

# SWZDI

## Smart Work Zone Deployment Initiative

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<b>Freeway Work Zone Lane Capacity</b>		
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<b>Abstract</b> <p>The focus of this report is a capacity analysis of two long-term urban freeway Work Zones. Work Zone #1 tapered four mainline lanes to two, using two separate tapers; Work Zone #2 tapered two mainline lanes to one. Work Zone throughput was analyzed throughout the day over multiple days and traffic operations conditions were analyzed up to a distance of five miles upstream of the Work Zone entrance. Historical data from pavement-embedded detectors were used to analyze traffic conditions. The database consisted of five-minute volume, speed and occupancy data collected from 78 detectors for a total of 50 days.</p> <p>Congestion during each analyzed Work Zone existed for more than fourteen hours each day; Work Zone impacts adversely affected freeway operations over distances of 3.7 to 4.2 miles. Speed and occupancy conditions further upstream were, however, not affected, or even improved due to significant trip diversion. Work Zone capacity was defined based on the maximum traffic flows observed over a one-hour period; throughput values were also compiled over longer periods of time when traffic was within 90% of the maximum observed one-hour flows, as well as over the multi-hour mid-day period. The Highway Capacity Manual freeway capacity definition based on the maximum observed 15-min period was not used, since it would have no practical application in estimating Work Zone throughput when congested conditions prevail for the majority of the hours of the day.</p> <p>Certain noteworthy changes took place for the duration of the analyzed Work Zones: per-lane throughput dropped; morning peak periods started earlier, evening peak periods ended later and lasted longer; mid-day volumes dropped accompanied by the highest occupancies of the day. Trip diversion was evident in lower volumes entering the analyzed freeway corridor, higher volumes using off-ramps and lower volumes using on-ramps upstream of the Work Zones. The majority of diverted traffic comprised smaller vehicles (vehicles up to 21 feet in length); combination truck volumes increased and their use of the median lane increased, contrary to smaller vehicles that shifted toward a heavier use of the shoulder lane.</p>		

## **Freeway Work Zone Lane Capacity**

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## **ABSTRACT**

The focus of this report is a capacity analysis of two long-term urban freeway Work Zones. Work Zone #1 tapered four mainline lanes to two, using two separate tapers; Work Zone #2 tapered two mainline lanes to one. Work Zone throughput was analyzed throughout the day over multiple days and traffic operations conditions were analyzed up to a distance of five miles upstream of the Work Zone entrance. Historical data from pavement-embedded detectors were used to analyze traffic conditions. The database consisted of five-minute volume, speed and occupancy data collected from 78 detectors for a total of 50 days.

Congestion during each analyzed Work Zone existed for more than fourteen hours each day; Work Zone impacts adversely affected freeway operations over distances of 3.7 to 4.2 miles. Speed and occupancy conditions further upstream were, however, not affected, or even improved due to significant trip diversion.

Work Zone capacity was defined based on the maximum traffic flows observed over a one-hour period; throughput values were also compiled over longer periods of time when traffic was within 90% of the maximum observed one-hour flows, as well as over the multi-hour mid-day period. The Highway Capacity Manual freeway capacity definition based on the maximum observed 15-min period was not used, since it would have no practical application in estimating Work Zone throughput when congested conditions prevail for the majority of the hours of the day.

Certain noteworthy changes took place for the duration of the analyzed Work Zones: per-lane throughput dropped; morning peak periods started earlier, evening peak periods ended later and lasted longer; mid-day volumes dropped accompanied by the highest occupancies of the day.

Trip diversion was evident in lower volumes entering the analyzed freeway corridor, higher volumes using off-ramps and lower volumes using on-ramps upstream of the Work Zones. The majority of diverted traffic comprised smaller vehicles (vehicles up to 21 feet in length); combination truck volumes increased and their use of the median lane increased, contrary to smaller vehicles that shifted toward a heavier use of the shoulder lane.

Numerical findings are presented in summary tables and extensive Appendices provide supporting information.

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## DEFINITIONS

**ADT:** Average Daily Traffic

**Bottleneck:** A road element on which demand exceeds capacity. (HCM p. 5-2)

**Capacity:** The maximum sustainable flow rate at which vehicles or persons reasonably can be expected to traverse a point or uniform segment of a lane or roadway during a specified time period under given roadway, geometric, traffic, environmental and control conditions; usually expressed as vehicles per hour, passenger cars per hour, or persons per hour. (HCM p. 5-2)

**Demand:** The number of users desiring service on the highway system, usually expressed as vehicles per hour or passenger cars per hour. (HCM p. 5-4)

**DOT:** Department of Transportation

**E-N:** East-to-North

**HCM:** Highway Capacity Manual 2000 edition.

**Long-Term work zone:** work that occupies a location more than 3 days (MoDOT).

**Mile point 0.0:** A conventional mile point established at the core of the interchange where the **S-N** ramp crosses over the **W-E** ramp-see Appendix A, page 4.

**NB:** Northbound

**Normal** (traffic conditions): Weekday traffic conditions in the absence of Work Zone influence during April 1-9 and May 11-20, 2006.

**Peak hour volume:** the highest hourly volume computed as the sum of twelve successive five-minute traffic counts.

**Peak period:** Working definition—time period when hourly volumes are within 90% of the peak hour volume.

**Short-Term work zone:** work that occupies a location less than 3 days (MoDOT).

**SB:** Southbound

**S-N:** South-to-North

**S-E:** South-to-East

**S-W:** South-to-West

## DEFINITIONS (continued)

**vpd:** vehicles per day

**vphpl:** vehicles per hour per lane

**vpdpl:** vehicles per day per lane

**W-E:** West-to-East

**W-N:** West-to-North

**Work Zone:** “A work zone is an area of a trafficway with highway construction, maintenance, or utility-work activities. A work zone is typically marked by signs, channeling devices, barriers, pavement markings, and/or work vehicles. It extends from the first warning sign or flashing lights on a vehicle to the "End of Road Work" sign or the last traffic control device. A work zone may be for short or long durations and may include stationary or moving activities.” (Public Roads, May-June 1999)

**WZ:** Work Zone

**WZ1:** Work Zone 1 established between April 10 and April 25, 2006, at the **Wisconsin Avenue** overpass. Two of three normally available through lanes remained open (see **Figures B1, B2, C1, C2** and the corridor aerial photo-file **Corridor.pdf**).

**WZ2:** Work Zone 2 established between April 26 and May 10, 2006, on the South-to-North Zoo interchange ramp. One of the normally two available through lanes remained open (see **Figures B1, B3, C1, C2** and the corridor aerial photo-file **Corridor.pdf**).

# **Freeway Work Zone Lane Capacity**

## **INTRODUCTION**

As freeways operate closer to capacity, lane closures and other impediments disrupt traffic flow, causing longer traffic backups and delays. In order to better estimate the effects of freeway lane closures and to make good work zone project decisions, state DOTs are conducting more work zone impact and delay analyses. Accurately quantifying delays and other work zone impacts depends on having good estimates of work zone lane capacity. Some information is available in the Highway Capacity Manual, but details are lacking on the effects on capacity of various work zone activities and staging methods.

The present effort focuses on an in-depth analysis of two long-term urban freeway work zones established in the spring of 2006 in Milwaukee, Wisconsin. The work zones were chosen for analysis due to the significant impact they had on traffic operations.

Five-minute archived data were analyzed for a 50-day period that included a number of days before and after work zone activities were present, in order to establish prevailing traffic operations conditions in the absence of work zone activity. These base conditions were used to establish work zone impacts on traffic operations along the analyzed corridor. Traffic impacts were recorded upstream of the work zones for a distance of five miles. This corridor had a three-lane cross-section (one direction) and included six on-ramps and three off-ramps.

It is shown that the work zones led to a 20% traffic volume reduction in the vicinity of the work zones and a 10% reduction 4.4 miles upstream of the work zones. Less traffic entered the corridor; exiting volumes increased and entering volumes decreased significantly when a work zone was present.

A series of graphs documents the volume, speed and occupancy conditions at 11 mainline locations. Comparisons are drawn between normal traffic conditions and conditions during each of the work zones.

The collected information is used to establish that observed peak hourly volumes represented work zone capacity. The emphasis is on a practical work zone capacity definition, that is, a sustainable, observed (actual) and repeatable one-hour volume. Reported capacity figures are averages based on multiple count days. Maximum observed one-hour values and peak volume fluctuations (standard deviations) are reported as well to provide a sense of the stability of reported information.

The report includes a large number of figures in order to provide the interested reader the opportunity to evaluate the context in which conclusions were derived; also to provide fertile ground for new research ideas in the area of work zone capacity and work zone impacts. A 94 by 10-inch aerial photograph of the entire corridor is provided.

## REPORT ORGANIZATION

In the interest of report readability, very few tables have been incorporated in the report body. Figures and the remaining Tables are provided in self-contained Appendices. Each Appendix includes an introduction explaining the use of provided information-most also contain observations on the provided material. Appendix materials are cited by a letter, denoting the appendix and a number. For example, **Figure C1** is the first Figure in **Appendix C**. The body of this report is meant to be read with frequent references to Appendices where details can be found.

Following the introduction is a brief description of work zone location and duration. A general description of the evaluation methodology and a general description of the analyzed corridor cross section follow. The next section describes work zone geometry, followed by a description of the data collection and validation effort.

The three analysis periods [**Normal** traffic, Work Zone 1 (**WZ1**) and Work Zone 2 (**WZ2**)] and the specific dates used for each are introduced. The section on traffic characteristics findings is organized in three general parts, one for each of **Normal**, **WZ1** and **WZ2** conditions. Each general part is subdivided into 24-hour corridor and peak/off peak period overviews followed by descriptions of conditions at the **WZ1** and **WZ2** locations.

A summary of findings, conclusions and suggestions for future research topics conclude the report.

### *Study Locations and Time Periods*

Two urban freeway long-term work zones were identified based on their significant durations and traffic impacts. The work zones were established in the summer of 2006, in the Northbound direction of I-894/US 45, a North-South corridor crossing the “Zoo” interchange, located in Milwaukee County, WI<sup>1</sup> (see **Appendix A** and file **Corridor.pdf**). Detailed descriptions of each work zone can be found in the following pages. The first work zone (**WZ1**), located 4,270 feet North of the interchange core (see page **A3**, **Figure C1** and **Corridor.pdf**), was present between April 10 and 26; the second one (**WZ2**) was located at the interchange core (see page **A4**, **Figure C1** and **Corridor.pdf**) and was established immediately afterward, between April 27 and May 10. Work zone traffic operations impacts were analyzed in comparison to “**Normal**” traffic conditions at the corridor that were quantified for the periods prior to (April 1-9) and following work zone establishment (May 11-20). The abbreviations **WZ1**, **WZ2** and **Normal** are used extensively throughout the report to refer to the above-defined time periods. Depending on the context, the terms **WZ1** and **WZ2** may also denote the respective work zone location.

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<sup>1</sup> Latitude: N 43° 1' 38" Longitude: W 88° 2' 5.4"

## EVALUATION METHODOLOGY

“**Normal**” weekday traffic conditions and conditions during the period each work zone was in place were documented in order to establish work zone throughput as well as upstream impacts. The following traffic characteristics were assessed:

- Total traffic upstream and at the work zone location under “**Normal**” traffic conditions: this information was used to establish whether normal traffic volumes were likely to reach or exceed the capacity of open lanes when a work zone would be present. This was a necessary condition if work zone capacity was to be observed.
- Mainline traffic volume crossing cut lines located at various distances upstream from the work zone taper: differences between **Normal** and work zone (**WZ**) traffic volumes were used to estimate diverted traffic levels when a work zone was in place.
- Traffic speed and occupancy upstream and downstream from a work zone (**WZ**) location: differences in these characteristics between normal traffic and work zone conditions were used to establish the spatial and temporal extent of **WZ** impacts along the corridor.

## ANALYZED CORRIDOR GEOMETRY

The two analyzed long-term work zones (described in more detail in the following paragraphs) were located in the Northbound (**NB**) direction near the “Zoo” Interchange in Milwaukee County, Wisconsin—see **Appendix A, Figure C1** and **Corridor.pdf**.

The “Zoo” interchange, close to the North end of the analyzed corridor, is a full-directional interchange connecting I-94 (running East-West) with 894 (South leg) and US 45 (North leg). A conventional **mile point 0.0** was established at the core of the interchange where the South-to-North (**S-N**) ramp crosses over the West-to-East (**W-E**) ramp—see **page A4**.

On the southern part of the corridor, **NB** I-894 has three through lanes; it widens to four lanes 1,800 ft before the Zoo interchange. At the interchange, the newly introduced median lane continues as a connecting ramp to I-94 Westbound traffic toward Madison, Wisconsin (**S-W** ramp—see **page A4**), the two middle lanes carry **NB** traffic through the interchange core (**S-N** lanes) and the shoulder lane continues as a connecting ramp for I-94 Eastbound traffic continuing to downtown Milwaukee (**S-E** ramp).

