable lanes on the aerial photograph.

3. *Counting vehicles in the queue*. Count all vehicles appearing on the aerial photograph between these two lines, regardless of vehicle spacing, across all lanes available for that particular traffic movement.

Data reduction notes, queue marks, and vehicle counts were written directly onto each photograph with a permanent marker. Flags were used to identify unusual conditions that might warrant a supervisor's review. After these reviews and other quality control checks, the queue data from each stack of photographs (representing a single intersection) were entered into the database.

Average peak hour queue lengths for each intersection approach were calculated by averaging the queue counts taken during the corresponding peak hours. Left-turn movements were treated separately from combined through and right-turn movements.

Vehicle Densities on Freeway Segments

A different technique was used to analyze the aerial data for freeway segments. Rather than queue lengths (which are used for analyzing signalized intersections), vehicle density is the parameter of interest when analyzing freeway operations. Vehicle density is the vehicle population on a specific section of freeway at a particular time, and is expressed in terms of passenger cars per mile per lane.

At the beginning of the study, specific freeway segments were identified. In most cases, these segments were defined as the distance between successive interchanges (measured from the centerline of each overpass or underpass). However, freeway-to-freeway interchanges were analyzed as a series of uninterrupted flow ramps. Aerial data were analyzed for 346 individual freeway segments – 306 mainline segments and 40 freeway-to-freeway ramp segments. A single direction of travel was represented by each freeway segment.

Guidebooks were prepared to assist technicians in analyzing the aerial data. These books contained sets of overlapping photographs, taped together in sequential order, on which the limits of each individual freeway segment was clearly marked – together with the name of the segment. The guidebook showed where each vehicle count was to begin and end, and clarified exactly which lanes should be counted or excluded where complex ramp designs were involved. The exact length and the number of lanes were also identified for each freeway segment. On segments having a designated high-occupancy vehicle (HOV) lane, the HOV lane and the general purpose lanes were analyzed separately.

Each technician received a series of time-coded aerial photographs for a particular freeway segment, together with the applicable guidebook. He or she would mark the beginning and end of each segment on the photographs, and then proceed to count the number of vehicles within these boundaries. Each vehicle was placed into one of four vehicle categories – passenger car, truck, tractor-trailer, or bus – and a separate count was kept of each vehicle type. (A small pick-up truck or van was normally classified as a "passenger car," but would be considered a "truck" if it were twice the size of an average car.) Using proprietary software developed by Skycomp, vehicle densities were calculated for each defined freeway segment. These densities were printed out in such a way that all densities for a particular 15-minute period (regardless of survey date) could be viewed side by side. A supervisor checked each segment for uniformity across days and time periods and flagged any values that appeared out of line so that those particular photographs could be re-examined. Any incorrect counts or data entry errors were corrected. In cases where traffic accidents, vehicle breakdowns, roadway construction, or other anomalies could be identified, a special code was added to the corresponding data records, and these records were excluded when calculating density averages.

After scrubbing the data in this manner, average densities were calculated for each freeway segment. Because vehicle densities are expressed in terms of passenger cars per mile per lane, a "passenger car equivalent (PCE)" was assigned to each vehicle type during these calculations:

Vehicle Type	PCE
Passenger Car	1.0
Truck	1.5
Tractor-Trailer	2.0
Bus	1.5

LEVEL OF SERVICE CALCULATIONS

"Level of service (LOS)" is the most common measurement of peak hour traffic conditions. A scale of A to F (similar to school grades) is used, with Level of Service A representing optimum flow conditions, and Level of Service F representing severe stop-and-go congestion. Specific procedures for determining the level of service can be found in the *Highway Capacity Manual*.[1]

[1] The analytical procedures used in this study are based on the 1994 version of the *Highway Capacity Manual,* which was in effect at the time this study began. Significant revisions to these procedures can be found in the most recent (1997) version of the HCM.

Intersections and freeway segments operating at LOS A through C are usually considered to operating "under capacity," LOS D is considered "near capacity, " and LOS E and F are considered "over capacity." LOS E and F indicate levels of traffic congestion and delay that are generally unacceptable to most drivers in major metropolitan areas.

In general, the level of service calculations for major intersections focus on the average stopped delay per vehicle, which is based on observed peak hour queue lengths. The level of service calculations for freeway segments are based on the traffic density (passenger cars per mile per lane) during the peak periods.

Major Intersections

The *Highway Capacity Manual* (HCM) recommends that the average stopped delay per vehicle be used to determine levels of service on urban arterial streets. Levels of service for a signalized intersection are defined in terms of the average stopped delay per vehicle entering the intersection during a 15-minute analysis period (the 15-minute period having the highest traffic volume). Traffic rarely flows uniformly throughout the hour, especially near major traffic generators, and the flow of traffic during the peak 15-minute period is typically 10 – 15 percent higher than the average flow for the entire hour. Consequently, congestion will be worse during the peak 15-minute period than during the rest of the hour.

In order to determine intersection levels of service in a cost-effective manner, MAG staff developed a two-step process – the average stopped delay for the peak hour was calculated first, and then the LOS was estimated for the 15-minute period having the highest traffic volume.

There are two approaches to determining stopped delay now in general use. One way is to calculate it using the operational analysis methodology described in the HCM; this approach uses traffic volumes, intersection geometric data, and signal data as input. The other way to determine stopped delay is to measure it as described in the Institute of Transportation Engineers' *Manual of Transportation Engineering Studies*. In this method, the number of vehicles stopped on an intersection approach is counted every 10 – 15 seconds; the total number of vehicles leaving the approach is also counted. This information is then used to estimate the average stopped delay.

A study was conducted, as part of MAG's 1989 Congestion Study, to evaluate the minimum number of samples needed to estimate stopped delay for a particular movement on an intersection approach. The results indicated that using 12 samples gave a reasonable estimate of the average queue length for that movement over the hour. The queue length data could then be used to estimate the average stopped delay during the hour through the following formula:

$$D_m = (3600 * Q_m)/V_m \text{ where}$$

D_m = Average stopped delay for a particular movement,

3600 = Number of seconds in an hour,

Q_m = Average number of vehicles queued for that movement, and

V_m = Peak hour volume of that movement.

A methodology to estimate the level of service (LOS) for each intersection approach was developed during MAG's 1989 Congestion Study. This methodology adjusts the average vehicle delay (as determined from queue length data) by taking into account the peak hour factor, traffic volumes, traffic signal characteristics, and intersection geometric data. This adjustment process uses the relationships among these variables documented in the HCM. A more complete discussion of this methodology for estimating LOS can be found in *Documentation of Selected Traffic Characteristics*, a work paper prepared for the 1989 Congestion Study.

The HCM uses the following criteria to define the various levels of service:

Level of Service	Average Stopped Delay (Sec/Veh)
A	$\leq$ 5.0
B	5.1 – 15.0
C	15.1 – 25.0
D	25.1 – 40.0
E	40.1 – 60.0
F	> 60.0

Freeway Segments

Vehicle density (measured in terms of passenger cars per mile per lane) is the parameter used by the *Highway Capacity Manual* to define levels of service for freeway segments. In this study, the following maximum densities were used to define the various levels of service:

Level of Service	Maximum Density (pc/mi/ln)
A	10
B	16
C	24
D	32
E	43
F	44 or more

The *Highway Capacity Manual* indicates that the maximum density for LOS E on a particular freeway segment can vary significantly, depending upon the free-flow speed and the number of lanes. However, after reviewing extensive traffic data available from ADOT's Freeway Management System (FMS) – a sample of which is shown in Exhibit 8 – MAG staff determined that 43 passenger cars per mile per lane represented a reasonable estimate of the upper limit for LOS E flow in the Phoenix area, and that this simplification would not significantly alter the study results.

In this study, freeway densities were determined from the vehicle counts taken from the aerial photos (after appropriate adjustments were made to convert larger vehicles into passenger-car equivalents). For a particular freeway segment or ramp, the vehicle densities derived from all available photographs for the peak 30-minute period in the morning were averaged together to obtain a single value to represent the density during the AM peak hour. The same process was also used to derive the density for the PM peak hour.

Exhibit 8
SAMPLE SPEED - DENSITY RELATIONSHIP ON FREEWAY

4. STUDY RESULTS

A primary focus of this study was to provide an objective measure of the relative congestion at major intersections and on selected freeways segments throughout the Valley. This chapter includes a summary of the major study findings regarding peak hour congestion, as well as a brief discussion of the information obtained from the various traffic counts and vehicle classification counts.

TRAFFIC VOLUME DATA

The large number of traffic counts conducted specifically for this study, supplemented with similar counts obtained from member agencies, provided MAG with detailed information about the existing traffic volumes on nearly all major arterials and freeways in the most densely developed areas of the valley. MAG staff used these counts to produce an updated (1998) regional traffic flow map.[2]

Exhibit 9 shows the 1998 average weekday traffic volumes on the Valley's freeway system. The highest volumes – well over 200,000 vehicles per day – were found on two sections of I-10 (between I-17 and SR 51, and between SR 51 and SR 143). Portions of I-17 and SR 202 carried over 190,000 vehicles per day. In general, the lowest freeway volumes were found near the outer limits of the study area – on the Agua Fria section of Loop 101, on I-10 south of Ahwatukee, and on the eastern portion of US 60.

Exhibit 10 shows the estimated number of heavy trucks carried on the various freeways. The highest truck volumes were observed on I-10, confirming the importance of this facility as a major through route for commercial traffic. Relatively few heavy trucks used SR 51 or the Agua Fria section of Loop 101.

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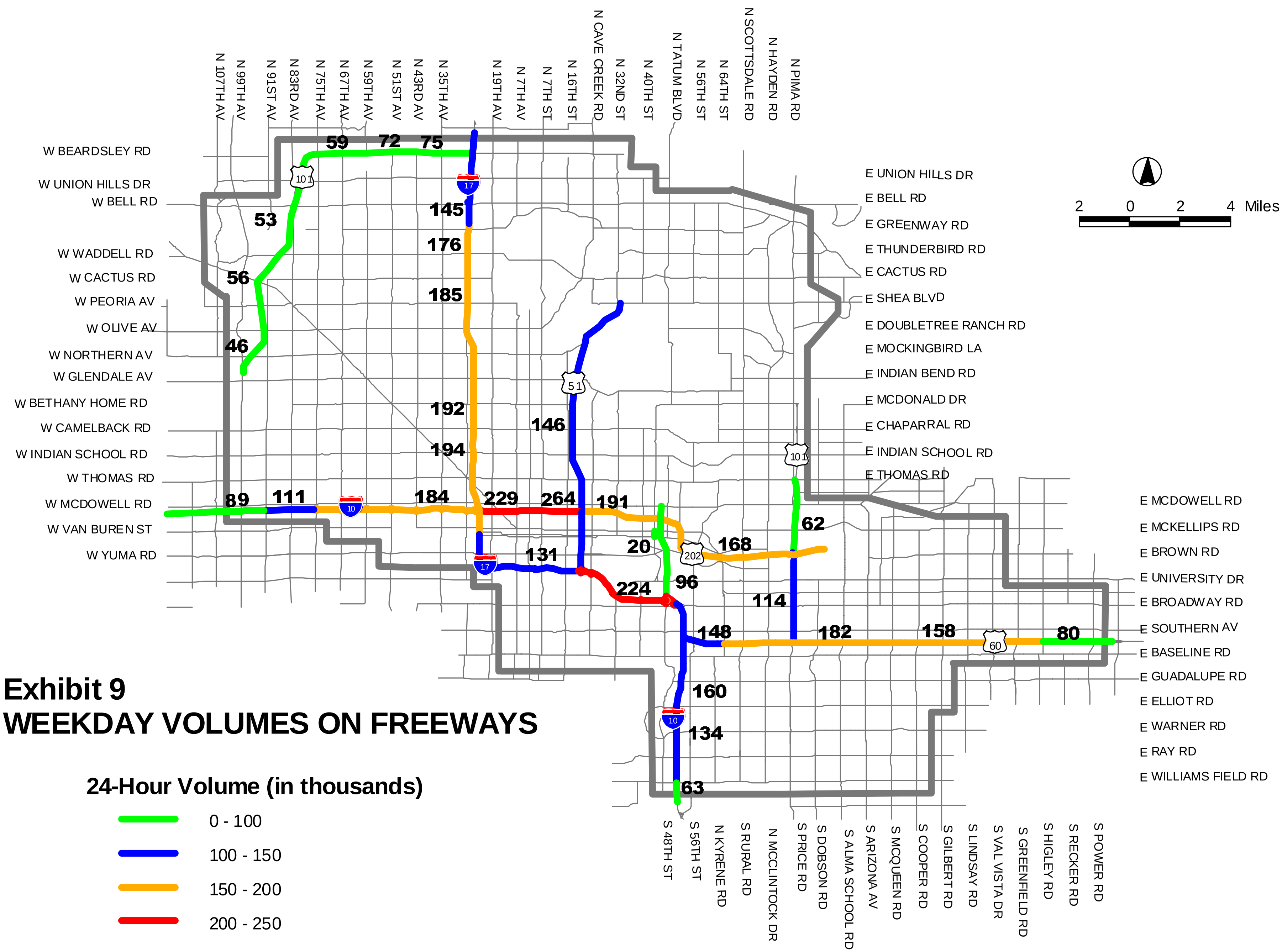
[2] Due to the large number of counts, this map could not be reproduced in this report, but it is included on a CD-ROM, *Traffic Quality in the Metropolitan Phoenix Planning Region*. A large-scale print version of the traffic count map is also available from MAG.

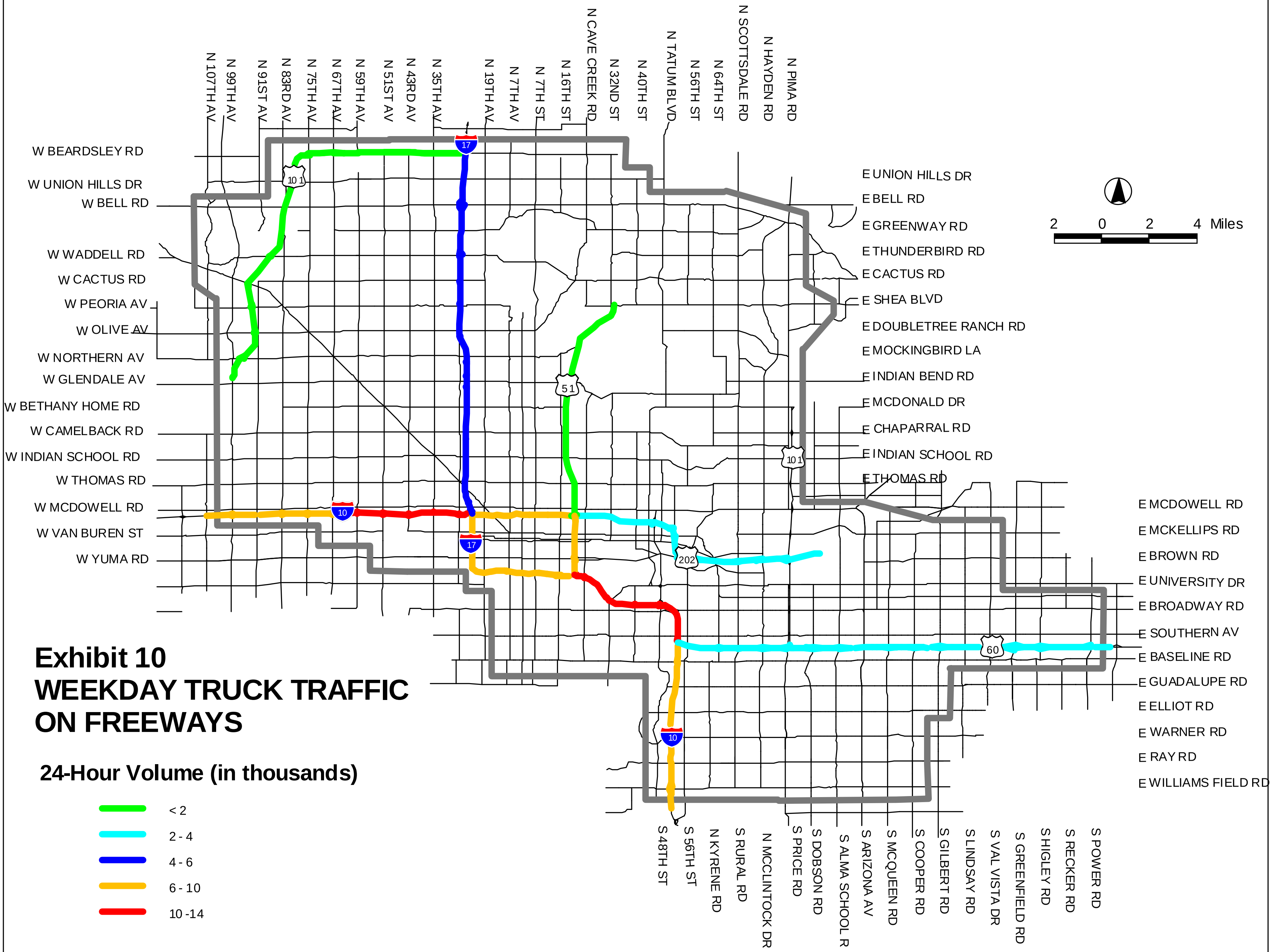
Exhibit 9
WEEKDAY VOLUMES ON FREEWAYS



24-Hour Volume (in thousands)

- 0 - 100
- 100 - 150
- 150 - 200
- 200 - 250

Exhibit 10
WEEKDAY TRUCK TRAFFIC ON FREEWAYS



VEHICLE CLASSIFICATION DATA

The vehicle mix on a particular roadway facility will affect traffic performance, because different vehicles have different operating characteristics. In particular, a single heavy truck can have an impact that is equivalent to that of several passenger cars. Therefore, the vehicle mix must be considered when analyzing peak hour operating conditions, and also when designing transportation facilities.