Past the Zoo interchange, the two **NB** lanes (**S-N** lanes) are joined by a left-hand one-lane ramp used by Eastbound I-94 traffic continuing Northbound on US 45 (**W-N** ramp), and a one-lane right-hand ramp used by Westbound I-94 traffic continuing Northbound on US 45 (**E-N** ramp)—see **Figure B1**. Thus, US 45 has four lanes North of the interchange



core. The median lane is carried past the **Bluemound Road** overpass and dropped just upstream of the **Wisconsin Avenue** overpass at a distance of 3,700 feet from the **W-N** ramp (4,200 ft from mile point 0.0), using a taper of 750 feet. The **E-N** ramp continues as a through freeway lane (shoulder lane). Thus, three lanes are present past the **Wisconsin Avenue** overpass. They continue across the Milwaukee County border, which is located approximately 12 miles North of the interchange core.

A short exit taper precedes the **Bluemound Road** right-hand loop ramp, 2,000 feet from the **E-N** ramp gore.

## WORK ZONE GEOMETRY

The two analyzed work zones described in detail below were established in order to maintain the bridge piers supporting the **Bluemound Road** and **Wisconsin Avenue** overpasses, located 3,130 ft and 4,270 ft respectively from mile point 0.0.

### Work Zone #1 (WZ1)

The first analyzed work zone was established in the Northbound (**NB**) direction of US 45 between April 10, and April 26, 2006 in order to perform maintenance work on the bridge piers located on the freeway median at the **Bluemound Road** and **Wisconsin Avenue** overpasses (**Figure B2**).

Continuous 12-foot shoulders were present on either side of the freeway at the **Bluemound Road** overpass, with four 12-ft wide lanes. A 670-foot left-hand taper was used upstream of the overpass to close the median lane, leaving three lanes open for traffic. A 1,050-foot left-hand taper upstream of the **Wisconsin Avenue** overpass eliminated the left-most open lane, leaving two lanes open at **Wisconsin Avenue**. The two-lane cross section at **Wisconsin Avenue** created the most restrictive conditions for the entire work zone area.

Both above-mentioned tapers were delineated with drums spaced every 50 feet, fitted with warning lights type C. The shoulder was closed with a 50-foot taper, for 530 feet before the start of the **Bluemound Road** lane closure taper. **Appendix H** provides details on **WZ** traffic control plans (the term “Stage 1” is used for **WZ1** on these plans).

Each maintenance site was protected with a 300-foot-long Jersey barrier set, tapered at a 15:1 rate that protected the left shoulder and the closed median lane. The **Bluemound Road** exit was open throughout the **WZ1** period.

Three directions of traffic fed into this work zone: West-to-North (**W-N**) traffic (one lane), East-to-North (**E-N**) traffic (one lane) and South-to-North (**S-N**) traffic (two lanes). Thus, four feeding lanes were reduced to two lanes at the **Wisconsin Avenue** overpass.

## Work Zone #2 (WZ2)

The second work zone was established between April 27, and May 10, 2006 in order to perform maintenance on bridge piers located on the freeway right shoulder at the **Bluemound Road** overpass. As part of the traffic management plans for this work zone, a taper was established that reduced the two through South-to-North (**S-N**) lanes at the Zoo interchange to one lane (the left lane was kept open-**Figure B3**). The taper was established near **milepoint 0.0**, on a bridge structure. The one-lane cross section on the ramp structure created the most restrictive conditions for the entire **WZ** area.

The taper was delineated with drums spaced every 50 feet, fitted with warning lights type C. The right shoulder was closed with a 50-foot taper, for 530 feet before the start of the lane closure taper. The closed lane was protected with a 300-foot-long Jersey barrier set tapered at a 15:1 rate that protected the closed shoulder lane. **Appendix H** provides details on **WZ** traffic control plans (the term “Stage 2” is used for **WZ2** on these plans).

A continuous 4-foot left shoulder was present on the ramp structure, with a Jersey barrier-shaped parapet adjacent to the left edge of this shoulder.

## DETECTOR DATA COLLECTION AND VALIDATION

Archived five-minute detector data were downloaded from the WisTransPortal web site.<sup>2</sup> All available detectors in the analysis corridor (from **Wisconsin Avenue** on the North end, to the **Hale Interchange** on the South end—a distance of five miles-**Figure C1**) were queried for the period between April 1 and May 20, 2006. Thus each detector was expected to provide 14,400 five-minute observations.<sup>3</sup> A total of 78 detectors (one detector per lane) were analyzed (1,123,200 five-minute observations). Information was synthesized into 24-hour counts and compared to available WisDOT 2005 and 2006 Average Daily Traffic (ADT) counts, in order to establish detector reliability. Comparisons to WisDOT counts were performed at eleven mainline locations and thirteen freeway ramps (five off-ramps and eight on-ramps-**Figure C3**) using 42 reliable detectors. Details of these comparisons and discussion are provided in **Appendix C**.

Cross street locations used to reference detector locations can be found in **Figure C1**; mainline detector distances in **Figure C2**; Wisconsin Department of Transportation (WisDOT) and detector 24-hour counts in **Figure C3**.

In general, detector data were very close to WisDOT 2005 and 2006 ADT, allowing for seasonal variations and reconstruction activities at the major downtown Milwaukee, WI Marquette Interchange, located on I-94 approximately five miles due East of the **Zoo**

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<sup>2</sup> <http://transportal.cee.wisc.edu/> maintained by the TOPS laboratory of the University of Wisconsin-Madison for the Wisconsin Department of Transportation.

<sup>3</sup> 50 days x 24 hours per day x 12 five-minute observations per hour = 14,400 observations.

**Interchange.** (Long- and short-term ramp closures at the Marquette Interchange affected directional traffic distributions at the **Zoo Interchange**.)

Detector-counted volumes in the periods before and after work zone activities in the summer of 2006 matched exceptionally well, providing an additional degree of confidence in the collected data. Detector data were therefore deemed to be reliable and were used in all analyses performed herein. **Normal** traffic conditions statistics were based collectively on data collected during the periods before and after **WZ** were present, in order to increase the database size.

Additional detector data reliability checks were performed using comparisons between lanes at each location and between upstream and downstream detectors. Days with few- or no- missing data were used to provide the statistics reported herein. In general no more than one or two five-minute periods were missing during any of the analyzed peak periods. Missing information was substituted by interpolating adjacent five-minute periods.

## **FINDINGS PRESENTATION ORGANIZATION**

The overall effect of work zone presence on traffic operations was evaluated using mainline and ramp detector-based data. Two separate analyses were undertaken.

- The main focus of this report was the **area in the vicinity of each work zone**. Volumes, speeds and occupancies were monitored at the closest upstream and downstream detector locations for **WZ1 (South of the Zoo interchange and Wisconsin Avenue, respectively)** and an upstream location for **WZ2 (South of the Zoo interchange)** in order to assess traffic conditions at each work zone.
- An additional area of interest in this report was the effect that each work zone had on upstream traffic in terms of speeds, occupancies and diverted traffic. For this analysis, data were obtained from detectors within **the five-mile-long Wisconsin Avenue-to-Hale interchange corridor, upstream of each work zone**.

The following presentation is based on information compiled from archived five-minute loop detector data during the 50-day period of April 1 to May 20, 2006. Twenty-four hour traffic volume information is presented first, setting up the background against which **WZ** traffic operations impacts were established.

## **ANALYSIS TIME PERIODS**

A total of 50 days of five-minute volume, occupancy and speed data were collected, covering the period from April 1 to May 20, 2006. Work zone 1 (**WZ1**) lasted seventeen days; Work zone 2 (**WZ2**) was in place the day after **WZ1** was removed and lasted fourteen days. In addition, the nine days preceding **WZ1** and the ten days following **WZ2** were chosen to provide statistics for “normal” traffic operations, abbreviated to “**Normal**” in what follows. The three time periods relevant to this analysis were:

**Normal:** April 1-9 and May 11-20  
**WZ1:** April 10-26  
**WZ2:** April 27-May 10

After an exhaustive traffic detector data analysis, the dates listed in **Table 1** were identified as the best available for statistics compilation, based on the availability of 24-hour data for reliable traffic detectors.

Table 1. Dates selected to provide weekday statistics.

	Type of analysis	
Analysis period	Wisconsin Ave.-to-Hale corridor analysis	WZ vicinity
<b>Normal</b>	Tue 4/4, Wed 4/5, Tue 5/16, Wed 5/17, Thu 5/18, Fri 5/19	Tue 4/4, Wed 4/5, Thu 4/6
<b>WZ1</b>	Tue 4/11, Fri 4/14, Mon 4/17, Tue 4/18, Wed 4/19, Thu 4/20	Thu 4/13, Fri 4/14, Tue 4/18, Wed 4/19, Thu 4/20
<b>WZ2</b>	Mon 5/1, Wed 5/3, Thu 5/4, Fri 5/5, Tue 5/9	Mon 5/1, Wed 5/3, Thu 5/4, Fri 5/5, Tue 5/9, Wed 5/10

**Note:** Date selection based on 24-hour detector data availability.

## Normal Traffic Operations

### *Corridor Overview*

**24-hour counts:** A total of 71,600 vpd entered the analyzed corridor South of **Coldspring Road (Figure C4)**. Traffic gradually increased toward the North end of the corridor, as on-ramp traffic exceeded exiting traffic. Total on-ramp traffic was 29,450 vpd and the off-ramp traffic was 16,200 vpd, between the **Hale** and the **Zoo** interchanges. Thus 13,250 vpd were added to the traffic entering the corridor, for a total of 84,850 vpd just South of the **Zoo Interchange**.<sup>4</sup>

An average of 46,200 vpd traveled on the **S-N** two-lane structure, joined by 15,100 vpd from the **W-N** ramp and 28,300 vpd from the **E-N** ramp, for a total of 89,600 vpd immediately north of the Zoo interchange.<sup>5</sup> Since 87,100 vpd were counted 250 feet North of the **Wisconsin Avenue** overpass, 2,500 vpd used the **Bluemound Road** exit.

**Peak and Off-Peak Periods:** Traffic volumes increased rapidly along the corridor starting after 4:00 am, reaching a peak by 6:00 am (for volumes see **Figures D1** and **E1**- for mainline detector locations see Figure C2). Peak per-lane volumes increased from

<sup>4</sup> This number balances well with the 84,800 vpd measured through mainline detectors South of the Zoo Interchange.

<sup>5</sup> Refer to distances in Figures C1 and C2.

1,750 vphpl at the South end of the corridor (**Coldspring**) to 1,900 vphpl at the North end (**Greenfield**).<sup>6</sup> A 2,200 vphpl volume was present at the **Wisconsin Avenue** overpass.

Speed and occupancy patterns (**Figures D2, E2 and D3, E3**, respectively) reflected changes in volumes, with the lowest speeds and occupancies reached as volumes peaked. Free-flow speeds at the South half of the corridor were 61 mph. They fluctuated between 58 and 66 mph on the North half of the corridor. The most significant speed drops and occupancy increases during the peak period were observed at the **Oklahoma, Cleveland, National** and **Lincoln** locations where speeds were between 28 and 30 mph and occupancies were between 30% and 26%, respectively. **Beloit** and **Howard** had occupancies at the lower end of this range. The rest of the corridor experienced speeds between 37 and 48 mph with occupancies around 20%, with the exception of **Wisconsin Avenue** that was operating at 55 mph and a maximum occupancy of 15%.

#### *Vicinity of Future WZ1 Taper Location*

Available detector locations dictated where information was collected. Thus, volume and speed information was collected 250 ft downstream from where the taper was to be placed during **WZ1** (see **Figures C1 and C2**). Speed information was also collected at the **South of Zoo** interchange location, 5,400 ft upstream from the **WZ1** taper. Three through lanes were open at **Wisconsin Avenue** during normal operations and four lanes were open at the **Bluemound Road** location.

Four lanes fed traffic into the three **Wisconsin Avenue** overpass lanes (see **Figure B1**): the **W-N** and **E-N** ramps, with one lane each, and the two **S-N** lanes. Hourly throughput at **Wisconsin Avenue** and speeds downstream of the **WZ1** location are shown in **Figure F1**. Detailed statistics are presented in **Table G1** for the hours when higher volumes were present (6:00 to 18:05 hrs).

The highest per-lane volume was 2,141 vph when average speed was 52.8 mph and average occupancy was 15.0% indicating that the facility operated below capacity during **Normal** traffic operations. This value is quite close to the average of 2,061 vphpl maintained between 6:00 and 9:10 hrs. A maximum hourly volume of 2,189 vphpl was observed at **Wisconsin Avenue** during one of the analyzed six days (see **Table 1**).

The effects of minor congestion are evident in terms of lower speeds and higher occupancies at the **South of Zoo** detector location (5,400 ft upstream of the **WZ1** location). There was good correspondence between peaking volumes at the **WZ1** location and lower speeds at the **WZ2** location (**Figure F2**—see discussion in **Appendix F**). For example, during the highest one-hour throughput, upstream occupancy was 23.1% vs. 15.0% at **Wisconsin Avenue** and speed is 41.9 mph compared to 52.8 mph. Evidence of traffic turbulence upstream of **Wisconsin Avenue** is also provided in terms of higher occupancy and speed standard deviations upstream of the **WZ1** location.

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<sup>6</sup> The South of the Zoo detector location reports on the two N-S lanes—the drop in per-lane volume is due to the introduction of a left-hand lane that becomes the S-W ramp North of the Greenfield detector location. A four-lane cross section is present there; all other locations have a three-lane cross section.

The highest one-hour afternoon peak volume was 1,981 vphpl when average speed was 59.7 mph and occupancy was 12.1%. Average volumes between peak periods were 1,535 vphpl.

#### ***Vicinity of Future WZ2 Taper Location***

**Table G2** presents a summary of traffic conditions at the **WZ2** location (**S-N** lanes) during the hours when higher volumes were present (5:45 to 18:20 hrs). Lane volume and speed data were collected at the **South-of-Zoo** detector location, 1,130 ft upstream from where the taper was to be placed during **WZ2** (see **Figure C2**). Two through lanes were open during normal operations. Total volume and speed through the **S-N** lanes are shown in **Figure F3**.

Volumes peaked at 1,750 vphpl between 6:25 and 7:25 hrs. The average speed during this hour was 53.5 mph, under an average occupancy of 12.9%. Thus the facility operated below capacity during normal traffic operations. A maximum hourly volume of 1,777 vphpl was observed during one of the analyzed six days.

It is interesting to note in **Figure F2** that the lowest morning one-hour average speed of 42 mph coincided with the time that traffic peaked at **Wisconsin Avenue** and was due to downstream congestion rather than increasing volumes or reaching capacity at the **N-S** lanes.

The highest one-hour volume during the afternoon peak was 1,521 vphpl under an average speed of 54.9 mph and average occupancy of 9.9%.

Average volumes between peak periods were 1,248 vphpl with corresponding average speed of 55.9 mph and average occupancy of 10.0 %.

#### **Work Zone 1 (WZ1) Traffic Operations**

##### ***Corridor Overview***

**24-hour counts:** A total of 64,500 vpd entered the analyzed corridor South of **Coldspring Road** (**Figure C4**). Volumes gradually increased approaching the **Zoo Interchange**, as on-ramp traffic exceeded exiting traffic, but this increase was only 3,400 vph<sup>7</sup> compared to 13,200 vpd<sup>8</sup> under **Normal** traffic conditions.

This dramatic change was due to three contributing factors, resulting in 17,086 fewer vpd reaching the **Zoo Interchange** (see **Figure C5**):

1. 7,100 fewer vpd entering the South end of the corridor at **Coldspring Road**.
2. 4,436 more vpd using exit ramps (20,636 vs. 16,200 vpd).
3. 5,550 fewer vpd using on-ramps (23,900 vs. 29,450 vpd).

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<sup>7</sup> 67,900 vpd S of the Zoo – 64,500 vpd at Coldspring Ave.

<sup>8</sup> 84,800 vpd S of the Zoo – 71,600 vpd at Coldspring Ave.

Volume reductions South of **Cleveland** were 6,700 to 7,100 vpd and 14,000 to 17,400 vpd between **Cleveland** and the **Zoo Interchange**.

**Peak and Off-Peak Periods:** Traffic volumes increased rapidly along the corridor starting after 4:00 hrs. Five-minute flows peaked at 6:00 hrs (see **Figures D4** and **E4** for mainline detector locations see **Figure C2**). Volumes hovered around 1,500 vphpl from **Coldspring** to **Greenfield** (three mainline lanes). They were 1,100 vphpl at the two N-S lanes, and 2,100 vphpl at **Wisconsin Avenue**.

It is interesting to note that, because of lower mainline volumes during **WZ1**, morning peak speeds were higher South of **Oklahoma** (**Figures D5** and **E5**): +18 mph at **Coldspring** and **Howard** compared to normal conditions, +15 mph at **Beloit**, +8 mph at **Oklahoma**. Speeds remained unaffected at **Cleveland** and **National**. However, **WZ1** adversely impacted **Lincoln** (-13 mph), **Belton** (-14 mph), **Greenfield** (-22 mph), **S of Zoo** (-41 mph) and 250 ft downstream from the **WZ1** taper as vehicles accelerated through **WZ1** (-8 mph).

In the same vein, occupancies during **WZ1** were lower South of **Oklahoma** (**Figures D6** and **E6**): -9% **Coldspring**, -13% **Howard**, -12% **Beloit**, -3% **Oklahoma**. Higher occupancies were present at **Cleveland** (+3%), **National** (+5%), **Lincoln** and **Belton** (+9%), **Greenfield** (+10%) and **S of Zoo** (+32%).

#### *Conditions at the WZ1 Taper*

During **WZ1**, the four lanes feeding traffic into the **Wisconsin Avenue** overpass lanes were reduced to two through lanes (see **Figure B3**). For the purposes of the current study it was essential to establish whether **WZ** capacity was reached or not at this location. A number of observations point toward concluding that, indeed, this **WZ** was operating at capacity during parts of each weekday:

1. Total entering traffic during the morning peak under **Normal** operations exceeded 6,000 vph (**Figure F1**). This volume would correspond to 3,000 vphpl during **WZ1** when two lanes were open, a value that certainly exceeded lane capacity.<sup>9</sup> The possibility remained though, that, if enough traffic diverted, **WZ1** lanes could remain below capacity; however,
2. The high occupancy observed at the **S of Zoo** detectors during the morning and afternoon peaks indicated the presence of a significant queue (measurements taken 5,400 ft upstream of the taper), which guaranteed that demand would not drop below **WZ1** capacity during these peaks.

Traffic conditions for the hours when higher traffic volumes were present during **WZ1** (5:25 to 19:15 hours) are summarized in **Table G3**. The highest hourly throughput of 2,096 vphpl, was observed between 6:55 and 7:55 hrs. This volume was assumed to be the **WZ1** capacity for the above-stated reasons. The average speed under capacity was 47.6 mph and the average occupancy was 13.4% 250 ft downstream from the taper. At

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<sup>9</sup> However, mid-day entering volumes during normal operations would not exceed per lane capacity for two open lanes. Thus only peak periods were suitable for analysis if **WZ** lane capacity were to be observed.

the **S of Zoo** detectors, located 5,650 ft upstream of the taper, average speed was 9.1 mph and occupancy 47.5% during the same hour.

Speed standard deviation at the upstream location was 13.4 mph vs. 2.67 mph at the downstream location; occupancy standard deviations were 11.0% and 0.82%, respectively. These observations indicated turbulent upstream traffic conditions and much smoother traffic conditions within **WZ1**.

The maximum one-hour volume observed during any one of the six analyzed days was 2,167 vphpl. An average of 2,003 vphpl passed through **WZ1** between 5:25 and 9:30 hrs.

During the afternoon peak, the highest volume was 2,047 vphpl (16:40-17:40 hours) under an average speed of 49.3 mph and an average occupancy of 13.0% within **WZ1** a speed of 11.4 mph and an occupancy of 46.5% were present at the **S of Zoo** location. This volume was 50 vph lower than the **WZ1** capacity observed during the morning peak.

Mid-day average volume was 1,803 vphpl with a **WZ1** average speed of 47.4 mph and average occupancy of 13.0%. The upstream speed and occupancy were 12.1 mph and 47.9%, respectively.

## **Work Zone 2 (WZ2) Traffic Operations**

### ***Corridor Overview***

**24-hour counts:** A total of 63,500 vpd entered the analyzed corridor South of **Coldspring** compared to 71,600 vpd under normal conditions (**Figure C4**). Traffic volumes gradually increased approaching the **Zoo interchange**, as on-ramp traffic exceeded exiting traffic, but this increase was only 2,800 vph<sup>10</sup> compared to 13,200 vpd<sup>11</sup> under **Normal** traffic conditions.

This dramatic change was due to three contributing factors, resulting in 18,500 fewer vpd reaching the **Zoo Interchange**:

1. 8,100 fewer vpd entering the South end of the corridor at Coldspring.
2. 4,450 more vpd using exit ramps (20,650 vs. 16,200 vpd).<sup>12</sup>
3. 5,950 fewer vpd using on-ramps (23,500 vs. 29,450 vpd).

Volume reductions South of **Cleveland** were 7,900 to 8,600 vpd. Reductions ranged from 15,300 to 18,500 vpd between **Cleveland** and the **Zoo Interchange** (**Figure C6**).

**Peak and Off-Peak Periods:** Traffic volumes increased rapidly along the corridor starting after 4:00 hrs. Five-minute flows peaked at 6:00 hrs (**Figures D7 and E7**)-for mainline detector locations see **Figure C2**). Volumes were around 1,450 vphpl from

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<sup>10</sup> 66,300 vpd S of the Zoo – 63,500 vpd at Coldspring Ave.

<sup>11</sup> 84,800 vpd S of the Zoo – 71,600 vpd at Coldspring Ave.

<sup>12</sup> Beloit exit estimated 6,800 vpd during WZ2.



**Coldspring to Cleveland** and increased to 1,550 vphpl from **National to Greenfield**. They were 1,900 vphpl at the open **N-S** lane, and were 1,550 vphpl at **Wisconsin Avenue**.

Because of lower mainline volumes during **WZ2**, morning peak speeds were higher South of **Oklahoma (Figures D8 and E8)**: +19 mph at **Coldspring** and **Howard** compared to normal conditions, +14 mph at **Beloit**. Speeds remained unaffected at **Oklahoma**. However, **WZ2** adversely impacted **Cleveland** (-9 mph), **National** (-5 mph), **Lincoln** (-10 mph), **Belton** (-15 mph), **Greenfield** (-24 mph), and **S of Zoo** (-39 mph). Speeds remained unaffected at **Wisconsin Avenue**.

Reflecting speed changes, occupancies during **WZ2** were lower South of **Oklahoma (Figures D9 and E9)**: -18% **Coldspring**, -29% **Howard**, -15% **Beloit**. They remained unchanged at **Oklahoma**. Higher occupancies were present at **Cleveland** (+6%), **National** (+8%), **Lincoln** (+21%), and **Belton** (+18%), **Greenfield** (+28%) and at the **S of Zoo** location (+45%). **Wisconsin Avenue** had a lower occupancy (-7%) since all lanes were open and less traffic was feeding through the **N-S** lanes. This was an indication that the high occupancies at the **S of Zoo** location were not due to downstream backups.

#### *Conditions at the WZ2 Taper*

During **WZ2**, the two **S-N** lanes were reduced to one through lane (see **Figure B3**). Similar to the case of **WZ1**, the following observations point toward concluding that this **WZ** was also operating at capacity during parts of each weekday:

1. Total entering traffic during the morning peak under normal operations exceeded 3,000 vph (**Figure F3**), a value that exceeded the capacity of the single open lane during **WZ2**. The possibility remained though, that, if enough traffic diverted, the **WZ** could remain below capacity.
2. The high occupancy observed at the **S of Zoo**, **Greenfield** and **Belton** detectors during the morning peak indicated the presence of a queue length of at least 6,020 ft, which guaranteed that demand would not drop below **WZ2** capacity during the morning peak.

Traffic conditions for the hours when higher traffic volumes were present during **WZ2** (5:10 to 19:50 hrs) are summarized in **Table G4**. The highest hourly throughput of 1,906 vphpl, was observed between 5:30 and 6:30 hrs. This volume is assumed to be the **WZ2** capacity for the above-stated reasons. The average speed under capacity was 20.1 mph and occupancy 25.9% during the same hour.

The maximum volume observed during any one of the six analyzed days was 1,938 vphpl, only 2% higher than the average maximum throughput for all six days together, reinforcing the notion that **WZ2** was operating at capacity during the morning peak. An average of 1,817 vphpl passed through **WZ2** between 5:10 and 7:45 hrs.

During the afternoon peak, the highest volume was 1,757 vphpl (17:50-18:50 hrs) under an average speed of 25.5 mph and an average occupancy of 22.4%. This volume was 8% lower than the per-lane volume during the morning peak.

Mid-day average volume was 1,563 vphpl under an average speed of 13.3 mph and an average occupancy of 30.9%.

## **OBSERVATIONS AND CONCLUSIONS**

### **Introduction**

This report presents findings based on observations collected in two long-term urban freeway Work Zones. The analysis included observations collected within a 6.2-mile corridor. Analyzed traffic volume, speed and occupancy information was based on five-minute summary information collected through detectors at eight mainline and 13 ramp locations.

The Work Zones were selected based on the significant impact they had on freeway operations, and the extended hours of congestion they caused for the duration of the work performed at these locations. The presence of long queues, very low speeds and high occupancies was verified for each analyzed day, in order to make sure that the observed highest flows through each Work Zone represented maximum flows.

As with any urban freeway, the analyzed corridor geometry, ramp locations and traffic distribution were unique, thus a major effort was put in this report to document conditions in as much detail as possible, so Engineers and Researchers working on similar projects can draw their own conclusions about the applicability of findings at other locations.

Emphasis was placed on the practicality of findings. For example, the reported Work Zone capacity figures (highest one-hour throughputs) are based on actual counts (the sum of twelve 5-minute counts) rather than the highest 15-min flow during the peak hour. In addition to the highest one-hour count, the average hourly volume during each peak period (period during which volumes are within 90% of the peak hour volume) is reported, as well as average hourly mid-day throughput. Reported throughput values are accompanied by speed and occupancy statistics for the same time periods. These values provide traffic operations conditions attainable over many hours, rather than extreme values that can only be maintained for short periods—thus reported values are useful for long-term urban freeway work zone impact mitigation planning.