In this study, vehicle classification data were collected for both arterial streets and freeways. Since the vehicle mix usually varies throughout the day, the study data were divided into four time periods for reporting purposes: AM peak (6:00 AM – 9:00 AM), midday (9:00 AM – 3:00 PM), PM peak (3:00 PM – 6:00 PM), and night (6:00 PM – 6:00 AM).

Arterial Streets

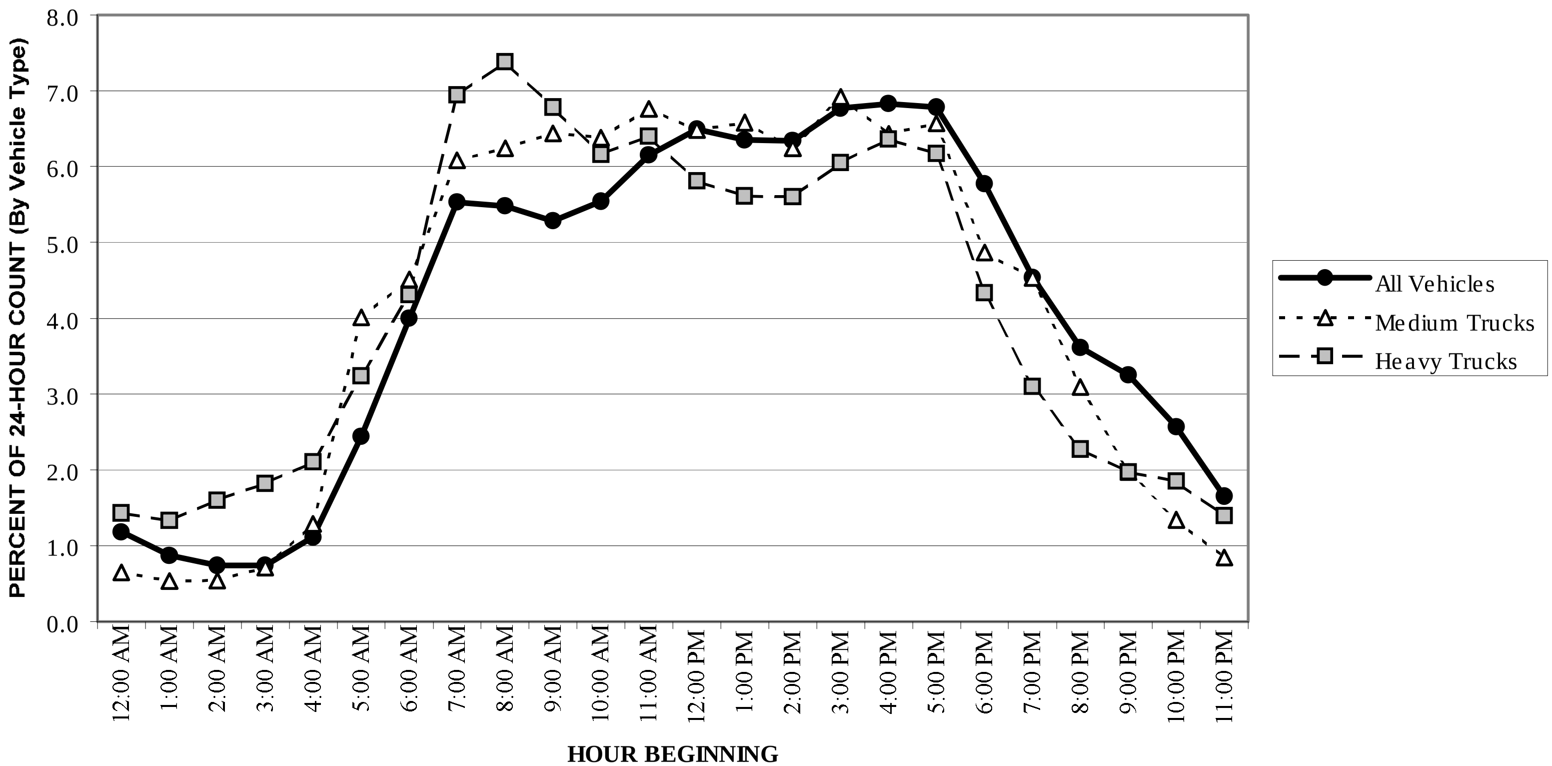
As shown in the following table, light vehicles – defined as passenger cars, sport utility vehicles (SUVs), vans, and pick-up trucks – accounted for over 90 percent of the total traffic passing by the 15 arterial street count locations; this held true for all time periods analyzed.

Time Period	Light Vehicles	Medium Trucks	Heavy Trucks	Total Traffic
6:00 AM – 9:00 AM	91.3%	4.0%	4.7%	100.0%
9:00 AM – 3:00 PM	92.3	3.9	3.9	100.0
3:00 PM – 6:00 PM	92.9	3.5	3.6	100.0
6:00 PM – 6:00 AM	94.5	2.9	2.5	100.0
Total 24 Hours	92.9	3.5	3.6	100.0

Exhibit 11, which is a composite of data points collected from all arterial count locations, shows the hourly variations in total traffic throughout the day, expressed in terms of the total 24-hour volume. The relative magnitude and duration of the AM and PM peak travel periods can easily be seen in this exhibit.

Count data for medium trucks (defined as buses, recreational vehicles, and all single-unit trucks) and heavy trucks (defined as all trailer trucks) are also shown separately on Exhibit 11. There were proportionately more heavy trucks on the arterial streets before 12:00 noon and

Exhibit 11
HOURLY VARIATIONS IN TRAFFIC: ARTERIAL STREETS



proportionately fewer after that time. In particular, there was a relatively high percentage of heavy trucks on the arterial streets during the AM peak period.

Freeways

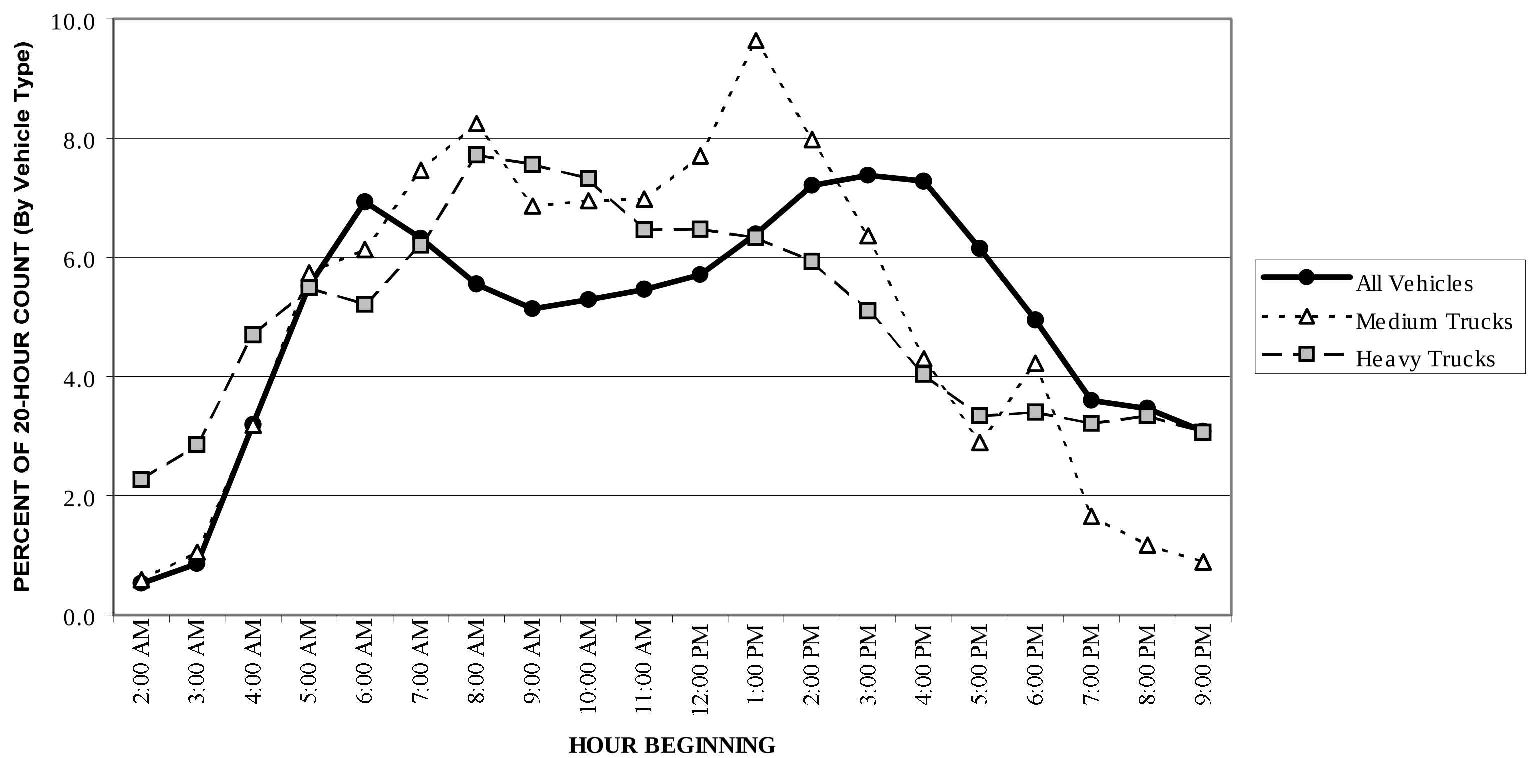
Similar vehicle classification data were also collected at the freeway count locations. However, due to the increased difficulty in collecting such data on freeways (with much higher volumes, higher speeds, and a greater number of lanes involved), 24-hour machine counts of all vehicles could not be made, as they were at the arterial count locations. Instead, a sampling of the vehicle mix was obtained through video surveillance.

The vehicle mix observed passing by the 27 freeway count locations was essentially the same as that seen on the arterial streets, with over 90 percent of the total traffic comprised of light vehicles and the remainder split fairly evenly between medium and light trucks. However, on the freeways, there was somewhat more variation in the vehicle mix by time period, as shown in the following table:

Time Period	Light Vehicles	Medium Trucks	Heavy Trucks	Total Traffic
6:00 AM – 9:00 AM	92.2%	4.3%	3.5%	100.0%
9:00 AM – 3:00 PM	89.2	5.8	5.0	100.0
3:00 PM – 6:00 PM	93.7	3.5	2.8	100.0
6:00 PM – 6:00 AM	93.5	2.5	4.0	100.0
Total 24 Hours	91.9	4.2	4.0	100.0

Exhibit 12 is based on the data from all freeway count locations. It shows the relative distribution by hour for the total traffic volume, as well as separate data for the medium truck and heavy truck categories. However, it should be noted that this figure does not represent a full 24-hour period (as does the analogous Exhibit 11 for arterial streets), but only the 20 hours for which data were collected (2:00 AM – 10:00 PM). Still, the same trend in heavy truck movements can be seen – with these vehicles accounting for a relatively higher percentage of the vehicle mix before 12:00 noon and a smaller percentage after that time.

Exhibit 12
HOURLY VARIATIONS IN TRAFFIC: FREEWAYS



AM PEAK PERIOD TRAFFIC CONDITIONS

For the purposes of this study, the AM peak period was assumed to occur between 7:00 AM and 9:00 AM and all data collection activities occurred during this two-hour time period. However, it should be noted that the peak period starts as early as 5:30 AM at some locations. Due to budget considerations and daylight constraints, data collection was limited to the two-hour time period noted above.

Major Intersections

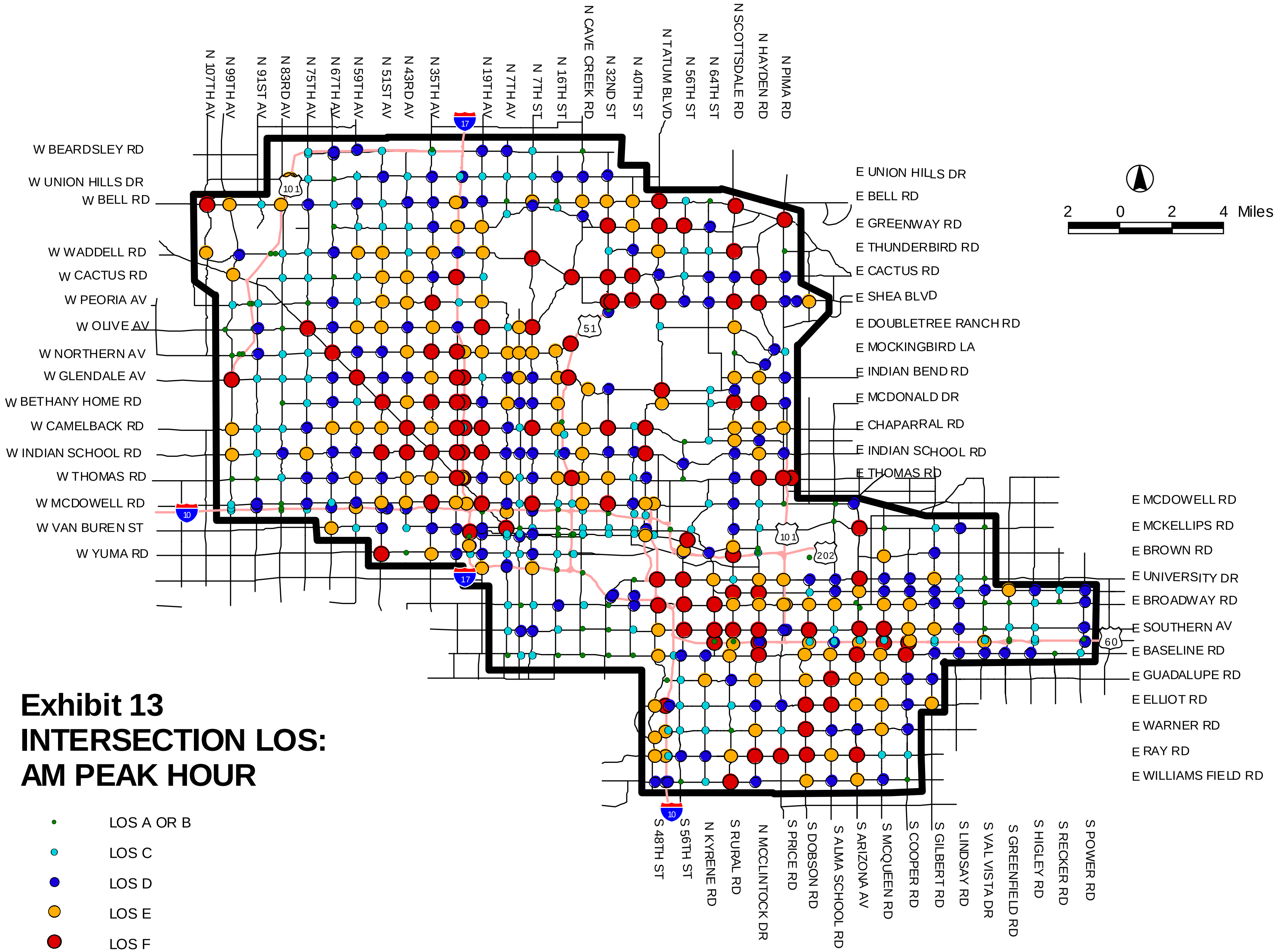
Exhibit 13 shows the calculated level of service (LOS) during the AM peak period for each intersection; this calculation is based on the peak 15-minute flow rate for the peak hour. As shown in the summary table below, 102 intersections – over 15 percent of all intersections analyzed – experienced "congestion" (LOS F) at some time during the AM peak hour:

Intersection Levels of Service: AM Peak Hour		
Level of Service	No. of Intersections Analyzed	Percent
A	15	2.3%
B	81	12.5
C	144	22.3
D	170	26.3
E	135	20.9
F	102	15.7
Total	647	100.0%

Exhibit 14 focuses on the duration of the "congestion" (LOS F) during the AM peak hour. A total of 17 intersections were identified as experiencing serious delays (of greater than 60 seconds/vehicle) lasting throughout the entire AM peak hour. Most of these intersections were found along Grand Avenue and in the vicinity of 32nd Street and Shea Boulevard. However, the LOS calculations identified 85 additional intersections that experienced similar levels of congestion, but such congestion lasted for shorter periods of time.