### **Normal Conditions Observations-WZ1 Location**

Under **Normal** conditions four lanes were reduced to three through lanes at the **Wisconsin Avenue** overpass through a long left-hand-side taper. A total of 87,100 vpd used the facility. The highest volumes of the day occurred during the morning peak hour (7:25 to 8:25 hrs) with a total of 6,422 vph over the three-lane mainline cross-section (2,141 vphpl) under a speed of 41.9 mph and an occupancy of 23.1%. The afternoon peak hour occurred between 15:15 and 16:15 hrs with an average of 1,981 vphpl at 56.3

mph and a 15.2% occupancy. Volumes remained within 90% of the peak hour between 6:00 and 9:10 hrs in the morning and 13:40 and 18:05 hrs in the afternoon. Mid-day volumes averaged 1,929 vphpl at 56.3 mph and a 15.2% occupancy.

### **WZ1 Conditions Observations**

During **WZ1** a four-lane freeway cross-section was reduced to two lanes at the **Wisconsin Avenue** overpass. Throughput was limited to 66,700 vpd. Significant congestion was measured at the closest upstream detectors 5,650 ft from the **WZ1** location from 5:25 to 19:15 hrs. Upstream speeds were very low throughout this time period; morning peak hour throughput was slightly higher than the afternoon peak hour (2,096 vphpl vs. 2,047 vphpl). Volumes remained at 90% of the peak hour volume between 5:25 and 9:30 hrs in the morning and between 13:55 and 19:15 hrs in the afternoon.

Long queues were present upstream of the entrance to **WZ1**. Average speed was 9.1 mph and average occupancy was 47.5% at a distance of 5,650 ft from **WZ1** during the morning peak hour. An average speed of 11.4 mph and an occupancy of 46.5% were present at the same location during the afternoon peak. Conditions did not improve noticeably during the rest of the day: average speed was 12.1 mph and average occupancy 47.9% under a volume of 1,803 vphpl.

Despite a significant volume reduction in advance of **WZ1** (10% less traffic entered the corridor; off-ramp traffic increased 20%-37%; on-ramp traffic dropped by 3%-26% within the corridor), lower speeds prevailed upstream to **Cleveland Avenue**, located approximately three miles from **WZ1**.

Traffic composition changes that occurred during **WZ1** were mainly due to approximately 9,800 fewer smaller vehicles traveling past the **Cleveland Avenue** overpass. Approximately 220 fewer single unit trucks and 650 more combination vehicles traveled on the corridor during **WZ1**.

### **WZ1 Conclusions**

When a four-lane cross-section was reduced to two through lanes, the normally marginally congested three-lane mainline cross-section at **Wisconsin Avenue** carrying 6,422 vph during the morning peak hour became **severely congested** at 4,190 vph. Speeds dropped from 42 mph to 9 mph and occupancy increased from 23.1% to 47.5%.

**Work Zone Capacity** (highest counted one-hour volume with two open lanes) measured during the morning peak was **2,100 vphpl** with an average daily vehicle mix of 84% smaller vehicles, 3.5% single-unit trucks and buses, and 12% combination vehicles.

Afternoon peak conditions were similar, with maximum measured one-hour flow of 2,050 vphpl.

**Congested conditions lasted** for approximately **thirteen hours and fifty minutes** during each work day (5:25 to 19:15 hrs). The **morning peak period** occurred **35 minutes earlier** as commuters attempted to compensate for the extra travel time they would need to cross the corridor; volumes remained within 90% of the peak hour volumes for a longer period: four hours and five minutes, compared to three hours and five minutes under normal traffic conditions for the morning peak period; five hours and twenty minutes, compared to four hours and twenty-five minutes for the afternoon peak period under **Normal** traffic conditions.

Sustained **throughput levels** for the **morning and afternoon peak periods**, with a total duration of nine hours and twenty-five minutes were **very similar at 2,000 vphpl**. Mid-day average volumes, sustained over five hours and twenty-five minutes were 1,800 vphpl. This lower per-lane mid-day volume was associated with a lower average speed and a higher average occupancy.

Total **daily traffic was 23% lower** through the Work Zone (**WZ**) site. Similar mainline traffic reductions were evident up to 2.9 miles upstream of the **WZ** entrance, with approximately 10% lower volumes further upstream and through the South end of the analyzed corridor (a distance of 5.0 miles).

Traffic reductions could be apportioned to three sources: **Fewer vehicles entering the South end of the corridor; increased off-ramp volumes; and decreased on-ramp volumes**. Off-ramp traffic volumes increased by 20% to 37%, with the highest increases at the furthest upstream ramp (4.2 miles from the **WZ** entrance) and the lowest at the closest ramp (1.6 miles upstream). On-ramp volumes decreased by about a quarter throughout the corridor.

Most of the measured **traffic reductions** were **due to 9,800 fewer passenger cars and pick-up trucks** entering the northern half of the analyzed corridor; single-unit truck and bus presence was lower by 200 vpd, but 640 **more combination vehicles** entered this part of the corridor. These observations indicate that smaller vehicle operators were more likely to choose an alternate route than heavy vehicle operators. The impact of heavy vehicles, especially combination vehicles should not be underestimated when planning for a long-term urban **WZ**.

The net effect of traffic volume changes was that, although **operating conditions** during the **WZ** were significantly worse close to the **WZ** entrance, conditions were **comparable or better** (in terms of higher speeds and lower occupancies compared to **Normal** traffic conditions) at a distance of 4.2 miles (**Beloit Road**) or **further upstream**.

**Lane distribution changed** during **WZ1**; a shift away from the median lane and toward the shoulder lane was evident. This may be explained by a desire for easy off-ramp access as drivers entered the congested part of the corridor. The exception was combination trucks, whose numbers and proportion increased in the median lane. This behavior may have been motivated by a desire to avoid ramp turbulence by long-haul combination vehicle operators who were not likely to divert.

## Normal Conditions Observations-WZ2 Location

Under **Normal** conditions two South-to-North (**S-N**) lanes were open at the **Zoo Interchange**. A total of 46,200 vpd used the facility. The highest volumes of the day occurred during the morning peak hour (6:25 to 7:25 hrs) with a total of 3,500 vph over the two open lanes (1,750 vphpl) under a speed of 53.5 mph and an occupancy of 12.9%. The afternoon peak hour occurred between 16:40 and 17:40 hrs with an average of 1,521 vphpl at 54.9 mph and a 9.9% occupancy. Volumes remained within 90% of the peak hour between 5:45 and 8:20 hrs in the morning and 14:45 and 18:20 hrs in the afternoon. Mid-day volumes averaged 1,248 vphpl at 55.9 mph and a 10.0% occupancy.

## WZ2 Conditions Observations

During **WZ2** only the left of the two-lane **S-N** lanes of the **Zoo Interchange** was open. Throughput was limited to 30,500 vpd. Significant congestion was measured at the closest upstream detectors located at 1,130 ft from the **WZ** entrance, from 5:10 to 19:50 hrs. Upstream speeds ranged between 13.3 mph and 18.7 mph; morning peak hour throughput at 1,900 vphpl was 7.8% higher than the afternoon peak hour. Volumes remained at 90% of the peak hour volume between 5:10 and 7:45 hrs in the morning and between 14:25 and 19:50 hrs in the afternoon.

Long queues were present upstream of the entrance to **WZ2**. Average speed was 20.1 mph and average occupancy 25.9% at a distance of 1,130 ft from **WZ2** during the morning peak hour. An average speed of 25.5 mph and an average occupancy of 22.4% were present at the same location during the afternoon peak. During the mid-day period the average speed was 13.3 mph under an occupancy of 30.9% with a throughput of 1,560 vphpl.

Despite a significant volume reduction in advance of **WZ2** (11% less traffic entered the corridor, off-ramp traffic increased by 20% - 40%; on-ramp traffic decreased by about a quarter), lower speeds prevailed during the day upstream of **WZ2**, to **Howard Avenue**, located approximately 3.7 miles from **WZ2**. Traffic approaching **WZ2** was 22% lower than traffic under **Normal** conditions.

## WZ2 Conclusions

When a **two-lane cross section** was **reduced to one through lane**, the normally moderately congested cross-section on the **S-N** lanes, carrying 3,500 vph during the morning peak hour, became **severely congested at 1,900 vph**—representing **the WZ capacity** (highest counted one-hour volume with one open lane). Speeds dropped from 53.5 mph to 20.1 mph, and occupancy doubled from 12.9% to 25.9%.

Afternoon peak hour volume was 1,750 vphpl under similar mean speed and occupancy conditions to the morning peak (25.5 mph, and 22.4%, respectively).

Traffic composition was 85.4% smaller vehicles, 3.1% single-unit trucks and buses, and 11.4% combination vehicles.

**Congested conditions lasted fourteen hours and forty minutes** each weekday (5:10 to 19:50 hrs). The **morning peak** period occurred **35 minutes earlier** than under **Normal** traffic conditions as commuters attempted to compensate for the extra travel time they would need to cross the corridor; volumes remained within 90% of the peak hour volume for the same length of time during the morning peak period; however, the afternoon peak period lasted five hours and twenty-five minutes compared to three hours and thirty-five minutes under **Normal** traffic conditions. Speeds were very similar during the morning and afternoon peak periods: 17.3 mph vs. 18.7 mph, respectively and occupancies were equal at 27.5% for both periods.

Average throughput was 1,820 vphpl during the morning peak period; an 8% drop in throughput (to 1,670 vphpl) was observed during the afternoon peak period. Mid-day average volumes, sustained over six hours and forty minutes were 1,560 vphpl under a lower average speed (13.3 mph) and a moderately higher average occupancy (30.9%).

**Total daily traffic was 22% lower** through **WZ2**. Similar mainline traffic reductions were evident up to 1.7 miles upstream of **WZ2** with approximately 11% lower volumes further upstream and through the South end of the analyzed corridor (a distance of 4.2 miles).

Traffic reductions could be apportioned to three sources: **Fewer vehicles entering the South end of the corridor; increased off-ramp volumes; and decreased on-ramp volumes.** Off-ramp traffic volumes increased by 20% to 40%, with the highest increases at the furthest upstream ramp (3.2 miles from the **WZ** entrance). On-ramp volumes decreased by about a quarter for the ramps that were closest to **WZ2**.

Most of the measured **traffic reductions** were **due to 10,400 fewer passenger cars and pick-up trucks** entering the northern part of the analyzed corridor; single-unit truck and bus presence was lower by 160 vpd, but 1,310 **more combination vehicles** entered this part of the corridor. These observations indicate that smaller vehicle operators were more likely to choose an alternate route than heavy vehicle operators. The impact of heavy vehicles, especially combination vehicles should not be underestimated when planning for a long-term urban **WZ**.

The net effect of traffic volume changes was that, although **operating conditions** during the **WZ** were significantly worse close to the **WZ** entrance, conditions were **comparable or better** (in terms of higher speeds and lower occupancies compared to **Normal** traffic conditions) at a distance of 3.7 miles (**Howard Avenue**) or **further upstream**.

**Lane distribution changed** during **WZ2**, when a shift away from the median lane and toward the shoulder lane was observed. This may be explained by a desire for easy off-ramp access as drivers encountered heavier congestion than under **Normal** conditions. Only combination vehicle presence increased in the median lane (both in terms of the

vehicle count and as a percentage of traffic in that lane). This change may have been motivated by a desire to avoid ramp turbulence by long-haul combination vehicle operators who were the least likely among corridor users to divert to alternate routes.

## **General Conclusions**

Long-term urban freeway Work Zones (**WZ**) severely affect traffic operations by reducing throughput at the entrance to the **WZ** and creating extensive congestion extending a few miles upstream of the **WZ** location. The morning peak hour starts earlier as drivers attempt to compensate for longer travel times through the congested facility; the afternoon peak lasts longer; congestion is present throughout the day; a significant number of drivers either avoid using the facility altogether, or use off-ramps upstream of the **WZ**.

Morning peak periods (defined herein as the periods when traffic volumes are at 90% of the peak hour volumes) may be longer when **WZ** are present; afternoon peak periods last significantly longer than when **Normal** traffic conditions are present. Significant congestion is manifested through high occupancy levels and low throughput between the morning and afternoon peak periods.

Diverted trips result in limiting the congestion effects to within a fixed distance upstream of the **WZ** (around four miles in the analyzed corridor); speeds and occupancies remain unaffected or even improve further upstream.

The majority of the vehicles that divert when a **WZ** is present are expected to be smaller vehicles; however, more combination vehicles may be present. Thus vehicle mix changes can be expected under **WZ** conditions, a fact that should be taken into account in the planning phases for **WZ** mitigation measures.

If the Highway Capacity Manual (**HCM**) is used in estimating **WZ** traffic operation conditions, engineering judgment should be exercised in applying the heavy vehicle factor ( $f_{HV}$ ) for the following two reasons: vehicle mix may change under work zone conditions; and, the effect of heavy vehicles varies with speed (much more pronounced in the presence of very low speeds), a fact not captured in the **HCM** heavy vehicle factor.

**Tables 2 and 3** in the following pages summarize the primary findings of the present study.

Table 2. Summary of findings for a Work Zone reducing a four-lane mainline cross-section to two lanes (**WZ1**).

<b>4-to-2 lane bottleneck (WZ1)</b>	
Morning peak hour Volume; Speed; Occupancy	Started 30 min earlier (@ 6:55 hrs) 2,100 vphpl; 9.1 mph; 47.5%
Morning peak period Volume; Speed; Occupancy	Started 35 min earlier; lasted 4h 05min (55 min longer) 2,060 vphpl; 16.1 mph; 45.1%
Mid-day Volume; Speed; Occupancy	Lastest 5h 25min 1,803 vphpl; 12.1 mph; 47.9%
Afternoon peak hour Volume; Speed; Occupancy	Started 1h 25min later (@ 16:40 hrs) 2,050 vphpl; 11.4 mph; 46.5%
Afternoon peak period Volume; Speed; Occupancy	Started 15min later; 5h 20min (55 min longer) 1,970 vphpl; 15.8 mph; 44.2%
WZ effect extent	4.2 miles upstream of WZ entrance
Traffic composition changes (Before/After)	Total traffic 78,376 / 69,004 Smaller vehicles 86.7% / 84.3% Trucks and buses 3.3% / 3.5% Combination trucks 10.0% / 12.2%
Vehicle mix changes	9,372 fewer smaller vehicles 220 fewer trucks and buses 641 more combination trucks
Trip diversion Number of vehs / % change	Entering corridor -7,100 / -10% Off ramps +4,450 / -22% On ramps -5,500 / -23% Entering from S. of Zoo -17,050 / -20%



Table 3. Summary of findings for a Work Zone reducing a two-lane mainline cross-section to one lane (**WZ2**).

<b>2-to-1 lane bottleneck (WZ2)</b>	
Morning peak hour Volume; Speed; Occupancy	Started 55 min earlier (@ 5:30 hrs) 1,900 vphpl; 20.1 mph; 25.9%
Morning peak period Volume; Speed; Occupancy	Started 35 min earlier; lasted 2h 35min; (no change) 1,820 vphpl; 17.3 mph; 27.5%
Mid-day Volume; Speed; Occupancy	Lastest 6h 40min 1,560 vphpl; 13.3 mph; 30.9%
Afternoon peak hour Volume; Speed; Occupancy	Started 1h 10 min later (@ 17:50 hrs) 1,760 vphpl; 25.5 mph; 22.4%
Afternoon peak period Volume; Speed; Occupancy	Started 20 min earlier; lasted 5h 25min (1h 50min longer) 1,670 vphpl; 18.7 mph; 27.5%
WZ effect extent	3.7 miles upstream of WZ entrance
Traffic composition changes (Before/After)	Total traffic 78,376 / 69,115 Smaller vehicles 86.7% / 83.3% Trucks and buses 3.3% / 3.6% Combination trucks 10.0% / 13.2%
Vehicle mix changes	10,400 fewer smaller vehicles 160 fewer trucks and buses 1,310 more combination trucks
Trip diversion	Entering corridor -8,100 / -11% Off ramps +4,450 / -22% On ramps -5,950 / -25% Entering bottleneck -18,500 / -22%

## RECOMMENDATIONS

1. It is recommended that any traffic operations analysis of urban long-term **freeway Work Zone** projects consider a Work Zone **capacity based on sustained observed multi-hour throughputs**. Maximum 15-minute flows will not be representative of sustainable throughput since demand may be expected to exceed capacity for twelve or more hours at these locations. The least conservative Work Zone throughput numbers provided herein are one-hour peak volumes, based on actual one-hour counts averaged over multiple days; if more conservative throughput values are desired, they can be based on the provided average “peak period” throughputs, calculated for the time periods when volumes were at least 90% of the peak hour volumes; finally, if the most conservative throughput values are desired, mid-day average throughput values can be used. Mid-day periods typically had low average speeds and high average occupancies, comparable to peak hours, but lower throughputs.
2. The **morning peak hour can be expected to start earlier and the afternoon peak can be expected to start later**; congested **conditions can be expected to last significantly longer** than under normal traffic conditions. It is recommended that these observations be taken into account in the planning for alternate routes (for example in signal timing plans and ramp metering plans) so alternate routes will function efficiently for the duration of the work zone.
3. It is recommended to assume that all **commercial vehicles (especially combination vehicles) will continue to use the Work Zone corridor**, and that **most of the diverted trips will consist of smaller vehicles**. These assumptions should be taken into account in the calculation of the heavy vehicle factor in the Work Zone vicinity, as well as in geometric design considerations for any chosen alternate routes.
4. The **presence of combination vehicles in the median lane was observed to increase**. This was attributed to their lower likelihood to divert, and thus a lower need to be near exit ramps and their associated turbulence. If space limitations dictate the use of lanes of uneven width through the Work Zone, the Engineer may choose to provide a wider median lane for use by heavy vehicles.
5. A significant percentage of **traffic will choose alternate routes** for the duration of the work zone. **Traffic operations conditions will remain unchanged at a certain distance from the Work Zone due to traffic diversion**. It is recommended to **use the provided Work Zone capacity estimates and micro-simulation** in order to estimate: i) traffic volume reduction at the Work Zone location; ii) the additional traffic that off-ramps can accommodate; and, iii) on-ramp traffic reductions. The simulated corridor should extend five or six miles from the Work Zone location. A properly calibrated model that includes a sufficient number of on- and off-ramps should show speeds, volumes and occupancies similar to those documented herein in the area immediately upstream of the Work Zone, and normal traffic speeds and occupancies (due to diverted traffic) present at a given distance from the Work Zone (four miles, for example).

# **APPENDIX A**

## **ANALYZED CORRIDOR AERIAL PHOTOS**

## INTRODUCTION

**Appendix A** presents the entire analyzed corridor in a series of eight overlapping aerial photos that provide an accurate plan view. Distances can be measured directly on the photos-a scale is included on each page (with the exception of page A8).

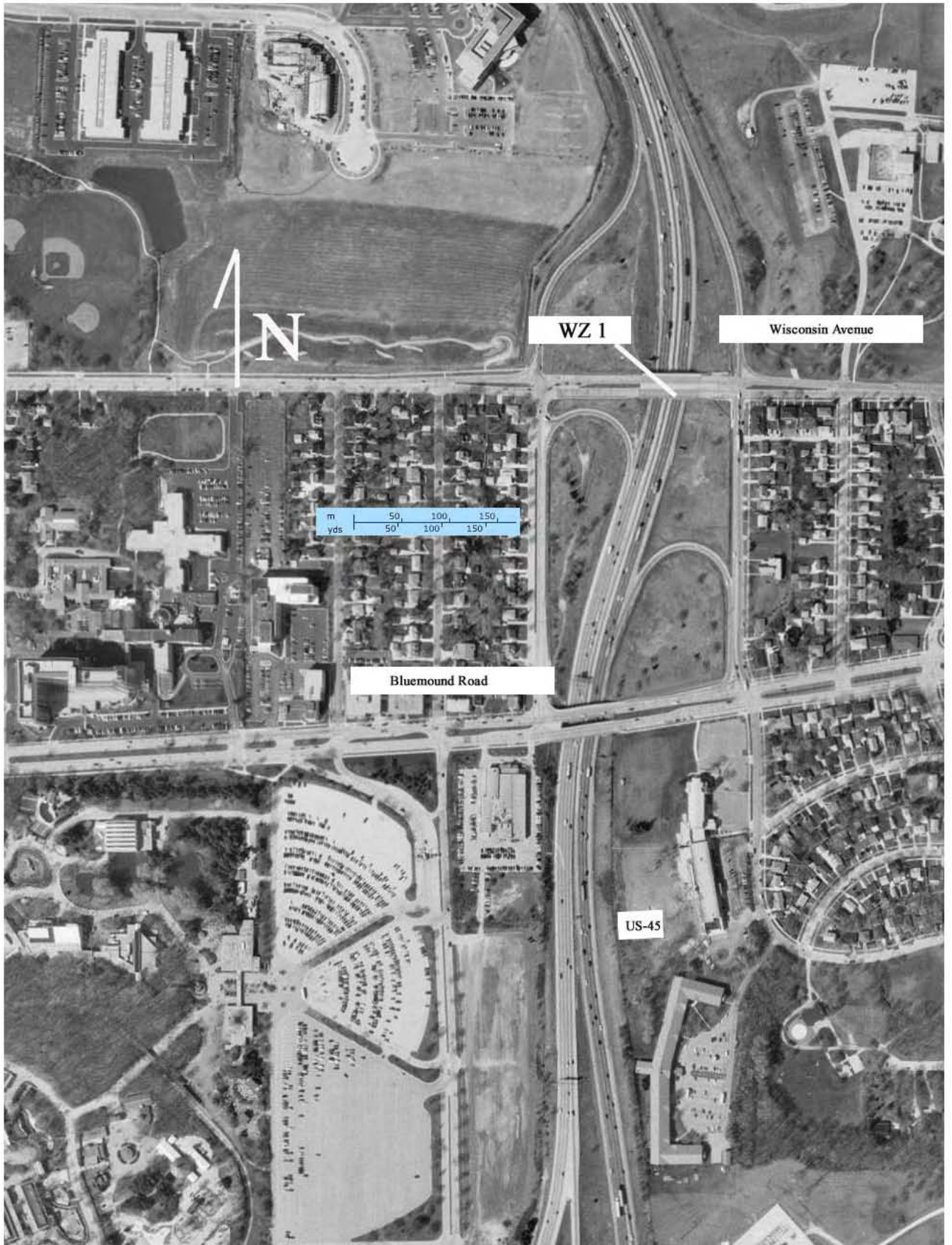
Cross street names, the locations of the two analyzed Work Zones (Work Zone 1-**WZ1** and Work Zone 2-**WZ2**), freeway ramp and mainline identifications, have been included for easier cross-referencing with other parts of the report.

A separate Acrobat file (**Corridor.pdf**) is provided to facilitate corridor review either on a computer monitor or printed on a plotter (approximate dimensions 10" x 94").

A conventional **mile point 0.0** was chosen at the **WZ2** location, where the South-to-North (**S-N**) ramp crosses over the West-to-East (**W-E**) ramp-see page A4. All distances mentioned in **Appendix C** pp. C4 and C5 are measured from this location.

**Appendix A** materials help the reader orient **Appendix H** Work Zone traffic control plans.

The **source of aerial photos** was TerraServerUSA <http://terraserver-usa.com>, a site sponsored by USGS and msn Virtual Earth. Freeway conditions as of 3/31/2000. No corridor geometry changes that affect this study occurred between that date and the analyzed period of 4/1/2006 to 5/20/2006.