Exhibit 15 shows the AM peak hour (actual or estimated) for each of the study intersections. At most locations, the AM peak hour began at 7:00 or 7:15 AM. However, it began slightly later (at 7:30 AM) in much of central Phoenix and southern Scottsdale. In the Sun City area, the peak hour did not begin until 8:00 AM.

Exhibit 13
INTERSECTION LOS: AM PEAK HOUR



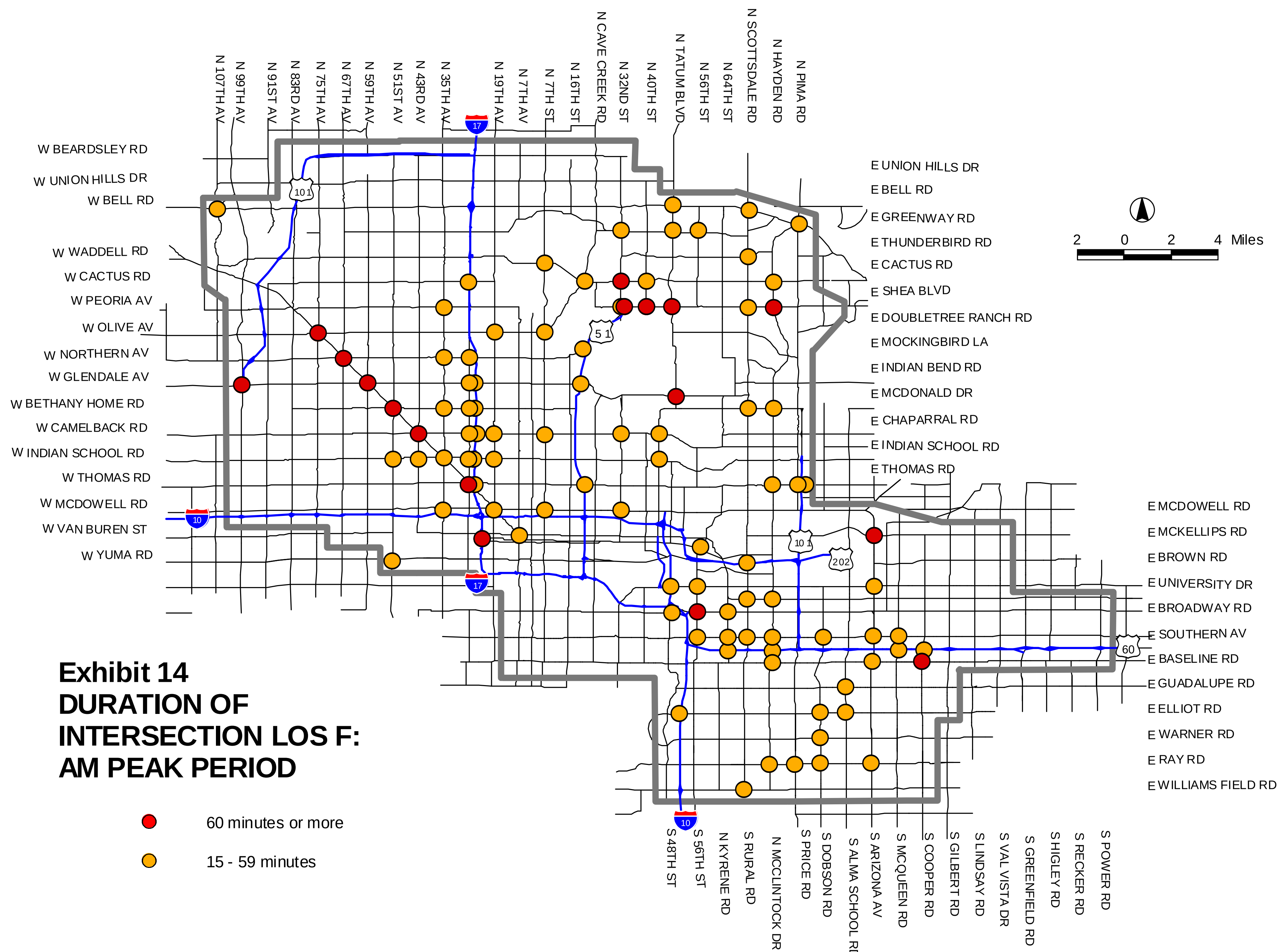


Exhibit 14
DURATION OF INTERSECTION LOS F: AM PEAK PERIOD

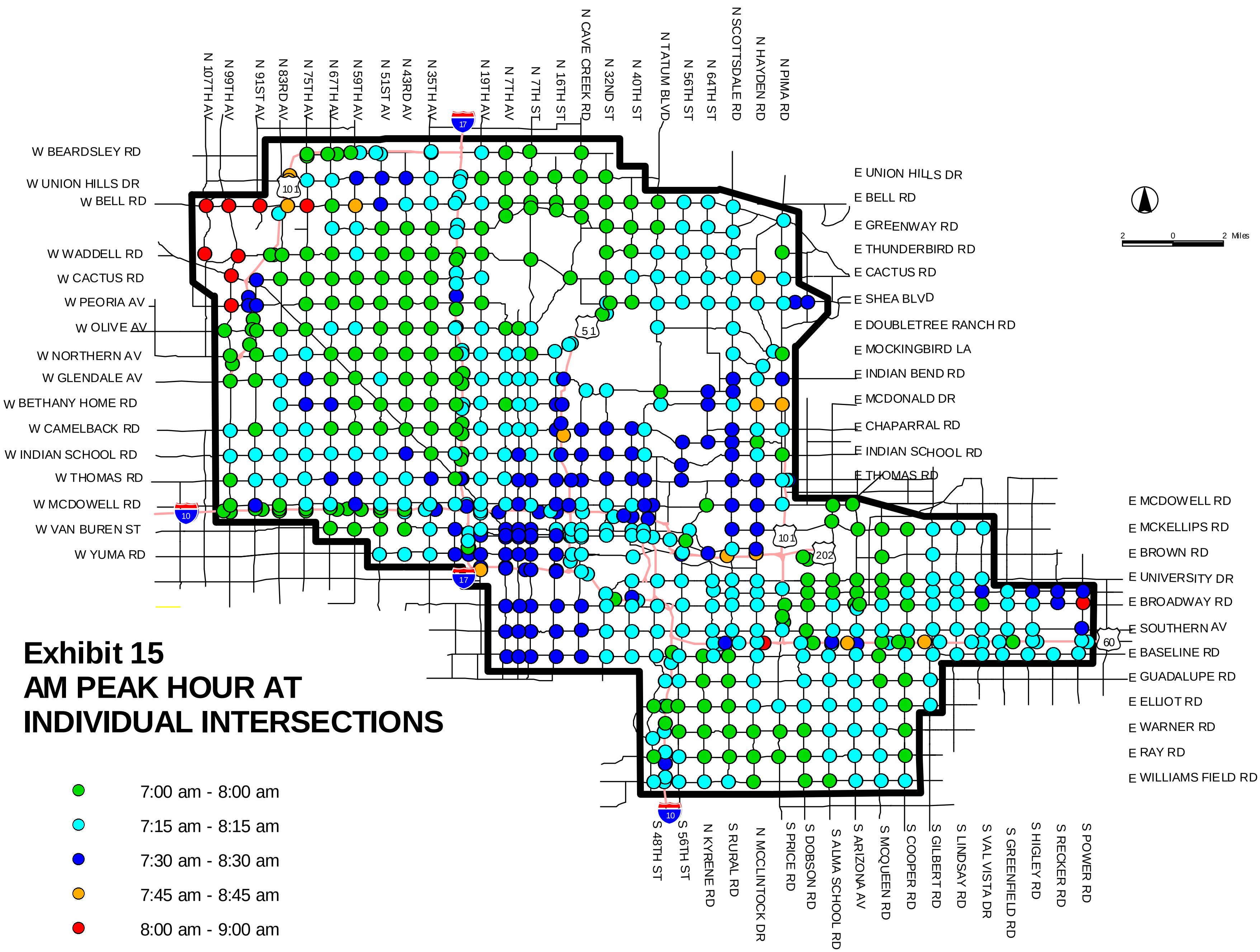


Exhibit 15
AM PEAK HOUR AT INDIVIDUAL INTERSECTIONS

- 7:00 am - 8:00 am
- 7:15 am - 8:15 am
- 7:30 am - 8:30 am
- 7:45 am - 8:45 am
- 8:00 am - 9:00 am

Freeways

Vehicle densities derived from the aerial photographs were used to determine freeway levels of service during the AM peak period (7:00 – 9:00 AM). Average vehicle densities for each 30-minute interval within this time period were calculated, and the maximum density for each freeway segment was used to determine its level of service. The results – for the general purpose lanes only – are displayed in Exhibit 16 and summarized in the following table:

AM Peak Period		
Levels of Service for General Purpose Lanes Only		
Level of Service	No. of One-Way Miles	Percent
A	19	8.2%
B	43	18.6
C	74	32.0
D	38	16.5
E	21	9.1
F	36	15.6
Total	231	100.0%

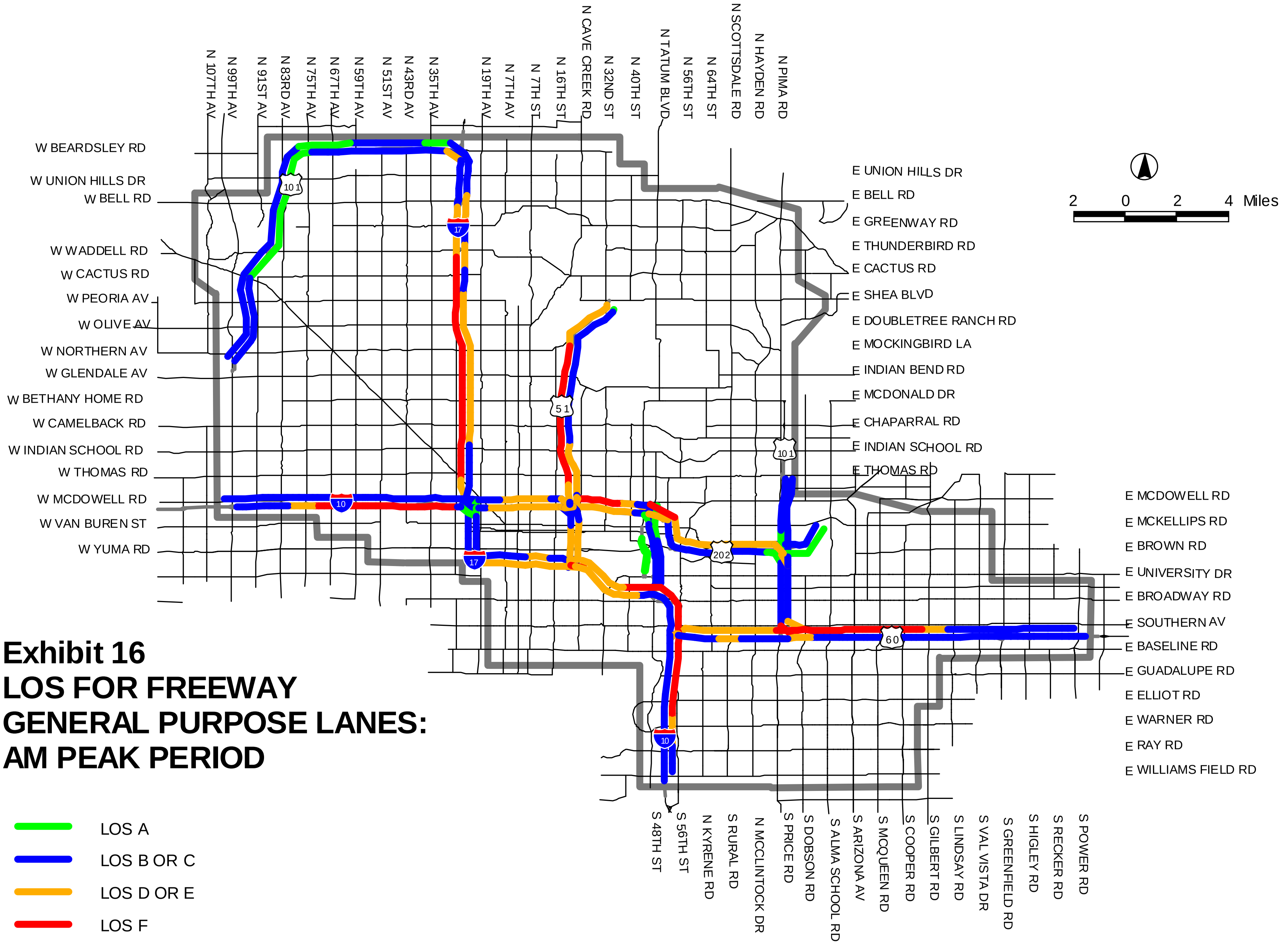
During the AM peak period, LOS F was found on many of the inbound (i.e., towards downtown Phoenix) freeway segments, although all of the outbound segments were operating at LOS D or better.

The vehicle density data were also reviewed to determine the relative duration of congestion on each freeway segment identified as operating at LOS F during the AM peak period. As shown in Exhibit 17, congestion on the inbound segments lasted for 60 – 120 minutes over portions of I-10, I-17, SR 51, and US 60.

It was determined from the available traffic counts that the AM peak hour was 7:00 – 8:00 AM on the Valley's freeway system. Exhibit 18 shows the peak hour traffic volumes on selected freeway links (by direction); these represent total traffic volumes, across all lanes of traffic.

Exhibit 19 focuses on the high occupancy vehicle (HOV) lanes. During the AM peak hour, the most heavily used HOV lanes were oriented towards downtown Phoenix. The highest usage (1,600 vehicles per hour) was recorded for the HOV lane on eastbound I-10, between 75th Avenue and I-17.

Exhibit 16
LOS FOR FREEWAY GENERAL PURPOSE LANES: AM PEAK PERIOD



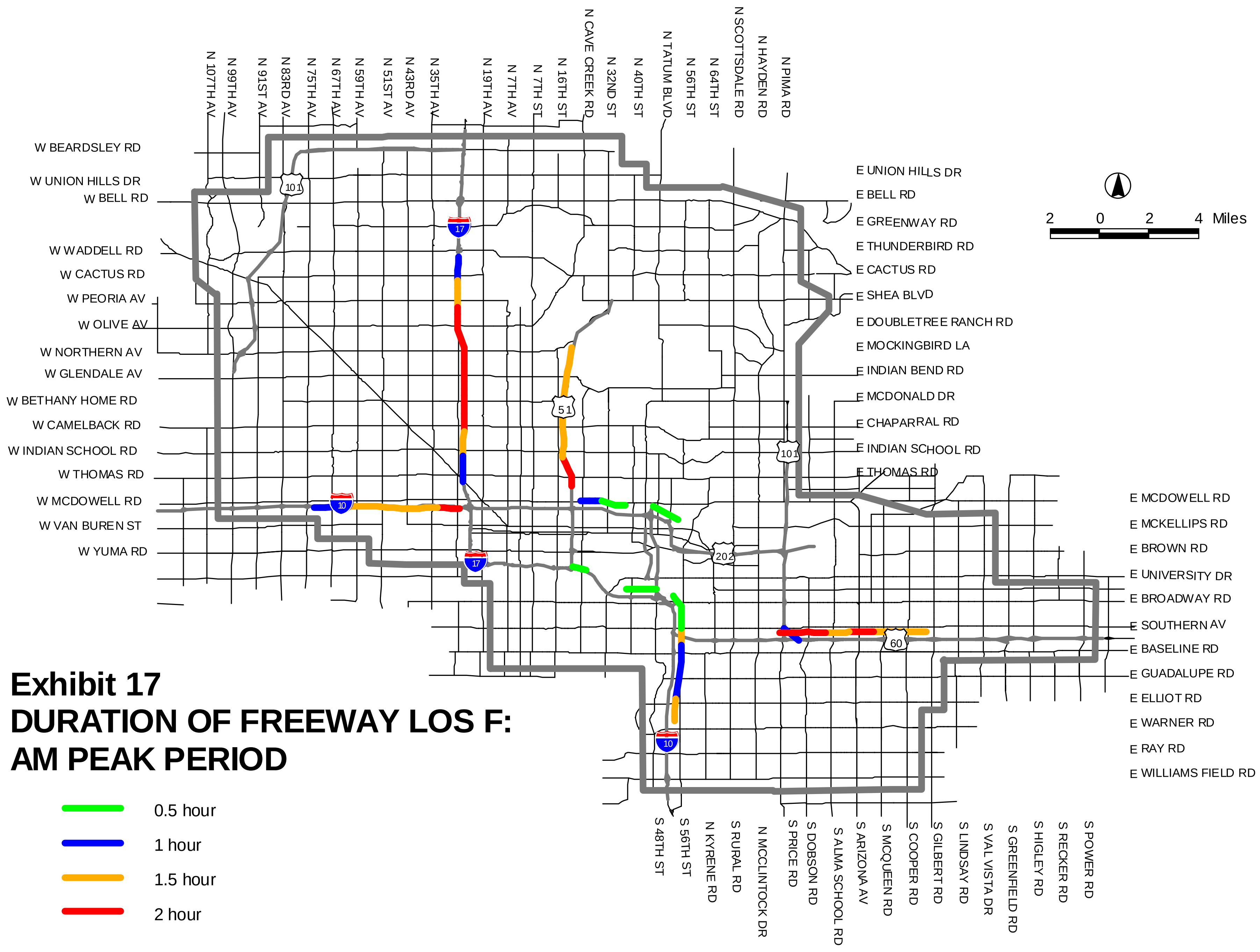


Exhibit 17
DURATION OF FREEWAY LOS F: AM PEAK PERIOD

- 0.5 hour
- 1 hour
- 1.5 hour
- 2 hour

Exhibit 18
TOTAL FREEWAY VOLUMES BY DIRECTION: AM PEAK HOUR

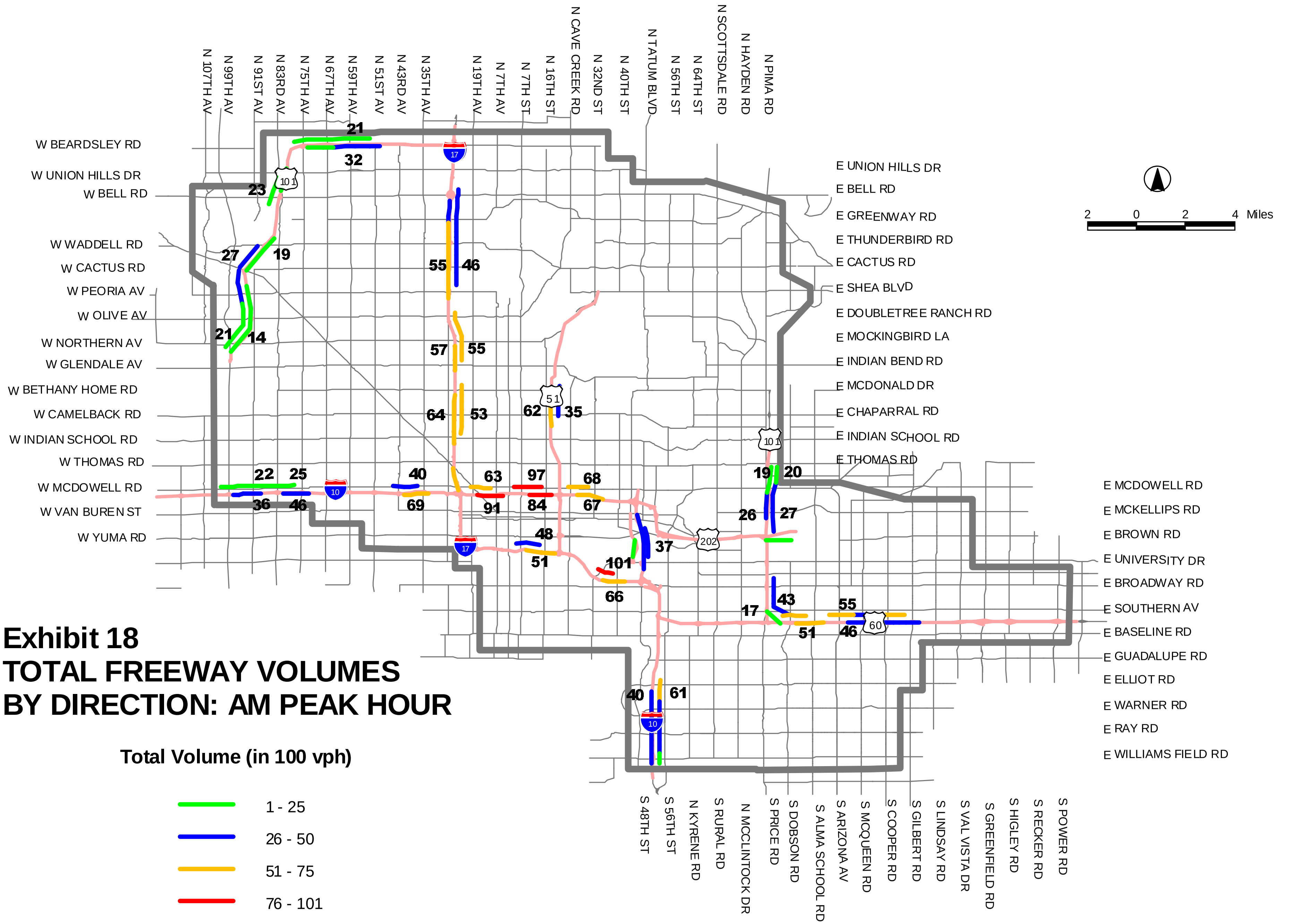
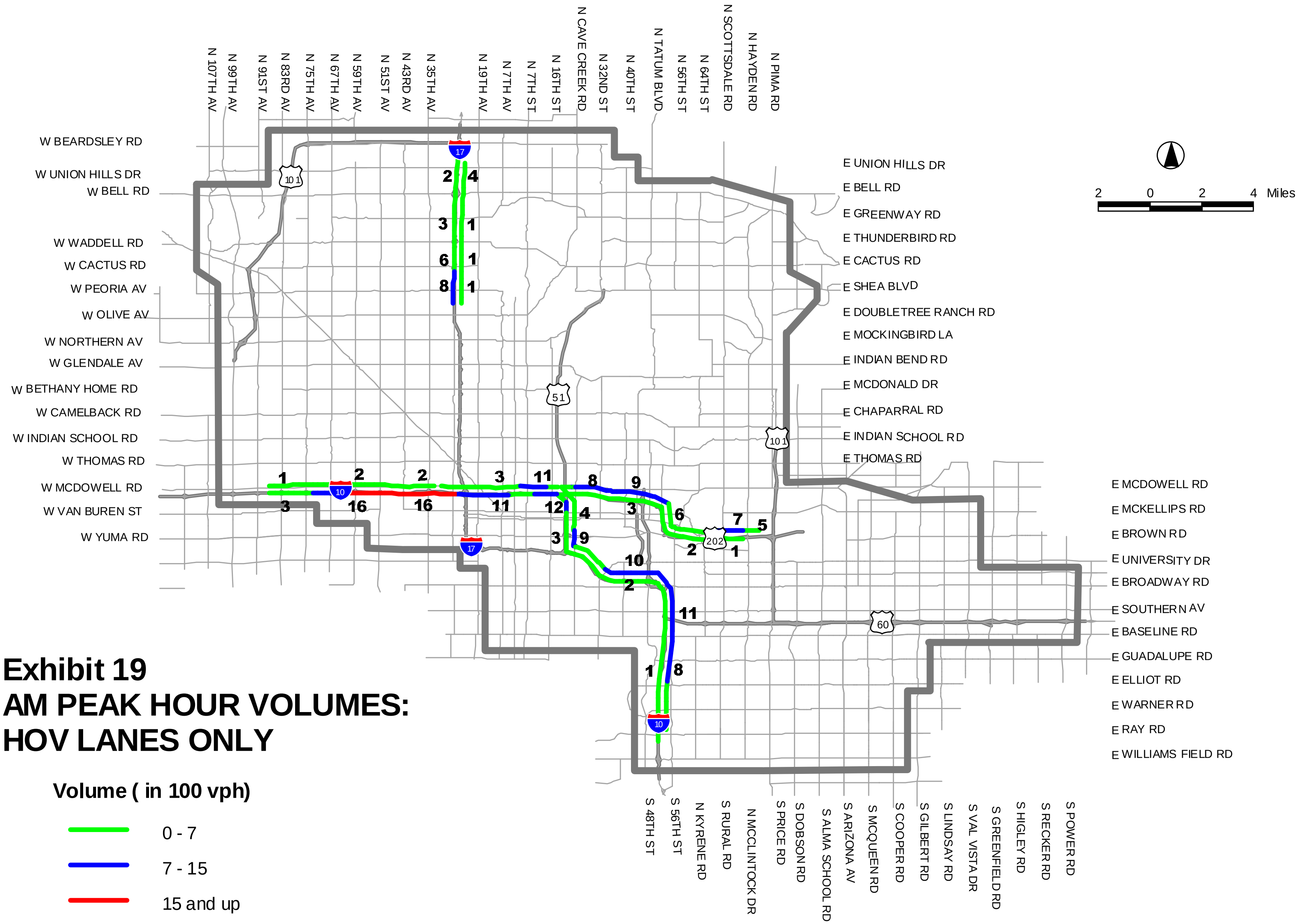


Exhibit 19
AM PEAK HOUR VOLUMES: HOV LANES ONLY



Volume (in 100 vph)

- 0 - 7
- 7 - 15
- 15 and up

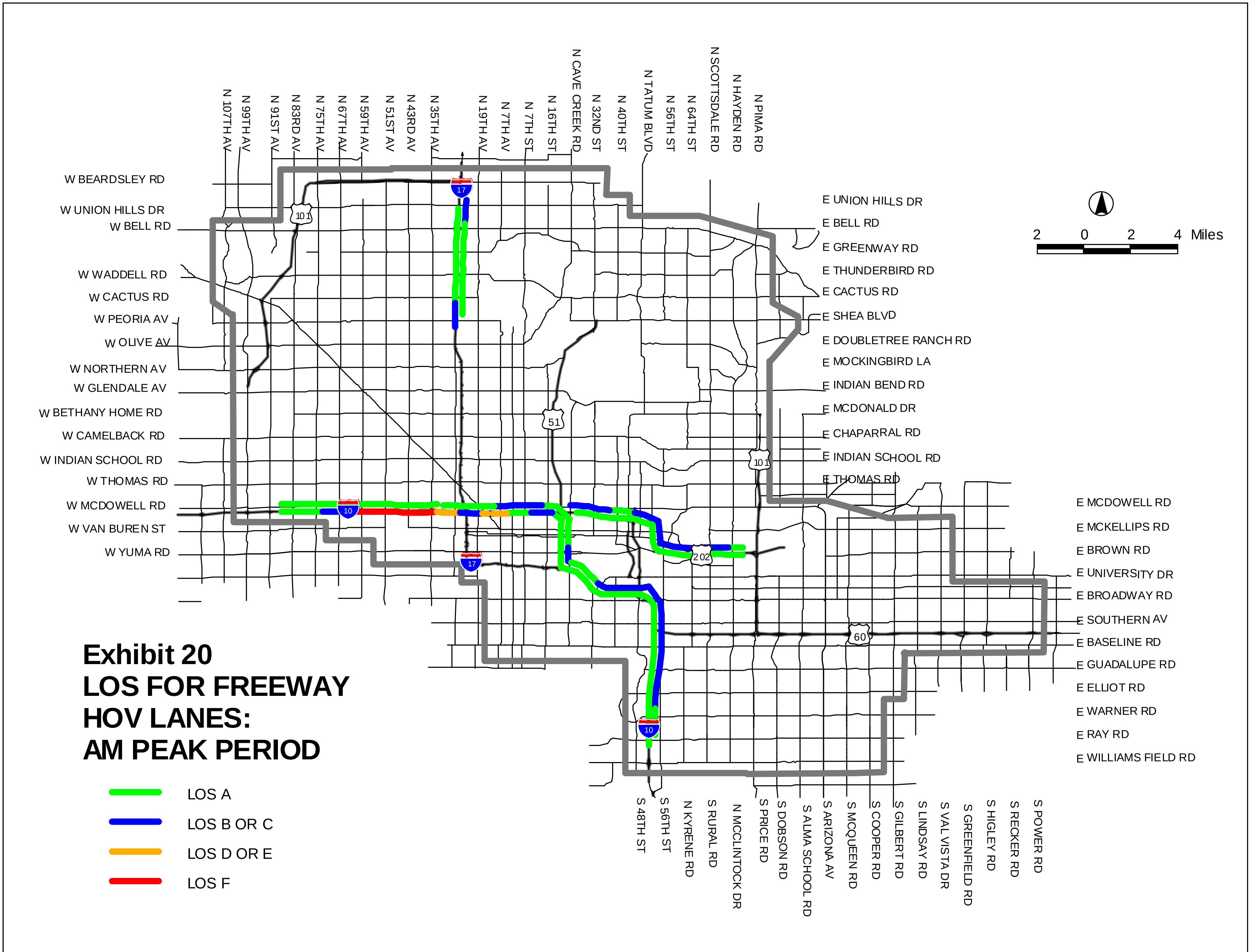


Exhibit 20
LOS FOR FREEWAY HOV LANES: AM PEAK PERIOD

Vehicle densities were also analyzed separately for high-occupancy vehicle (HOV) lanes; the resulting levels of service are shown in Exhibit 20. The HOV lanes generally enjoyed a much higher level of service than their adjacent general purpose lanes. The one exception was the eastbound HOV lane on I-10 between 67th and 35th Avenues. In that case, both the HOV lane and the adjacent general purpose lanes operated at LOS F during part of the AM peak period.

PM PEAK PERIOD TRAFFIC CONDITIONS

Study data for the PM peak period were analyzed in the same manner as the data for the AM peak period. Due to budget limitations, all data collection activities occurred between 4:00 and 6:00 PM. However, at some locations, the actual PM peak hour began before 4:00 PM or ended after 6:00 PM.