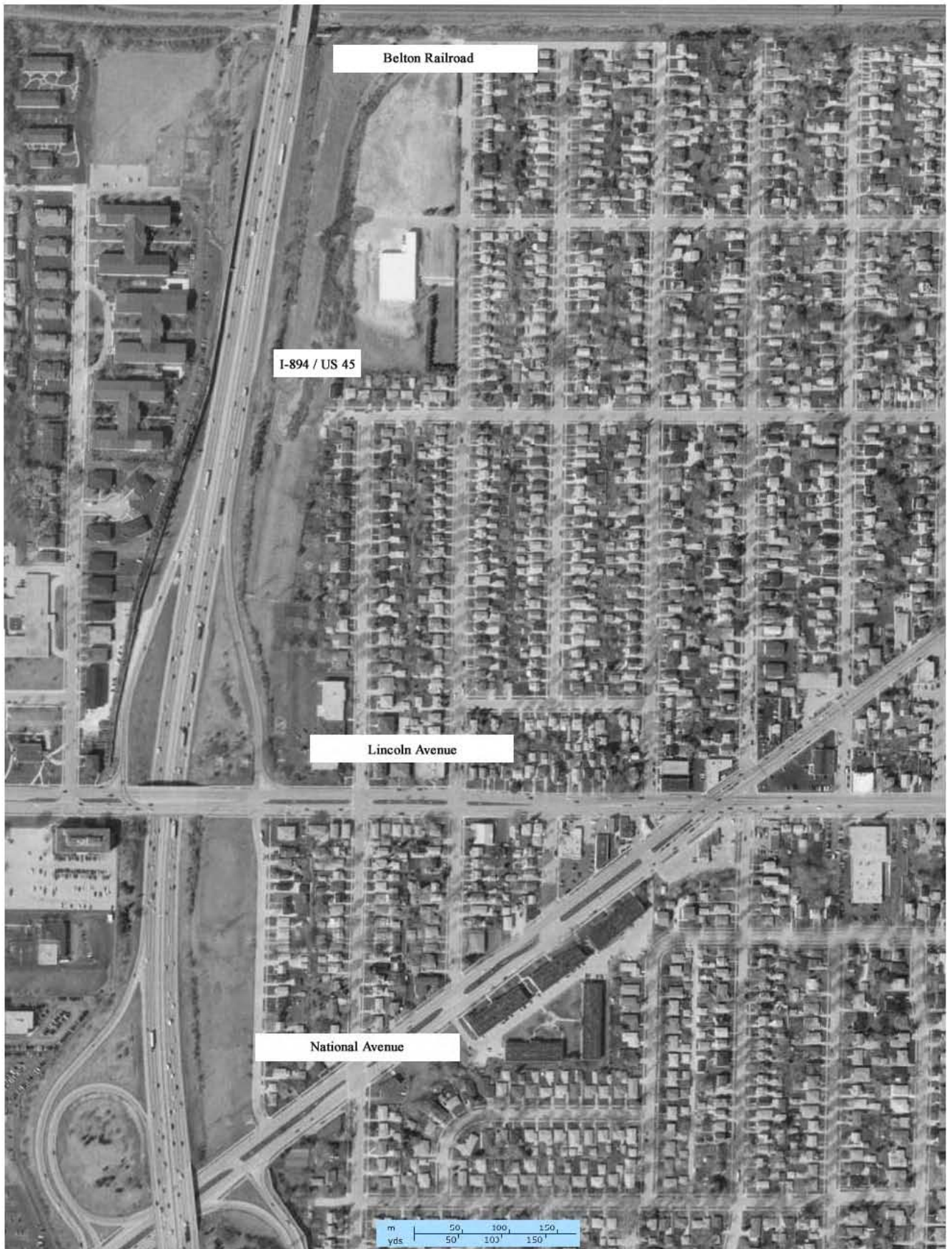














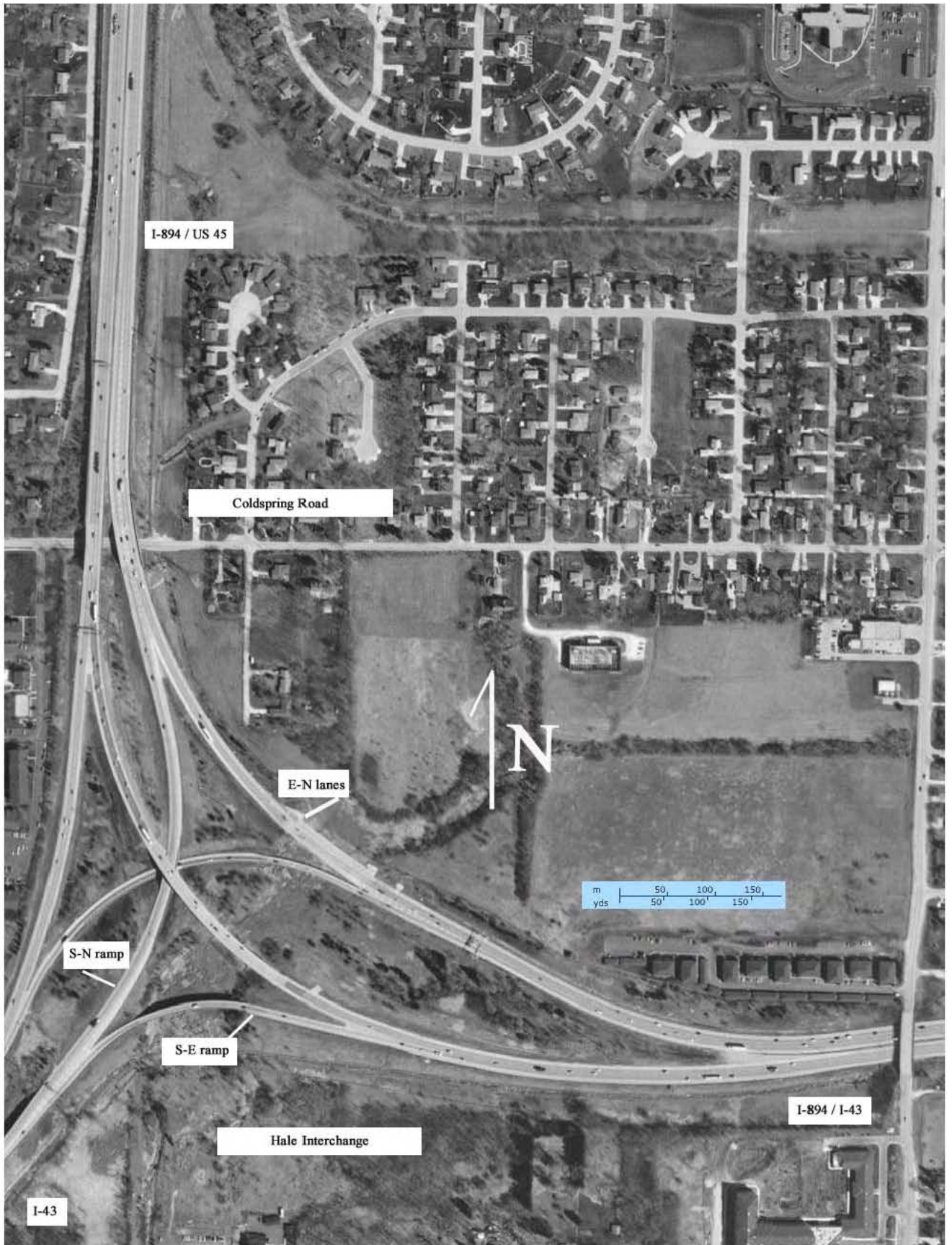












## **APPENDIX B**

### **FREEWAY LAYOUT IN THE VICINITY OF THE ANALYZED WORK ZONES**

## INTRODUCTION

**Appendix B** presents schematics of the area in the vicinity of Work Zone 1 (**WZ1**) and Work Zone 2 (**WZ2**) under Normal and Work Zone traffic conditions. These not-to-scale representations are intended to provide lane configurations and the relative locations of the West-to-North (**W-N**) and East-to-North (**E-N**) on-ramps and the South-to-North (**S-N**) lanes feeding the Bluemound Road and Wisconsin Avenue overpasses. They also provide the locations and number of open and closed lanes during **WZ1** and **WZ2**.

**Figure B2** provides a lane closure schematic during **WZ1**; **Figure B3** provides a lane closure schematic during **WZ2**.

For exact dimensions and work zone traffic control plans, the reader is referred to **Appendix H**, where **WZ1** is referred to as “Stage 1” and **WZ2** is referred to as “Stage 2” along sheet legends.

Aerial photos of the area depicted herein, are provided in **Appendix A** pp. A3 and A4 and are helpful in determining freeway feature dimensions.

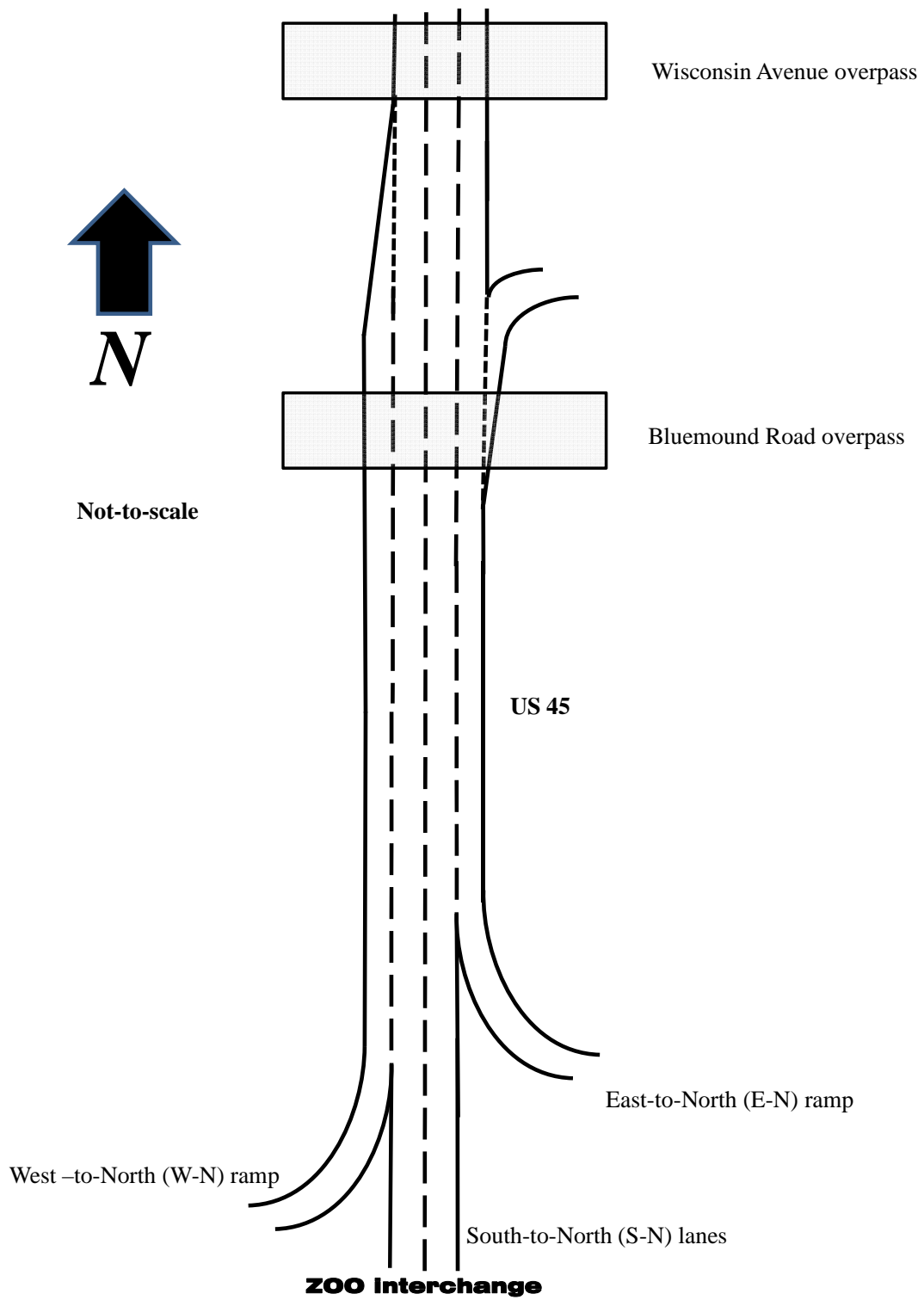


Figure B1. Normal conditions.

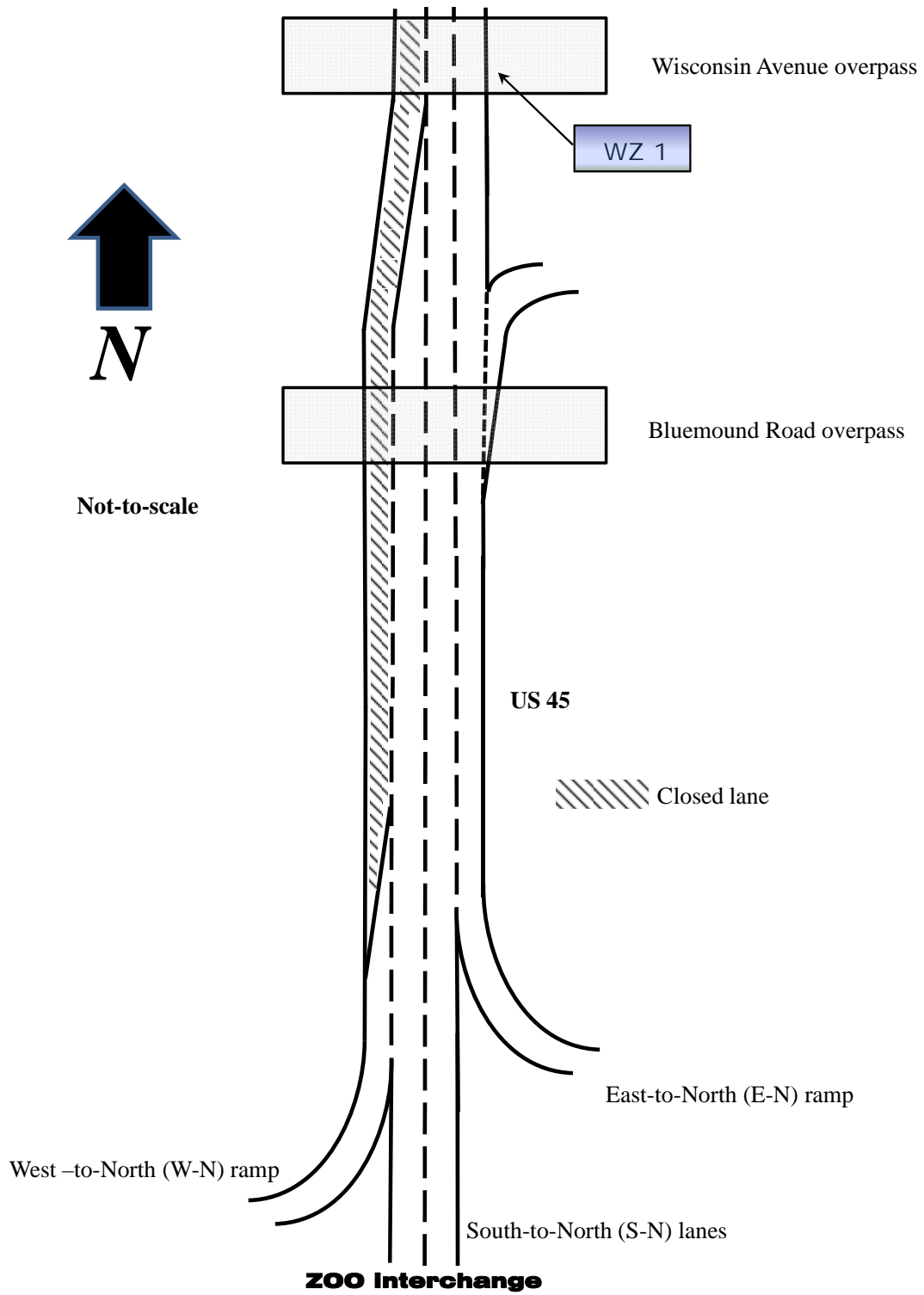


Figure B2. Work Zone #1 (WZ1) conditions.