Major Intersections

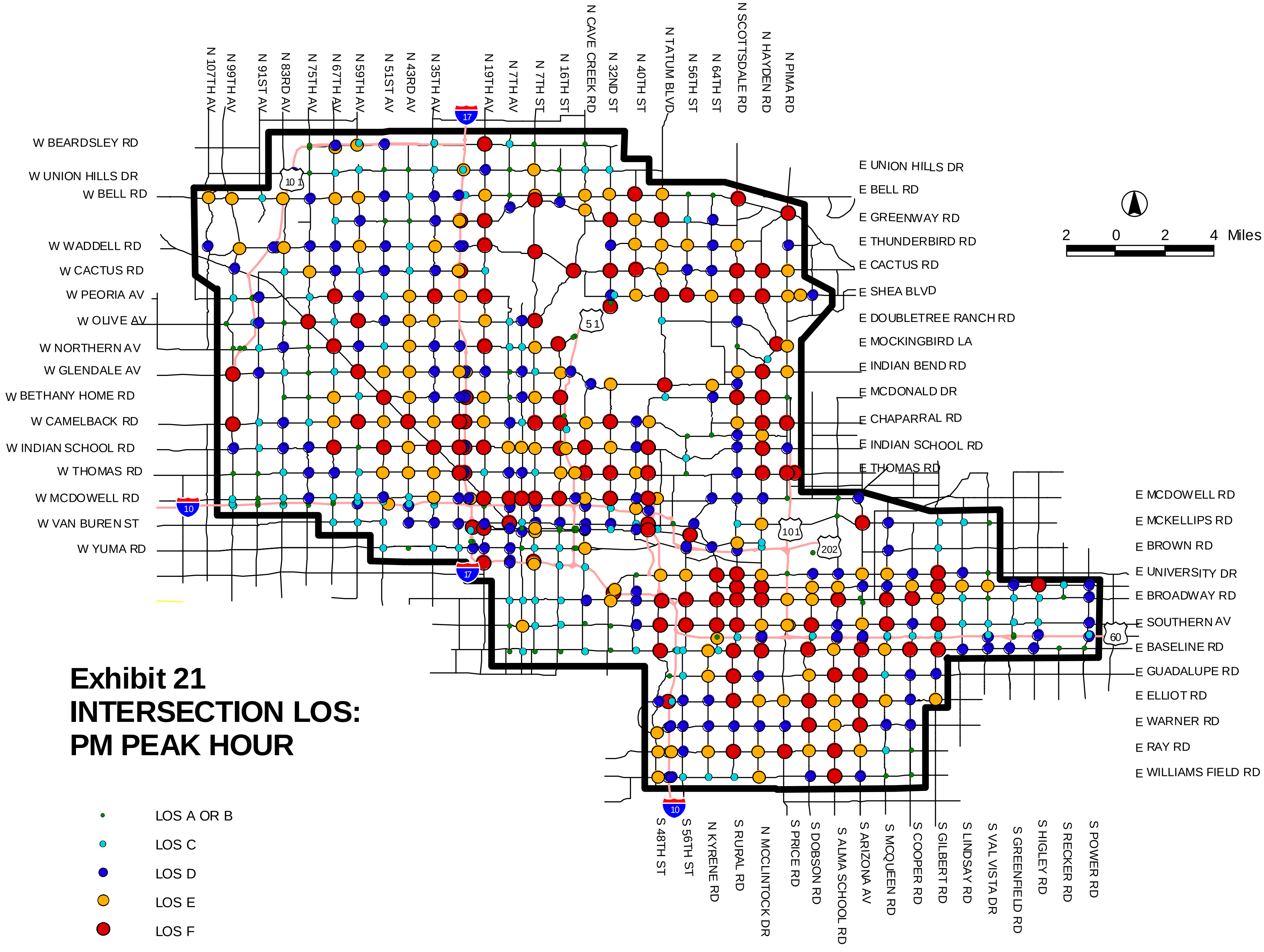
Levels of service (focusing on the peak 15-minute period) were also determined for the PM peak hour. The results are shown in Exhibit 21 and summarized in the following table:

Intersection Levels of Service: PM Peak Hour		
Level of Service	No. of Intersections Analyzed	Percent
A	15	2.3%
B	87	13.4
C	124	19.2
D	166	25.7
E	127	19.6
F	128	19.8
Total	647	100.0%

More intersections were identified as experiencing LOS F during the PM peak hour (128 intersections) than during the AM peak hour (102 intersections). Approximately 20 percent of the study intersections operated at LOS F during some portion of the PM peak hour.

Exhibit 22 provides information about the relative duration of "congestion" (LOS F) during the PM peak hour. This exhibit shows the 36 intersections that were identified as locations where drivers experienced average delays of more than 60 seconds/vehicle for the entire PM peak hour. Every study intersection on Grand Avenue fell into this category, but concentrations of

Exhibit 21
INTERSECTION LOS: PM PEAK HOUR



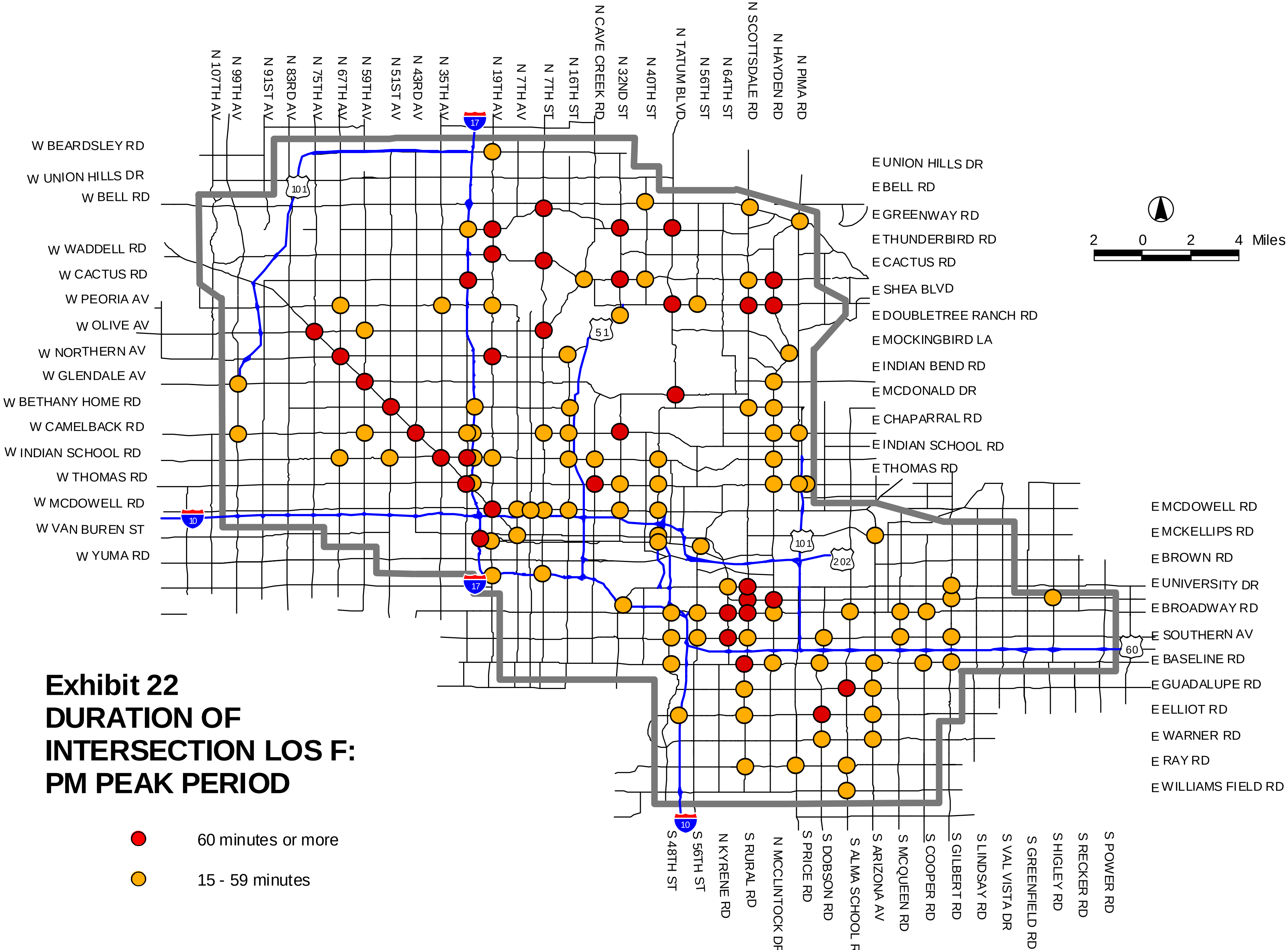
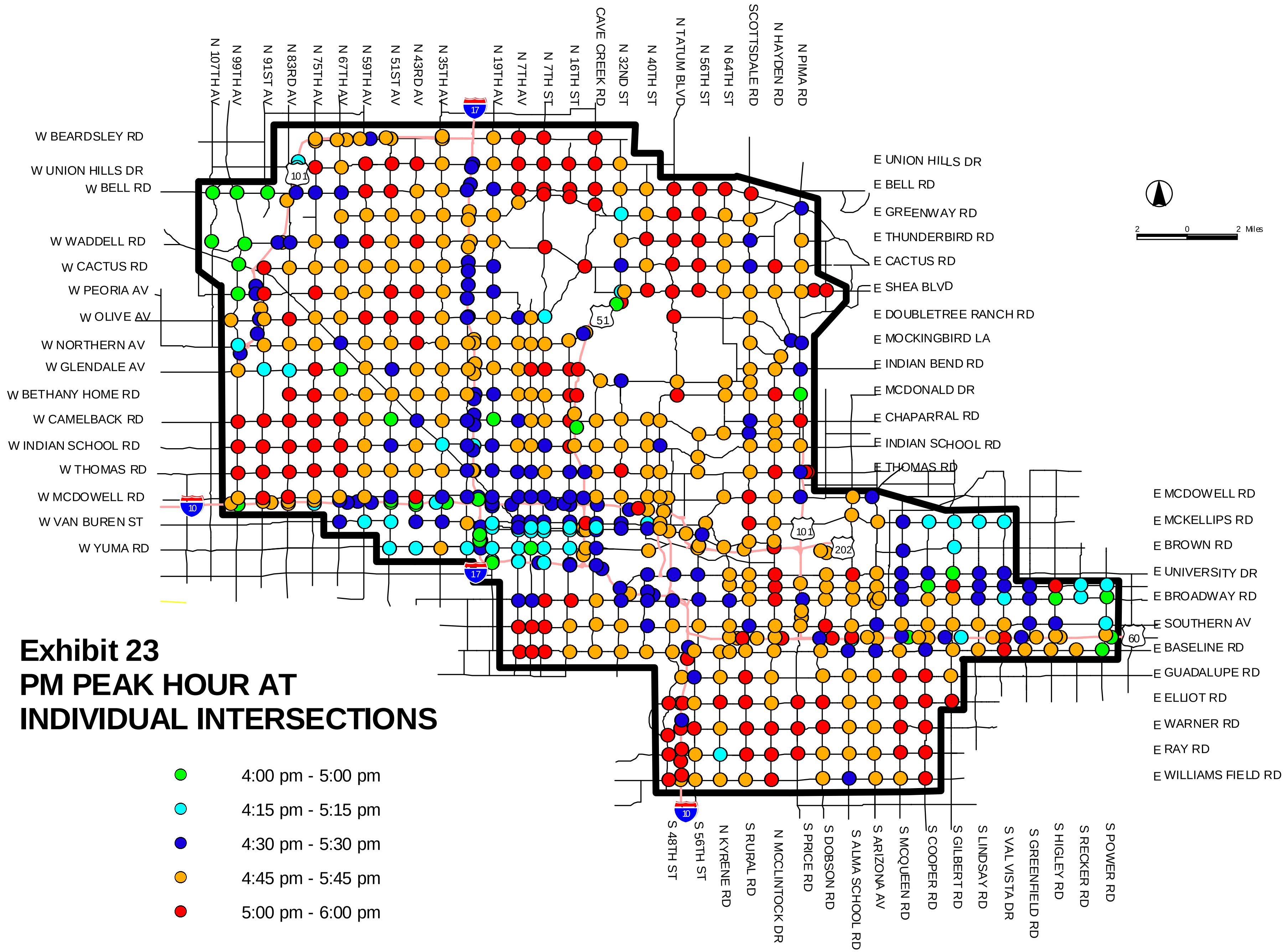


Exhibit 22
DURATION OF INTERSECTION LOS F: PM PEAK PERIOD

- 60 minutes or more
- 15 - 59 minutes

Exhibit 23
PM PEAK HOUR AT INDIVIDUAL INTERSECTIONS



congestion were also found in northeast Phoenix, Scottsdale, north Tempe, and the southeast Valley. In addition, 92 other intersections experienced similar levels of congestion (LOS F) during the peak 15-minute period.

The PM peak hour (actual or estimated) for each of the study intersections is shown in Exhibit 23. At most intersections, the PM peak hour was either 4:45 – 5:45 PM or 5:00 – 6:00 PM. The earliest starting times (4:00 or 4:15 PM) were found in downtown Phoenix, the Sun City area, and the far eastern end of the study area. Intersections along the I-17 corridor generally experienced peak traffic between 4:30 and 5:30 PM.

Freeways

Freeway levels of service during the PM peak period were determined from vehicle densities (measured on the aerial photographs), in the same manner as was done for the AM peak period. The results of this analysis are shown in Exhibit 24 and summarized in the following table:

PM Peak Period		
Levels of Service for General Purpose Lanes Only		
Level of Service	No. of One-Way Miles	Percent
A	16	6.9%
B	44	19.0
C	61	26.4
D	38	16.5
E	34	14.7
F	38	16.5
Total	231	100.0%

The PM peak hour on the Valley's freeway system was determined to be 4:30 – 5:30 PM. During the PM peak hour, LOS F was found on many outbound (i.e., away from downtown Phoenix) freeway segments. However, LOS F was also seen on two inbound segments – a two-mile stretch of southbound I-17 (between Dunlap Avenue and Cactus Road) and on southbound SR 51 approaching the I-10/SR 202 interchange.

Exhibit 25 focuses on just those freeway segments identified as experiencing LOS F during the PM peak period. With just a few exceptions, these freeway segments experienced congestion for an hour or more. Some portions of northbound I-17, northbound SR 51, and eastbound US 60 operated at LOS F for the entire two-hour PM peak period.

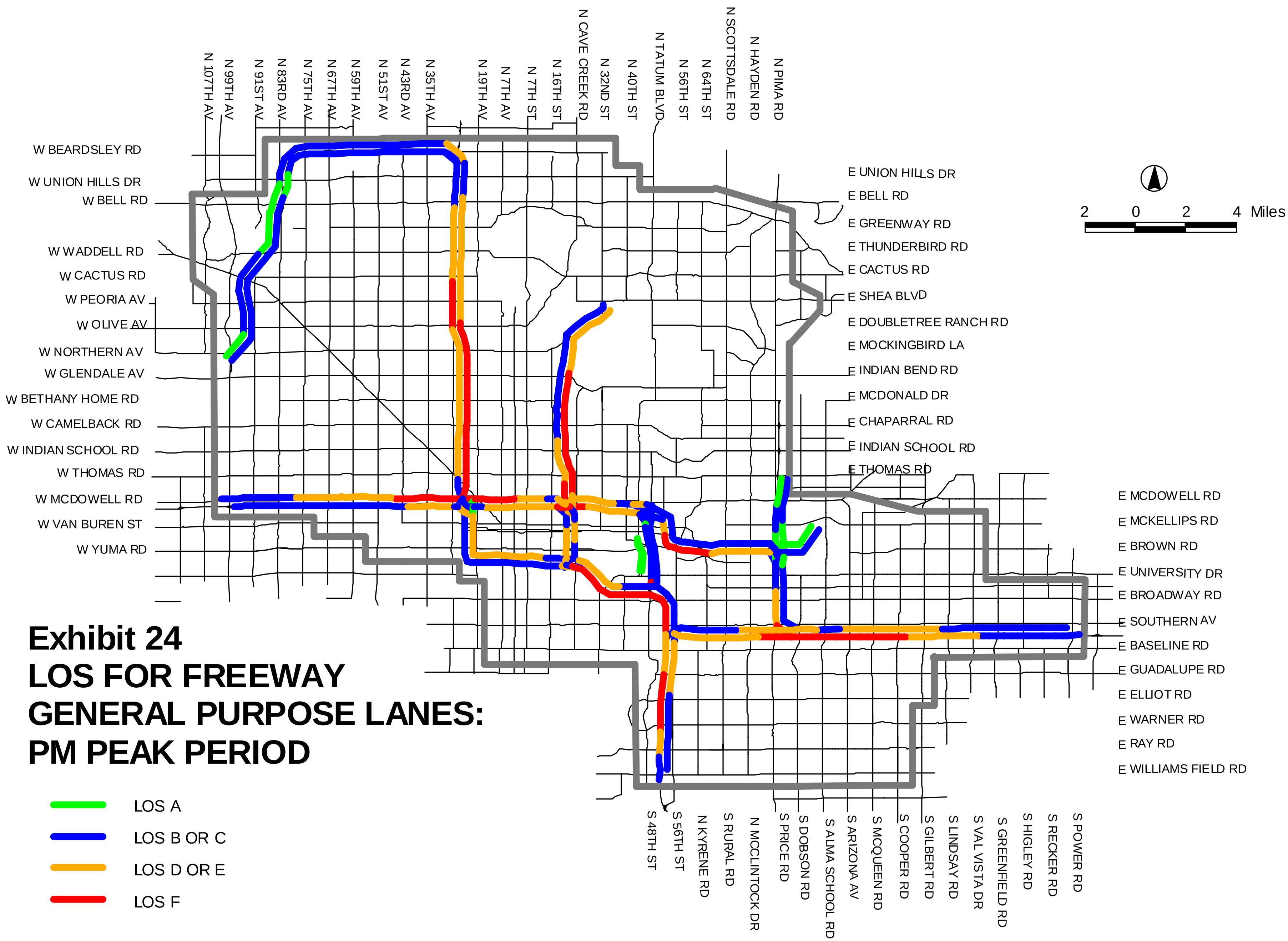
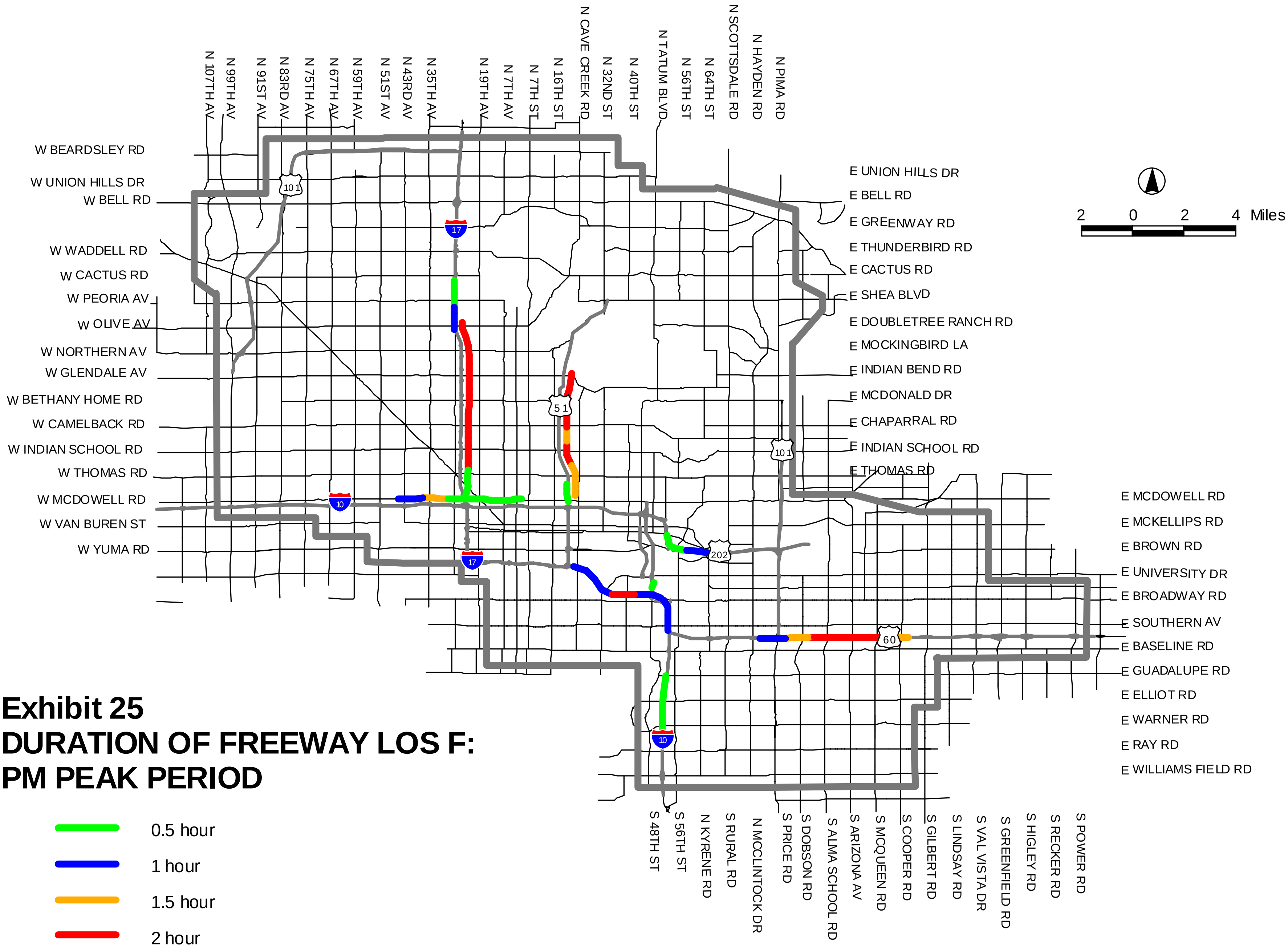