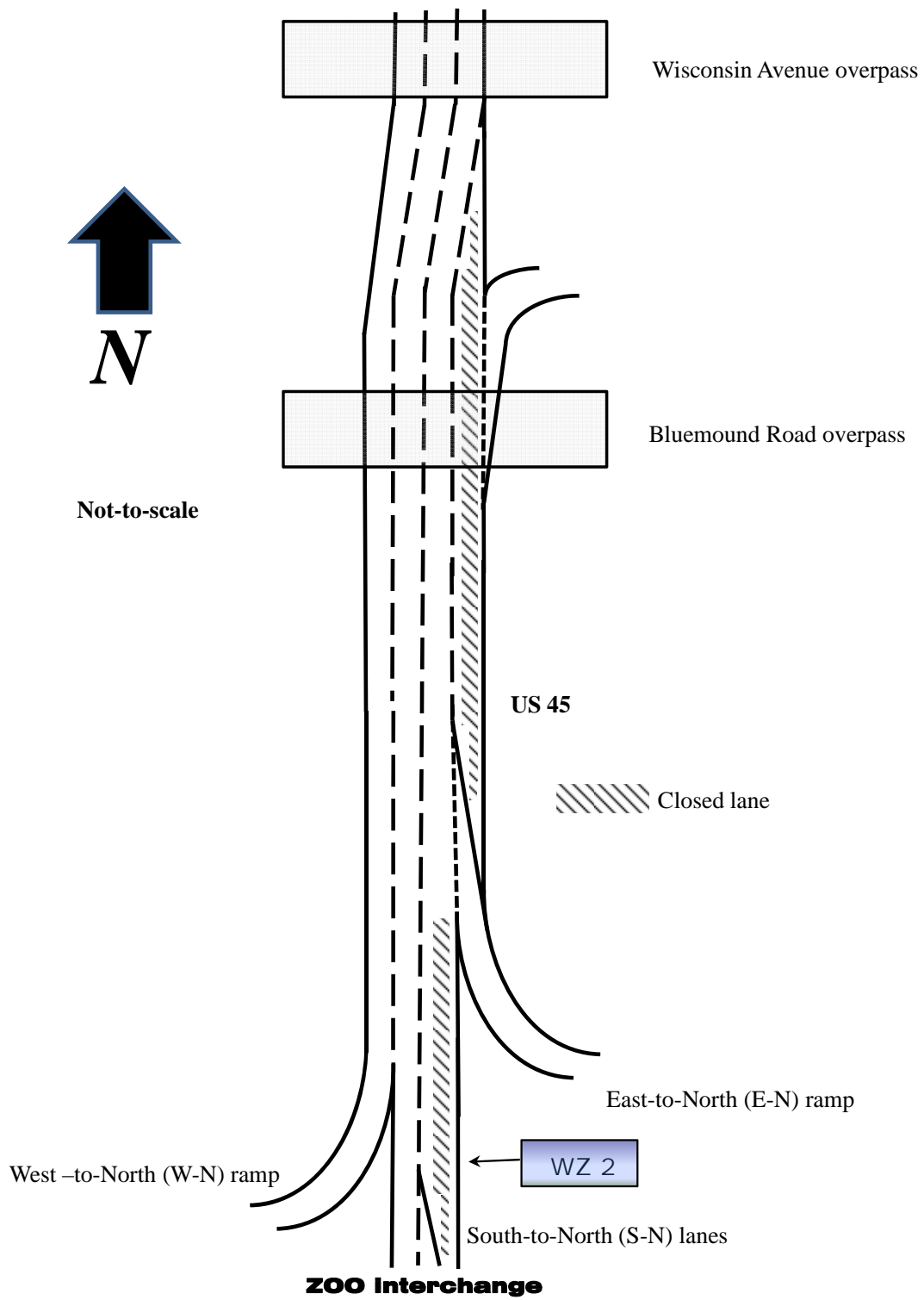


Figure B3. Work Zone #2 (WZ2) conditions.

## **APPENDIX C**

**CROSS STREET AND DETECTOR LOCATIONS  
WisDOT ADT AND DETECTOR COUNTS  
WZ1 & WZ2 CORRIDOR IMPACTS**

## INTRODUCTION

**Appendix C** presents two types of summarized corridor information on not-to-scale schematics.<sup>13</sup>

1. Important distances (**Figures C1 and C2**).
2. Twenty-four hour counts used to verify detector reliability and the extent of Work Zone impacts on traffic volumes (**Figures C3-C6**).

## CORRIDOR DISTANCES

All **Appendix C** distances are measured from the conventional **mile point 0.0** where the South-to-North (**S-N**) lanes cross over the West-to-East (**W-E**) lanes-see page A4. **Figure C1** presents distances to crossing facilities; **Figure C2** presents detector location (upstream or downstream from on- or off-ramps) and distances from mile point 0.0.

Accurate corridor plan views can be found in **Appendix A** (aerial photos) and **Appendix H** (Work Zone traffic control plans).

## DETECTOR INFORMATION RELIABILITY

**Figure C3** presents weekday Wisconsin Department of Transportation (**WisDOT**) ADT counts for 2005 and 2006, as well as detector-based 24-hour traffic volumes measured during periods of **Normal** traffic conditions, shortly before and after Work Zones 1 and 2 (**WZ1** and **WZ2**). The intent of this Figure is to compare the two sources of information in order to judge the reasonableness of detector-based data. An exact match between the two sources was not expected, since:

- i) **WisDOT** ADT information was averaged over an entire year, when detector-based information was obtained for two weeks and was affected by seasonal variations; and,
- ii) Construction at the major Marquette interchange, located on I-94, approximately 5 miles due East of the Zoo interchange affected traffic volumes during the analysis period.

In general, a good correspondence between **WisDOT** ADT and detector-based 24-hour counts was found. In addition, detector counts along the freeway mainline were consistent with measured on- and off-ramp volumes (that is, a downstream mainline

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<sup>13</sup> WZ1 and WZ2 locations are shown on all Figures as reference points. No Work Zone was present during Normal conditions; Figure C5: WZ1 was present; Figure C6: WZ2 was present.

count was consistent with an upstream count minus any off-ramp traffic, plus any on-ramp traffic). Thus, detector data were deemed to be reliable and were used in the compilation of this report.

## **ESTABLISHING “NORMAL” TRAFFIC CONDITIONS**

**Figure C4** provides detector-based 24-hour counts along the entire corridor for each of four sequential time periods: **Before WZ1**, during **WZ1**, during **WZ2** and **After WZ2**. This information was used to quantify the extent of trip diversion during each Work Zone. Because traffic levels were very similar in the period before and after Work Zone presence, data from the two periods collectively were used to represent **Normal** traffic conditions.

## **TRIP DIVERSIONS DUE TO WORK ZONE ACTIVITY**

**Figure C5** presents corridor-wide traffic volume changes during **WZ1**. Less traffic entered the South end of the corridor (-10%); the impact was much more noticeable at the **WZ1** location (Wisconsin Avenue) where traffic reduction was 23%. Off ramps showed a 20% to 37% volume increase and on-ramps a 3% to 26% volume decrease.

**Figure C6** presents corridor-wide traffic volume changes during **WZ2**. Less traffic entered the South end of the corridor (-11%); the impact was much more noticeable near the **WZ2** location (South-to-North ramp) where traffic reduction was 22%. Off ramps showed a 20% to 40% volume increase and on-ramps a 5% to 27% volume decrease.

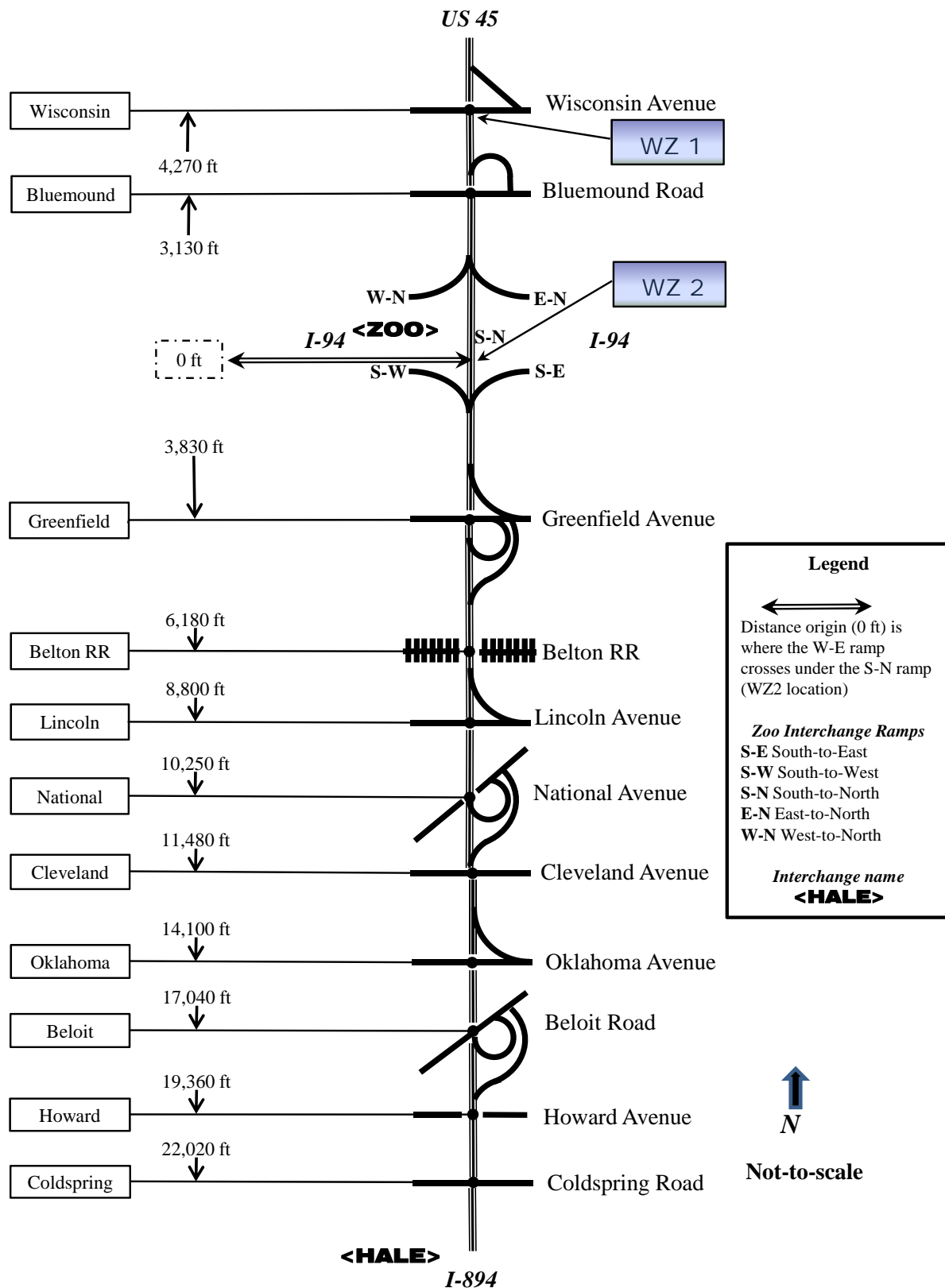


Figure C1. I-894 corridor NB direction, distances to cross streets.