Exhibit 24
LOS FOR FREEWAY GENERAL PURPOSE LANES: PM PEAK PERIOD

- LOS A
- LOS B OR C
- LOS D OR E
- LOS F

Exhibit 25
DURATION OF FREEWAY LOS F: PM PEAK PERIOD



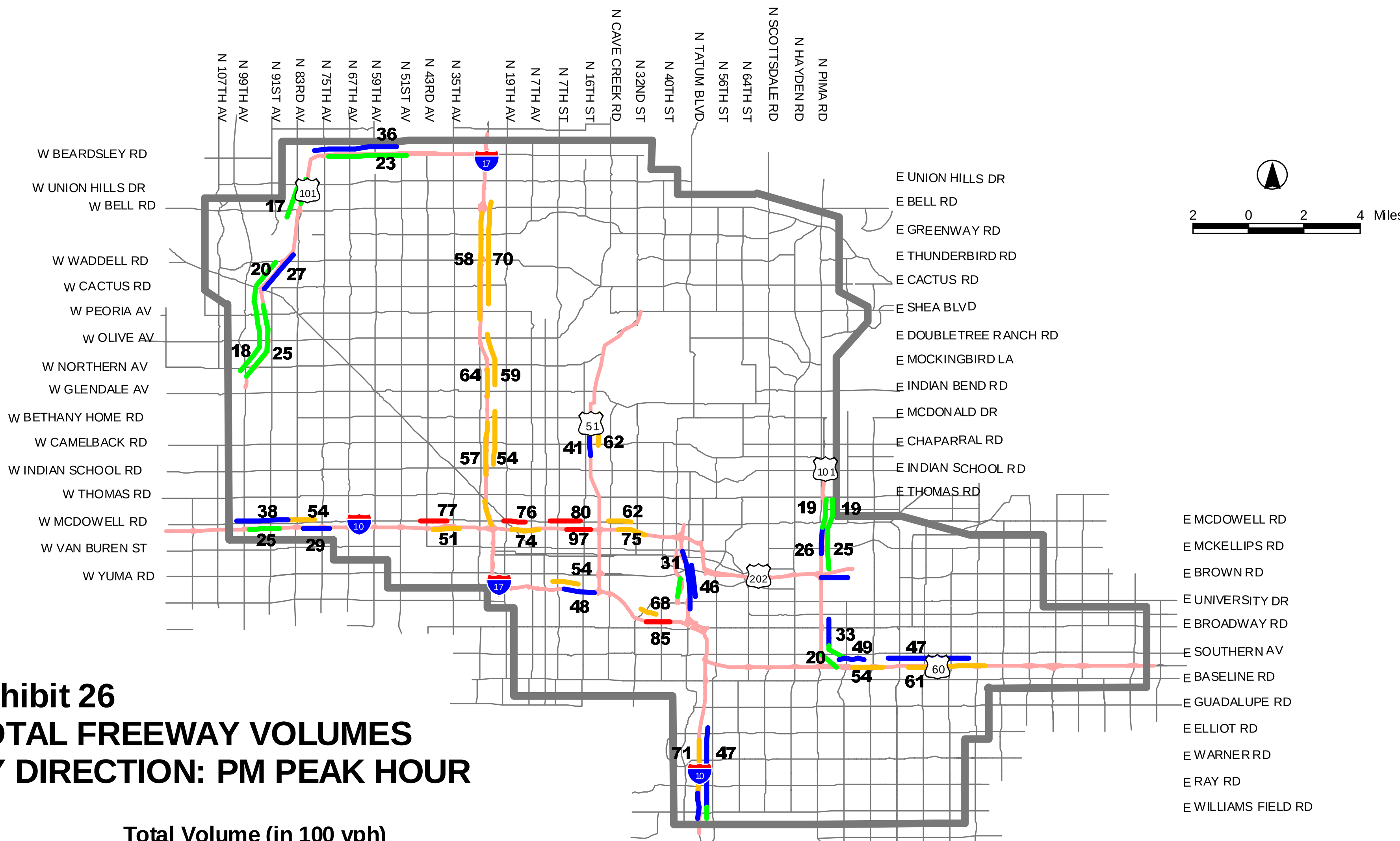


Exhibit 26
TOTAL FREEWAY VOLUMES BY DIRECTION: PM PEAK HOUR

Total Volume (in 100 vph)

- 1 - 25
- 26 - 50
- 51 - 75
- 76 - 101

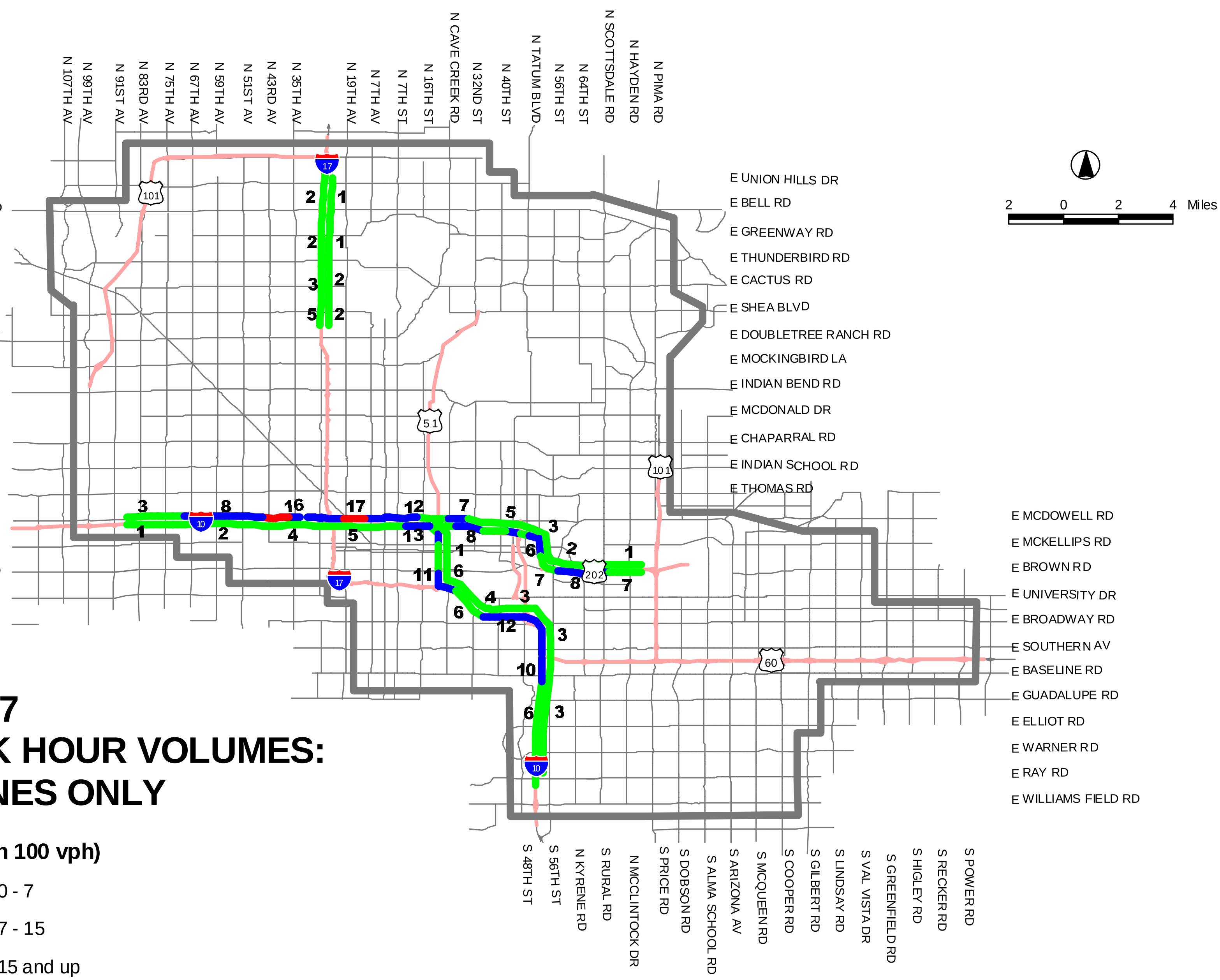


Exhibit 27
PM PEAK HOUR VOLUMES: HOV LANES ONLY

Volume (in 100 vph)

- 0 - 7
- 7 - 15
- 15 and up

Exhibit 26 shows the traffic volumes recorded during this hour on selected freeway segments. These are directional volumes, recorded across all lanes (both general purpose and HOV lanes). Exhibit 27 presents similar information for the HOV lanes only. During the PM peak hour, the most heavily used HOV lane was found on westbound I-10, immediately west of downtown Phoenix; this lane carried approximately 1,700 vehicles during the PM peak hour.

Exhibit 28 shows the PM peak hour levels of service for all high-occupancy vehicle (HOV) lanes on the Valley freeway system; this information is based on the vehicle density data obtained from aerial photographs. All HOV lanes were operating at a level of service equal to – and in most cases, better than – the level of service experienced by drivers in the adjacent general purpose lanes.

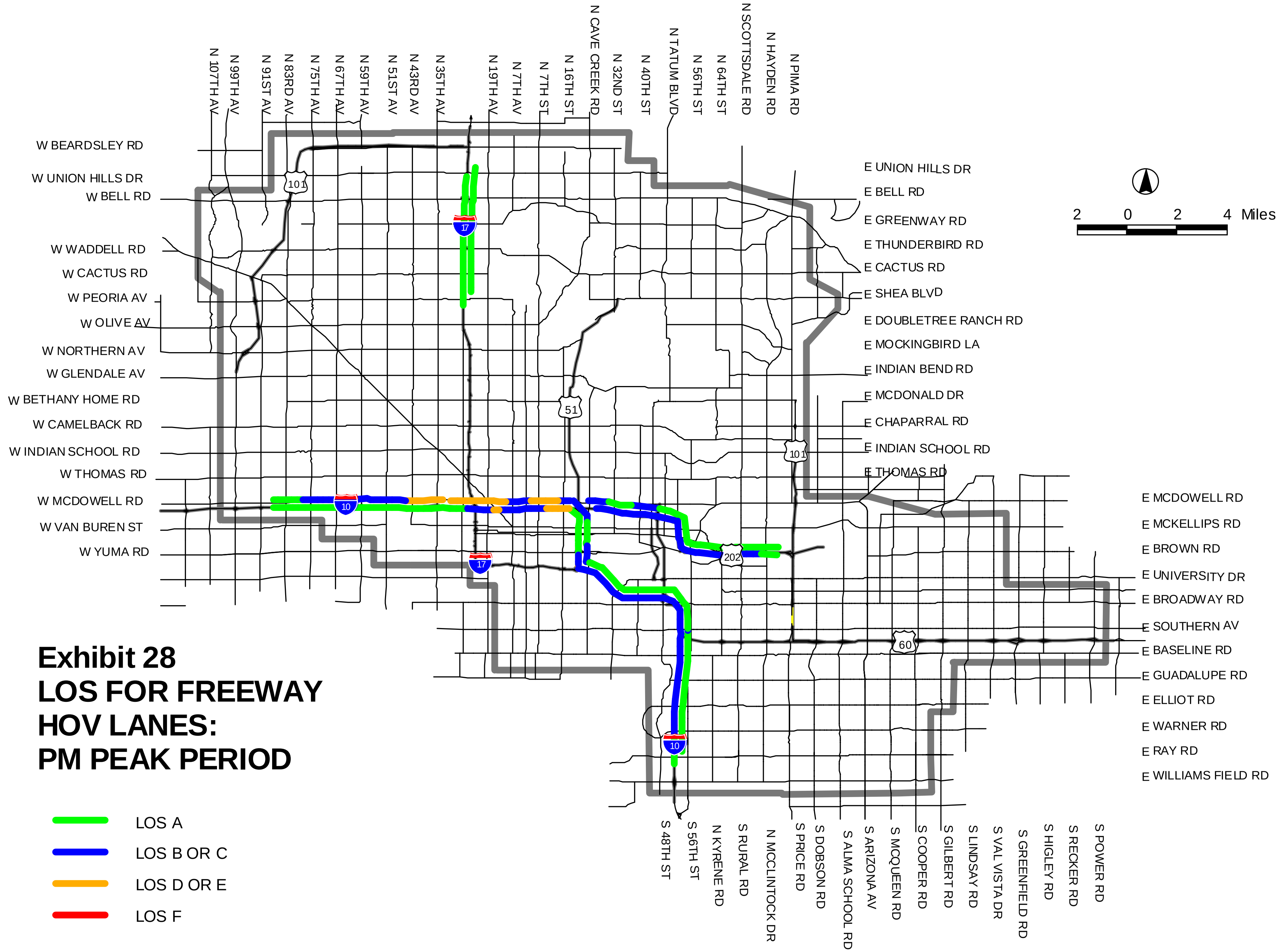


Exhibit 28
LOS FOR FREEWAY HOV LANES: PM PEAK PERIOD

5. COMPARISON OF 1989 AND 1998 CONDITIONS

The results of the 1998 MAG Regional Congestion Study were compared to the results of the 1989 study to identify any changes in the location, severity, and/or duration of peak hour congestion. These changes are discussed in this chapter and placed in the context of the tremendous growth seen in the Phoenix metropolitan area over the past ten years.

PM PEAK HOUR TRAFFIC CONDITIONS

The results of the 1998 study indicate that traffic volumes are generally higher – and as a consequence, traffic congestion is generally more severe – during the PM peak hour than during the AM peak hour. This was also true in 1989, when the previous study was done. Therefore, PM peak hour conditions were used as the basis of comparison between the two studies.

Major Intersections

The 1989 study investigated several different ways of measuring peak period congestion at major intersections, including the method used in this current study. Exhibit 29 shows the levels of service (LOS) that were calculated in 1989; the comparable exhibit for 1998 is Exhibit 21.

Exhibit 30 provides a side-by-side comparison of the results obtained from the intersection analyses conducted during the 1989 and 1998 studies. It is important to note that the limits of the study area were expanded in 1998 and 172 more intersections were analyzed, so that direct comparisons between the two studies are somewhat difficult to make. However, the boundaries for both studies were drawn to specifically include any areas likely to be experiencing some peak period congestion at the time of the study, so it would be reasonable to assume that any intersections not analyzed in 1989 were not experiencing any significant level of congestion (i.e., were operating “under capacity”). This adjustment for the number of intersections analyzed is reflected in the tables shown in Exhibit 30.

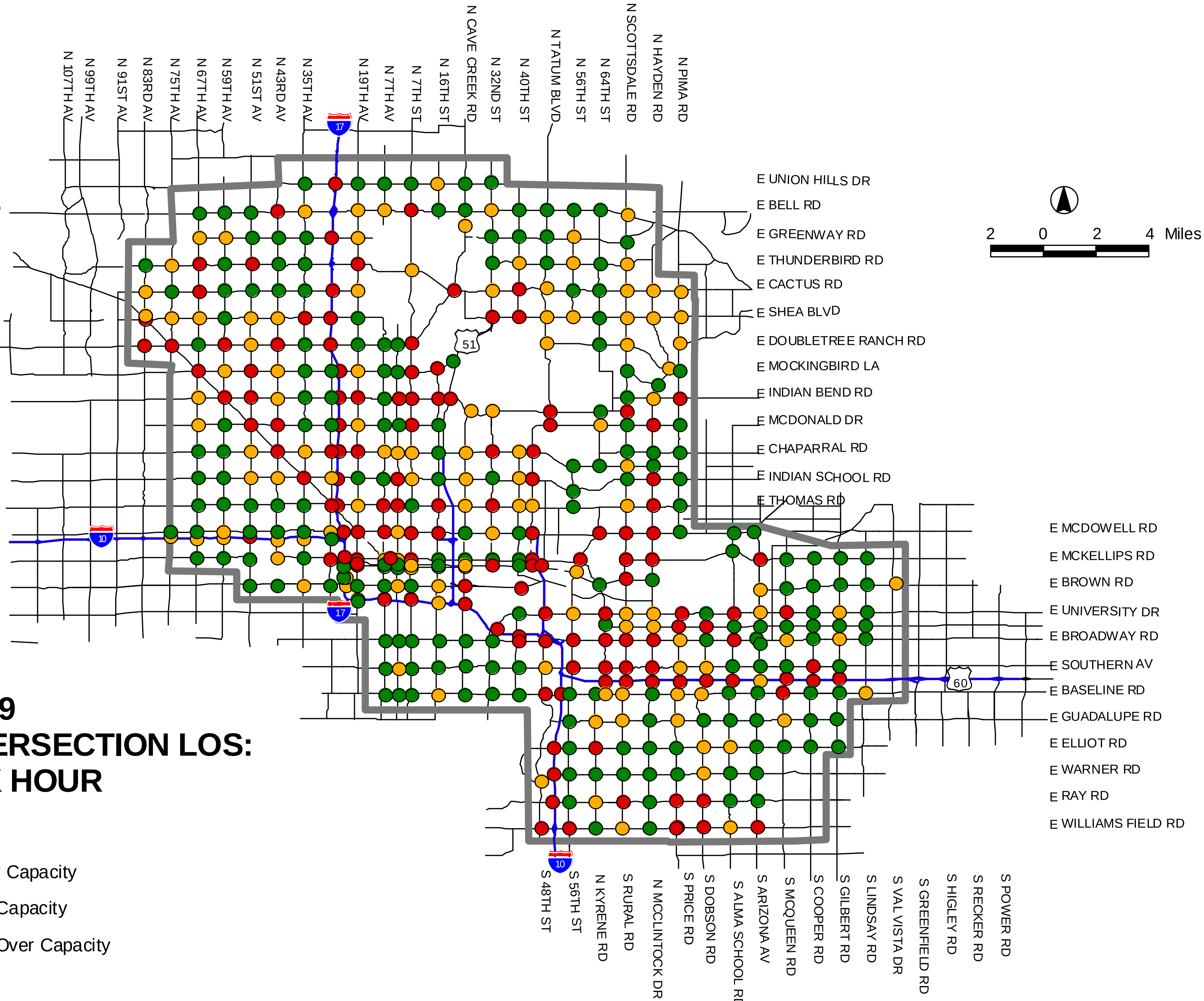


Exhibit 29
1989 INTERSECTION LOS:
PM PEAK HOUR

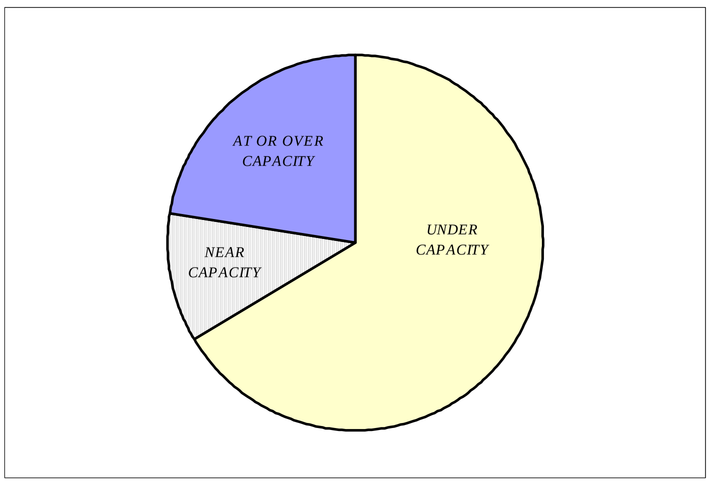
Under Capacity
Near Capacity
At or Over Capacity

Exhibit 30
COMPARISON OF PM PEAK HOUR CONDITIONS: INTERSECTIONS

1989

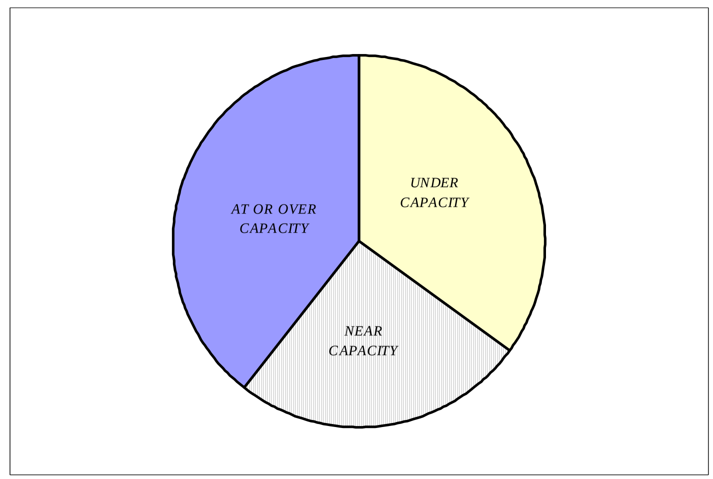
Level of Service	Number of Intersections	Percent of Total
LOS A, B, or C (Under Capacity)	430 *	66.4 %
LOS D (Near Capacity)	71	11.0
LOS E or F (At or Over Capacity)	146	22.6
Total	647	100.0 %

**Includes 172 intersections that were not analyzed in 1989 and are assumed to have been operating under capacity at that time.*



1998

Level of Service	Number of Intersections	Percent of Total
LOS A, B, or C (Under Capacity)	226	34.9 %
LOS D (Near Capacity)	166	25.7
LOS E or F (At or Over Capacity)	255	39.4
Total	647	100.0 %



Based on the peak 15-minute period within the hour.

Major differences between the two study years are seen when the calculated LOS (which is based on the peak 15-minute period) is used to identify congested intersections. As shown in Exhibit 30, the percentage of intersections experiencing LOS E or F for at least some portion of the PM peak hour increased from 23 to 39 percent between 1989 and 1998. The percentage of intersections approaching capacity (LOS D) also increased significantly – from 11 percent in 1989 to 26 percent in 1998. Consequently, the percentage of intersections operating at high levels of service (LOS A, B, or C) throughout the PM peak hour decreased substantially – from 66 percent of all intersections analyzed in 1989 to only 35 percent in 1998.

Freeways

Exhibit 31 shows the levels of service determined for the PM peak hour on various freeway segments in 1989; corresponding information for the current study was presented in Exhibit 24.

In general, freeway segments that were operating at lower levels of service (LOS E or F) in 1989 continued to do so in 1998 – most notably, portions of northbound I-17; eastbound US 60; and southbound I-10, around the Broadway curve into the Ahwatukee area. In 1998, there were more freeway miles open to traffic and some of these new freeway segments were already operating at LOS F during the PM peak hour – for example, portions of outbound SR 202 and SR 51. The level of service on a portion of outbound I-10 on the west side (in the vicinity of the I-17 interchange) had also deteriorated to LOS F during the PM peak hour by 1998.

Because 117 lane miles of freeways were constructed over the past ten years, twice as many freeway miles were analyzed in 1998 (231 miles) as in 1989 (114 miles). As shown in Exhibit 32, there were three times as many freeway miles operating at LOS E or F during the PM peak hour in 1998 than there were nine years before (72 miles vs. 24 miles). However, in 1998, there were also 68 more miles of freeway operating at high levels of service (LOS A, B, or C) during the PM peak hour. When total freeway miles are taken into account, the percentage of miles operating at or over capacity (LOS E or F) increased from 21 to 31 percent between 1989 and 1998, but the percentage of miles operating under capacity (LOS A, B, or C) also increased during that same time period – from 47 to 53 percent.

Exhibit 31
1989 LOS FOR FREEWAY GENERAL PURPOSE LANES: PM PEAK PERIOD

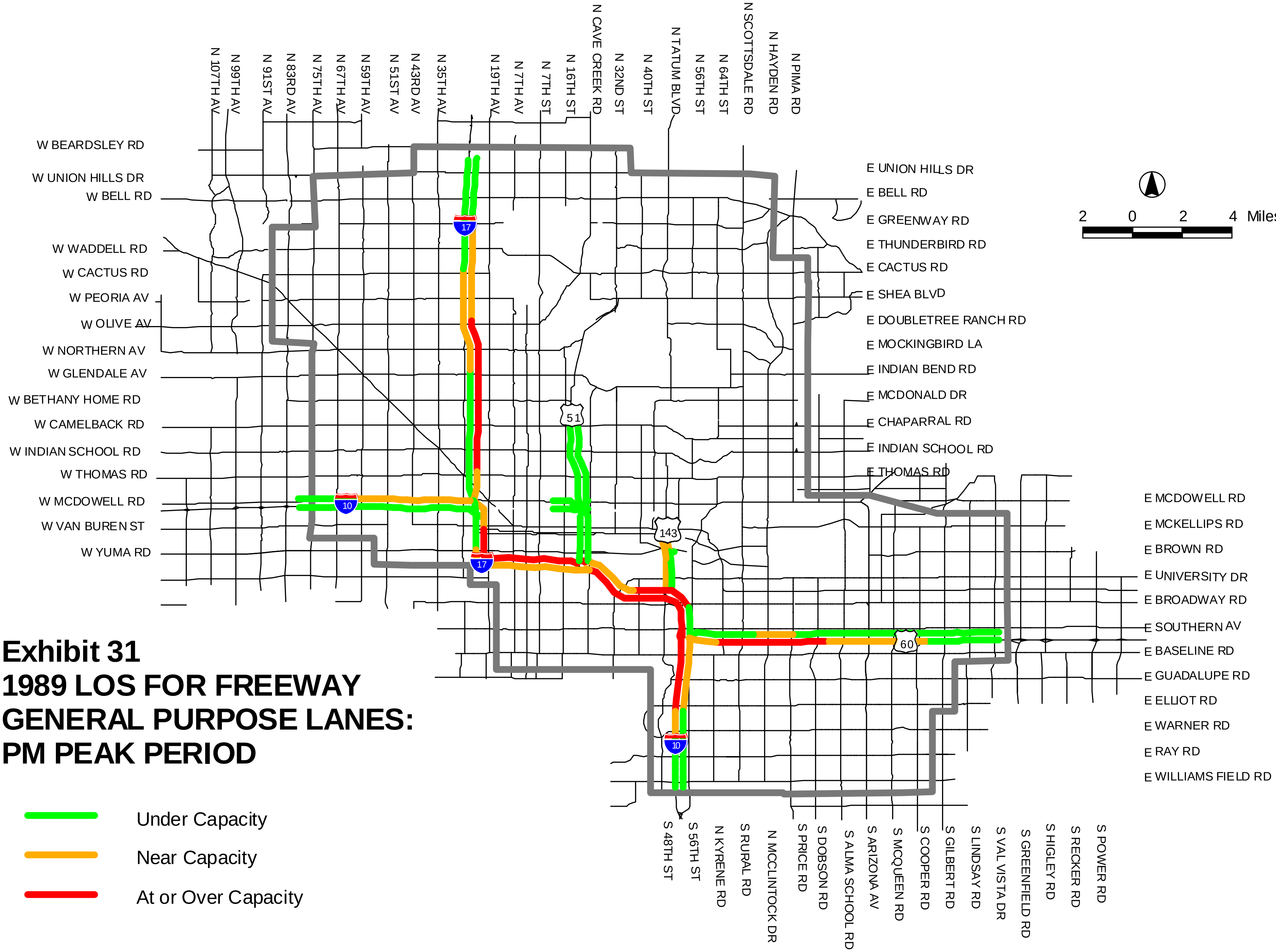
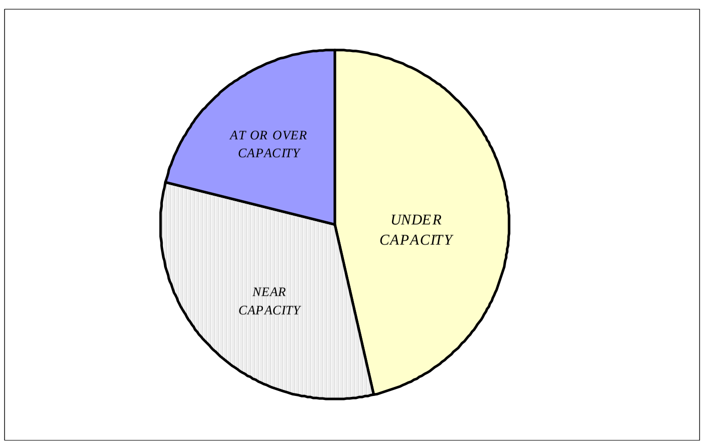


Exhibit 32
COMPARISON OF PM PEAK HOUR CONDITIONS: FREEWAYS

1989

Level of Service	No. of One-Way Miles Analyzed	Percent of Total
LOS A, B, or C (Under Capacity)	53	46.5 %
LOS D (Near Capacity)	37	32.4
LOS E or F (At or Over Capacity)	24	21.1
Total	114	100.0 %



1998

Level of Service	No. of One-Way Miles Analyzed	Percent of Total
LOS A, B, or C (Under Capacity)	121	52.4 %
LOS D (Near Capacity)	38	16.4
LOS E or F (At or Over Capacity)	72	31.2
Total	231	100.0 %

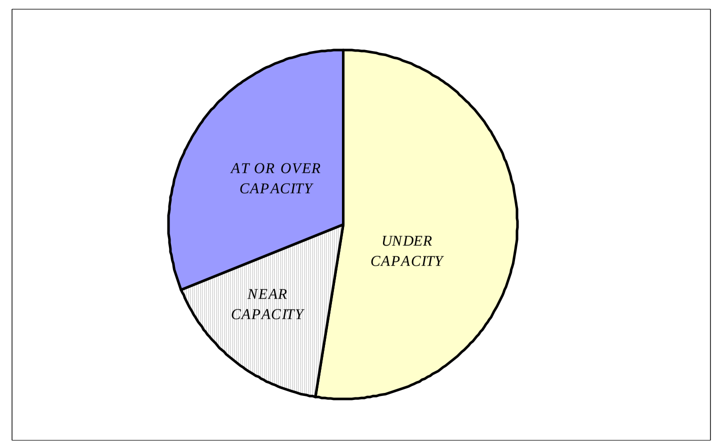


Exhibit 33
1998 EMPLOYMENT DENSITY

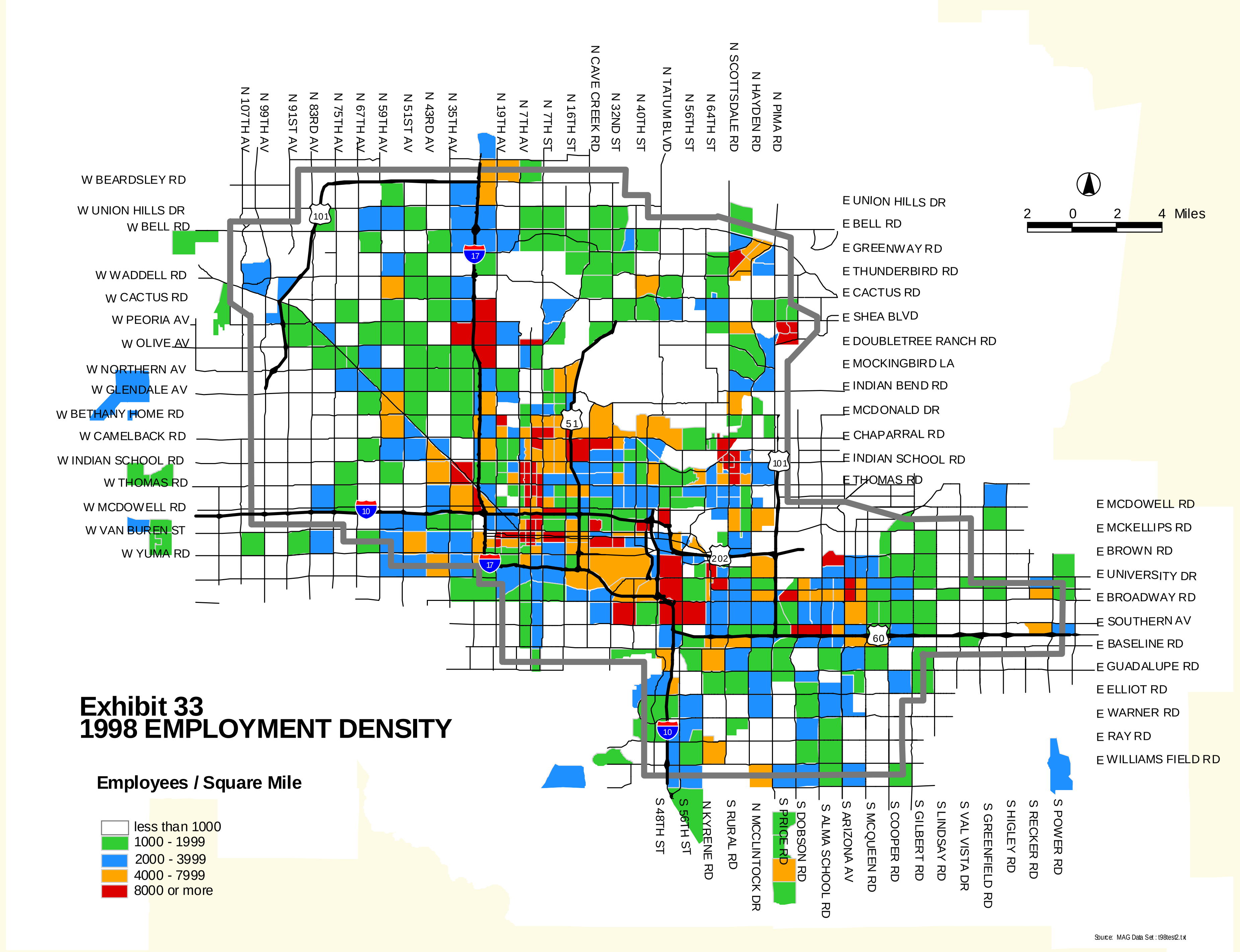
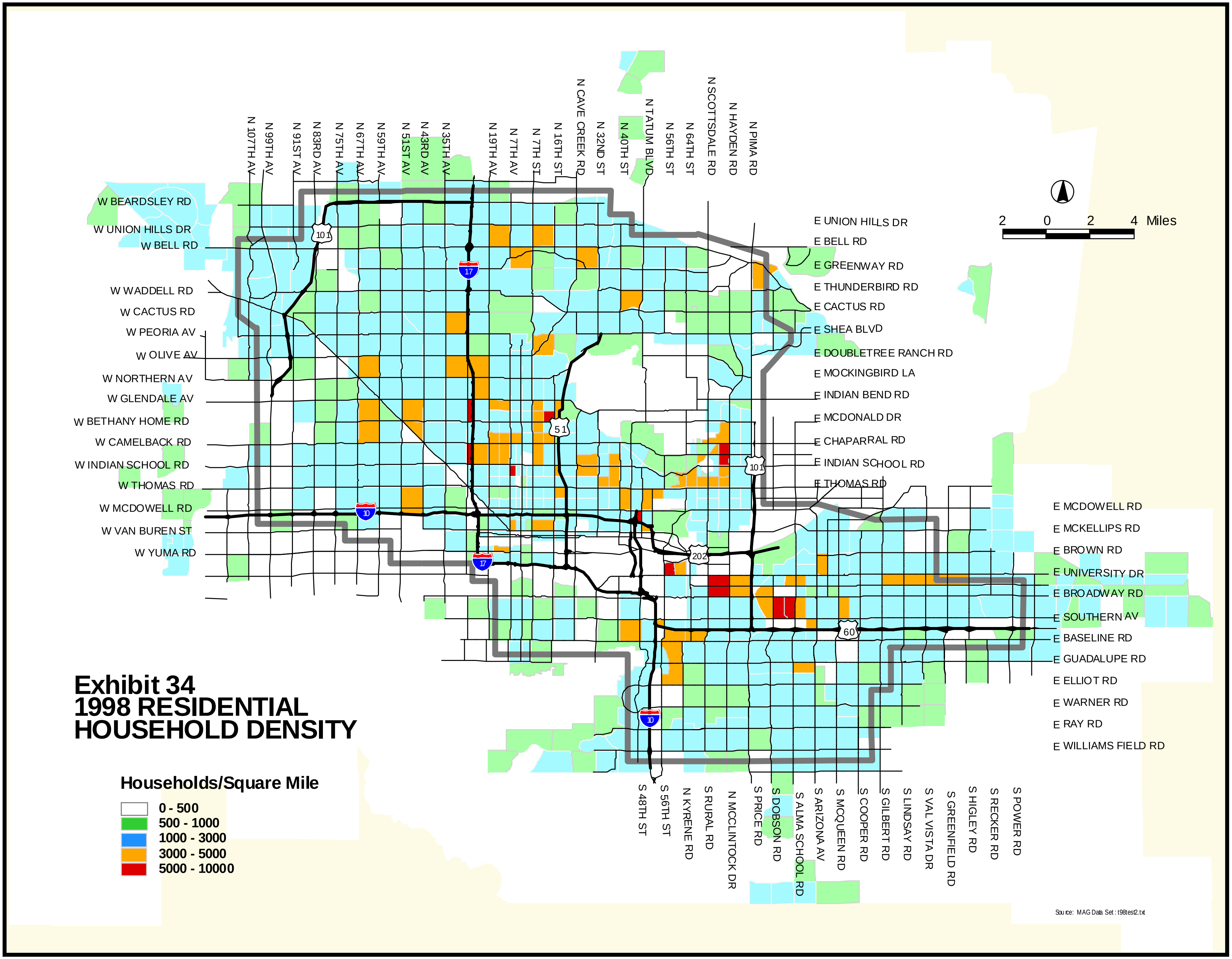


Exhibit 34
1998 RESIDENTIAL HOUSEHOLD DENSITY



GROWTH IN THE PHOENIX AREA

When the results of the 1998 MAG Regional Congestion Study are compared to those obtained in the 1989 study, it is clear that peak hour traffic congestion has become more severe and has spread to more locations throughout the Valley. This is not surprising, given the explosive growth that has been experienced by the Phoenix area over the past decade.

As expected, the freeway segments and major intersections that were identified in this study as experiencing peak-hour congestion are generally located in areas exhibiting higher concentrations of population and/or employment. In Exhibit 33, the study area boundaries have been superimposed on a map indicating relative employment densities for the Phoenix area; Exhibit 34 provides similar information with respect to household densities. These two exhibits confirm the fact that the defined study area includes all freeways and intersections likely to be experiencing some level of congestion during peak travel periods, because its boundaries incorporate those areas where the vast majority of the people live and work. These two exhibits also help to explain why congestion is generally more common and more severe in central Phoenix, in parts of the East Valley, and in the north Scottsdale/northeast Phoenix area, than it is in the West Valley.

The following table highlights the changes in population and employment that have occurred within the boundaries of the 1998 study area:

Statistic	1989	1998	Difference
Population	1,800,000	2,170,000	+ 20%
Employment	860,000	1,170,000	+ 36%

Source: MAG taz1990a.txt, and t98test2.txt

The surrounding area has been growing at an even faster rate than the study area itself, as shown by the following table, which provides population and employment statistics for the entire urban area (i.e., Maricopa County):

Statistic	1989	1998	Difference
Population	2,089,900	2,860,100	+ 39%
Employment	961,600	1,418,900	+ 48%

Source: Arizona Department of Economic Security

This rapid growth outside the study area is important because it generates many trips that are at least partially in the study area.

Exhibit 35 provides yet another perspective on recent growth in the Phoenix area. This exhibit shows where new housing construction has occurred since 1990. The greatest changes have been seen around the periphery of the study area – in particular, in the northern part of the Valley (Peoria, Glendale, north Phoenix, north Scottsdale) and in the southeast (Ahwatukee, Chandler, Gilbert, and east Mesa). Again, these are areas where significant congestion was identified in the 1998 MAG Regional Congestion Study.

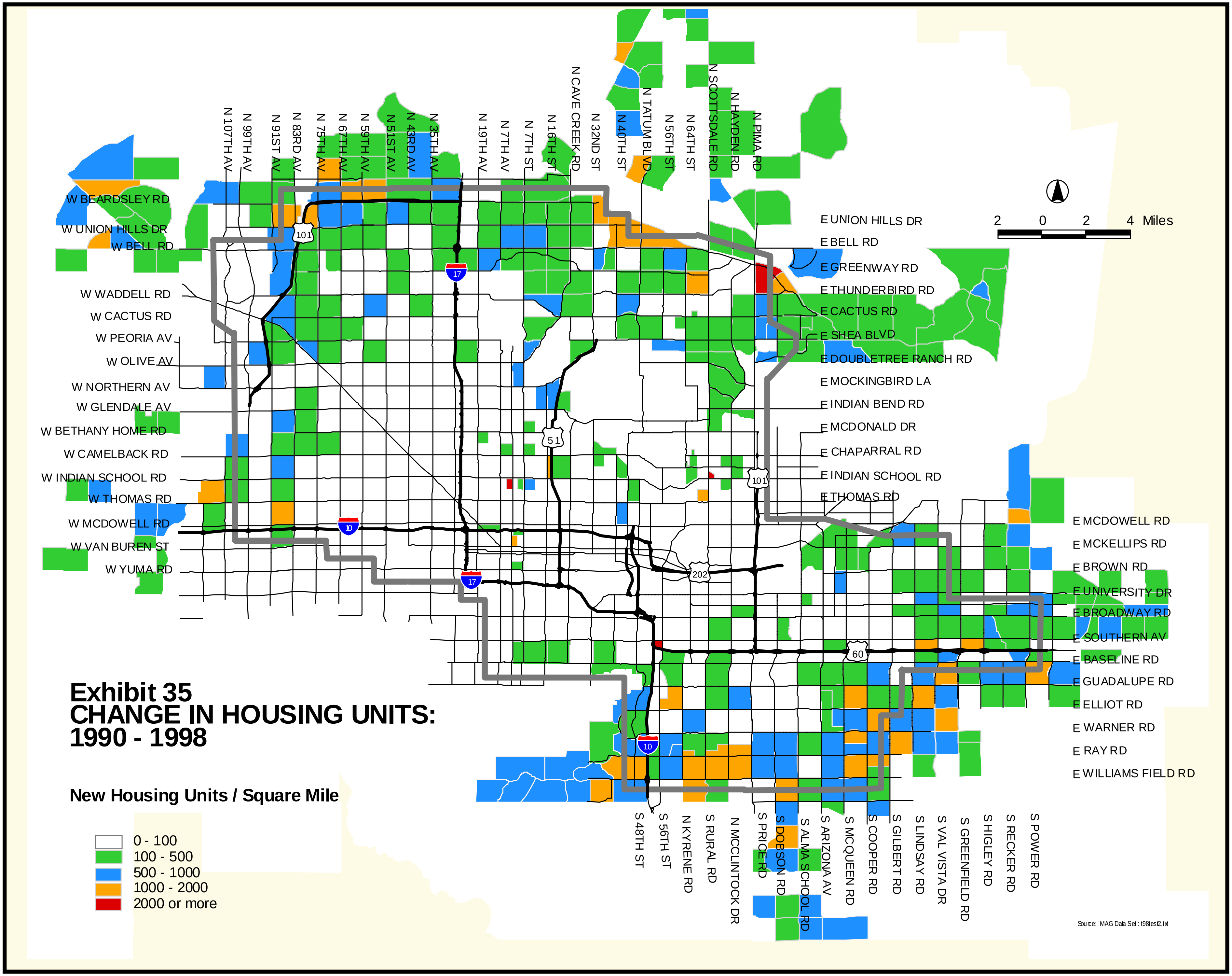
A necessary consequence of all this population and employment growth is an ever-increasing number of vehicle-trips being made on the area's streets and freeways. Vehicle-miles of travel (VMT) – a statistic that takes into account the length of these trips – has also increased, as shown by the following table:

Vehicle-Miles of Travel within the 1998 Study Area			
Facility Type	1989	1998	Difference
Arterial Streets	22,900,000	27,900,000	+ 22%
Freeways	6,600,000	14,000,000	+ 112%
Total	29,500,000	41,900,000	+ 42%

Source: MAG 1989bus & 1998k1 network

Although a significant number of new freeway miles have been constructed, freeways still constitute a small percentage of the Valley's total roadway miles. The number of lane-miles on arterial streets, which carry the bulk of the traffic, has increased only slightly since 1989. The following table shows the number of lane-miles for freeways and arterials within the 1998 study area boundaries, and compares these values to the comparable statistics for 1989:

Exhibit 35
CHANGE IN HOUSING UNITS: 1990 - 1998



Facility Type	Number of Lane-Miles		
	1989	1998	Difference
Freeways: General Purpose Lanes	403	765	+ 90%
Freeways: HOV Lanes	33	84	+ 155%
Freeways (All Lanes)	436	849	+95%
Arterial Streets	4,210	4,660	+ 11%

Source: MAG 1989bus & 1998k1 network

In order to provide a basis on which to compare the growth in VMT with the amount of street construction, the number of lane-miles for each facility type were converted to "daily capacity-miles." This was done by multiplying the freeway lane-miles by 21,000 vehicles per day (the assumed capacity for a single freeway lane) and by multiplying arterial lane-miles by 8,000 vehicles per day (the assumed capacity for a single lane of arterial street). The results are shown below:

Facility Type	Daily Capacity-Miles		
	1989	1998	Difference
Freeways	9,160,000	17,800,000	+ 95%
Arterial Streets	33,700,000	37,300,000	+ 11%
Total	42,860,000	55,100,000	+ 29%

Source: MAG 1989bus & 1998k1 network

Between 1989 and 1998, vehicle-miles of travel increased at approximately the same rate as the County population grew (40 - 42%), but roadway capacity increased at a much slower rate (29%). This difference in the rate of growth for VMT and the increase in roadway capacity is what is leading to increased congestion on the area's streets and freeways.