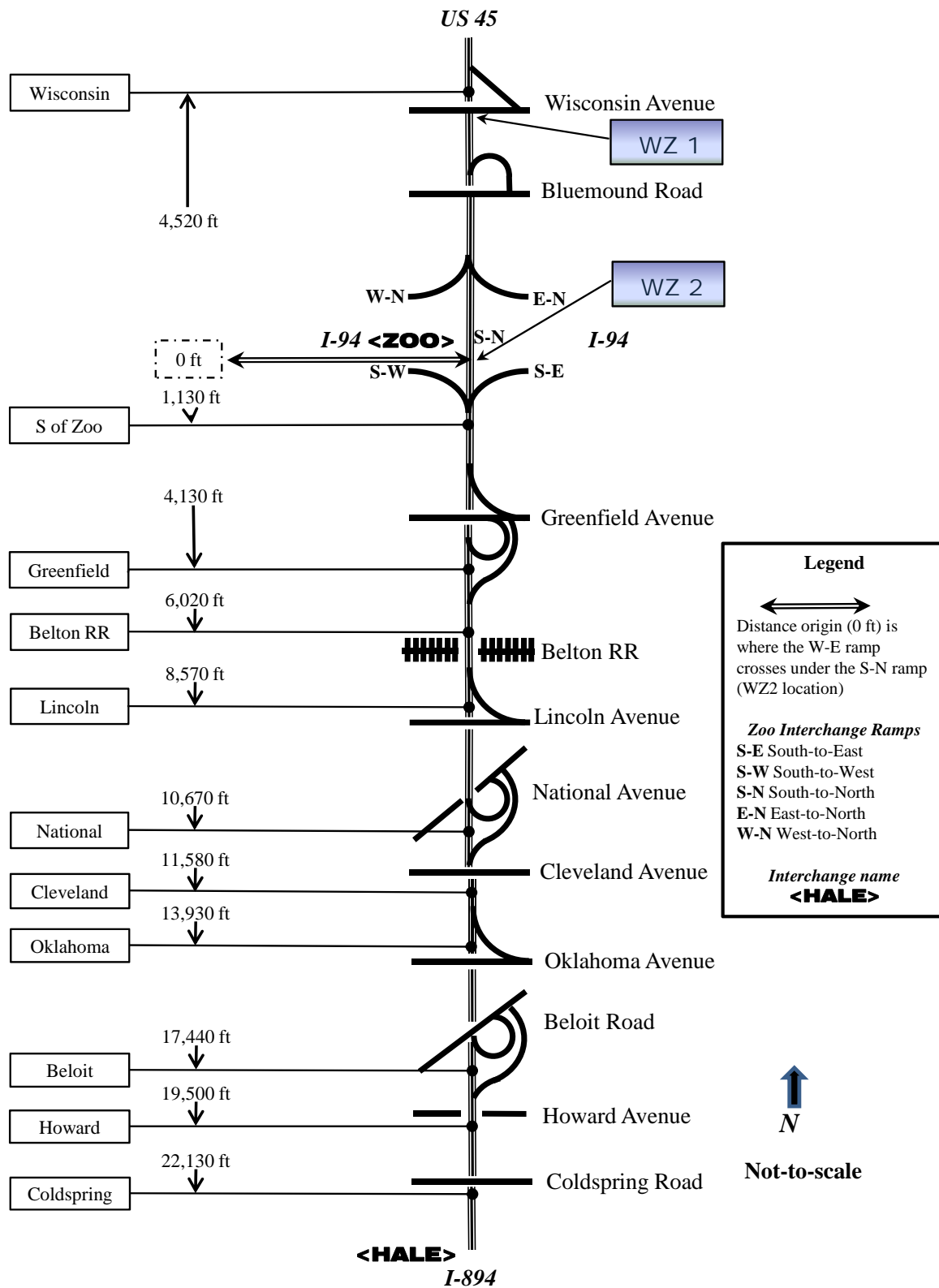


Figure C2. I-894 corridor NB direction mainline detector distances.



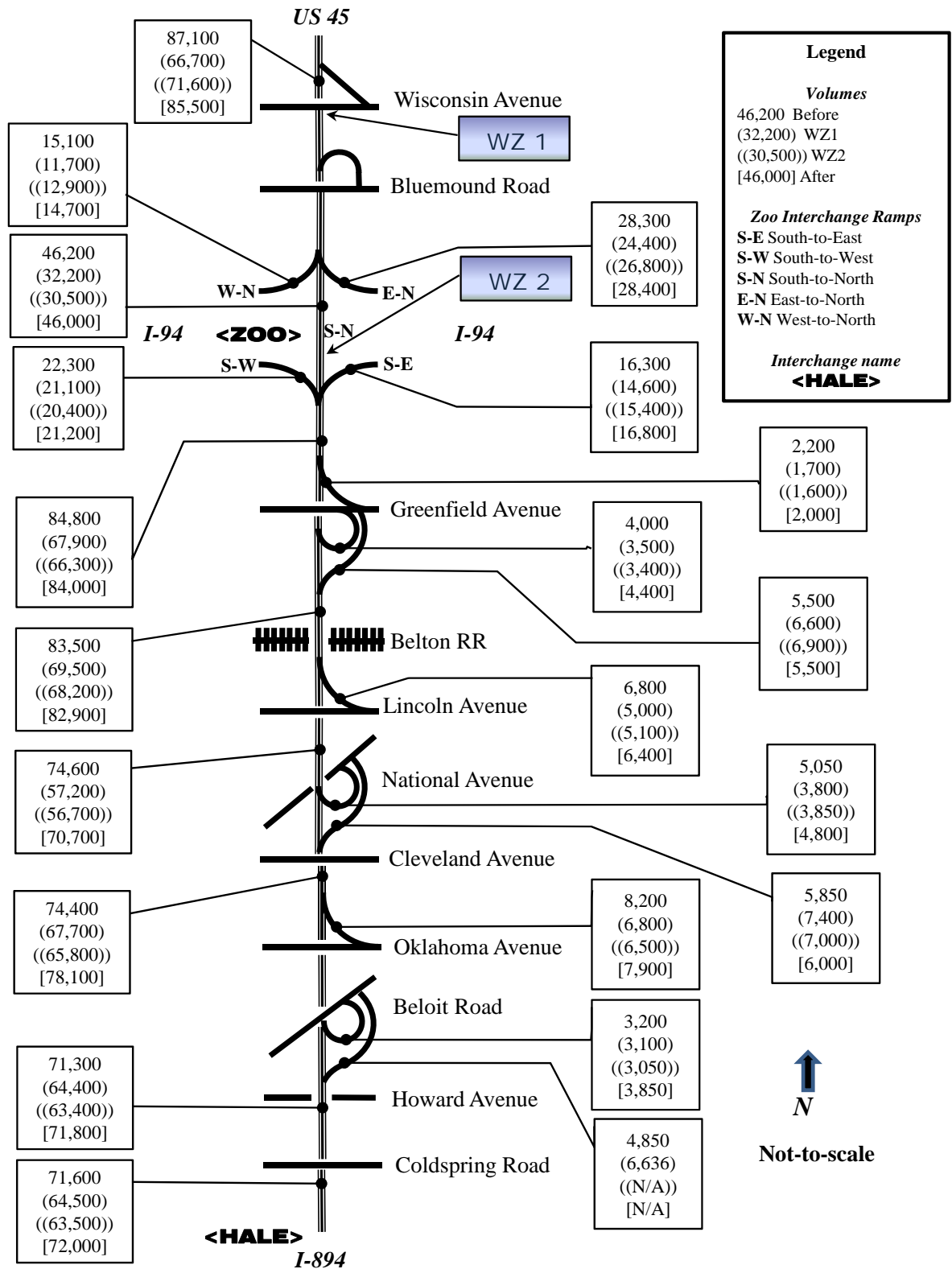


Figure C4. I-894 corridor NB direction, 24-hour detector counts.



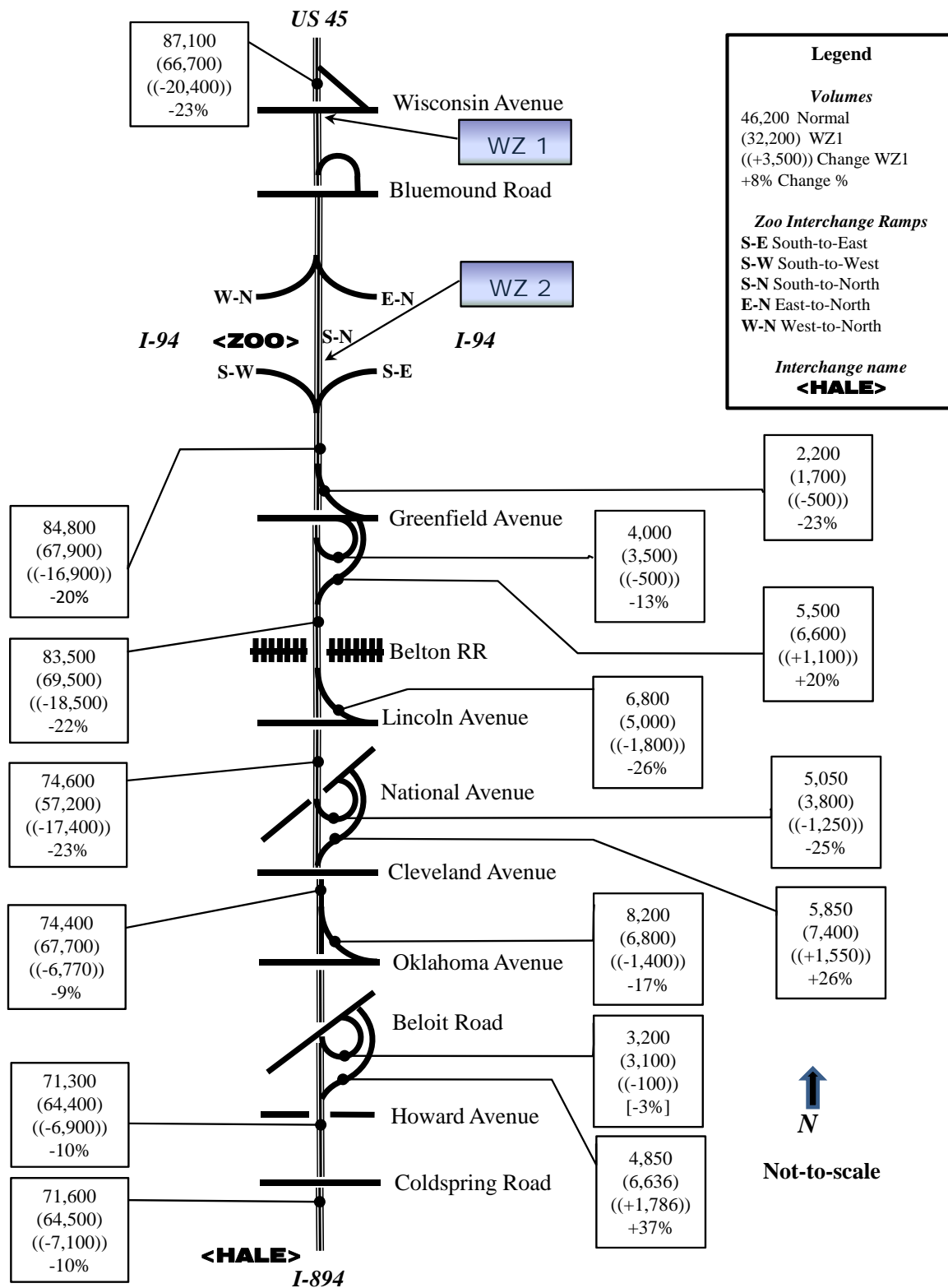


Figure C5. I-894 corridor NB direction, 24-hour detector counts-changes during WZ1.



## **APPENDIX D**

**CORRIDOR VOLUME SPEED AND OCCUPANCY DURING:**

**NORMAL CONDITIONS**

**WZ1 CONDITIONS**

**WZ2 CONDITIONS**

## INTRODUCTION

**Appendix D** presents detector-based average per-lane hourly volume, speed and occupancy diagrams for each of eleven mainline locations along the analyzed corridor under **Normal**, **WZ1** and **WZ2** conditions. No detector outages were present during the dates chosen to provide these statistics.

Facilities crossing the mainline are listed in a North-to-South sequence (top left to bottom right in each Figure). Facility locations can be found in aerial photos in **Appendix A**; they are summarized in and **Figure C1** in **Appendix C**. Detector location information can be found in **Figure C2**. Work zone traffic control plans can be found in **Appendix H**.

The intent of **Appendix D** is to help the reader visualize hourly fluctuations in the three fundamental traffic characteristics (volume, speed and occupancy) along the entire corridor under **Normal**, **WZ1** and **WZ2** conditions. Furthermore, since scales are identical among all figures representing a given traffic characteristic, comparisons between **Normal**, **WZ1** and **WZ2** conditions at a given location are straight-forward.

## GENERAL OBSERVATIONS

### Volume

**Figures D1, D4 and D7** show that during **WZ1** and **WZ2** per-lane volumes dropped along the entire corridor compared to **Normal** conditions; am and pm peaking was much less pronounced-traffic levels were pretty constant between the two peaks. The **S of Zoo** location had a lower per lane flow during **WZ1** because of the downstream congestion at **Wisconsin Avenue**. However the one open lane during **WZ2**, without any downstream congestion resulted in the highest observed per lane volume among **Normal**, **WZ1** and **WZ2** conditions. This volume was assumed to be the **WZ2** capacity.

Similar information is presented in **Appendix E, Figures E1, E4 and E7**, arranged to facilitate peaking characteristics comparisons between locations.

### Speed

**Figures D2, D5 and D8**, indicate minor speed drops under normal traffic conditions during the am peak at the **N of Wisconsin** and the **S of Zoo** locations; a noticeable speed drop is present during the pm peak at **Greenfield Avenue**, which is noticeable as far South as **Beloit Road**. Speeds remained unaffected during the pm peak at the **Howard Avenue** and **Coldspring Road** locations. Speeds were dramatically lower between the **S of Zoo** location and **Lincoln Avenue** during both Work Zones for the entire period between the am and the pm peak and during both peaks. Afternoon peak speeds were

lower as far South as **Beloit Road**. Speeds at **Howard Avenue** and **Coldspring Road** remained at high levels during the entire day when Work Zones were present.

Similar information is presented in **Appendix E, Figures E2, E5 and E8**, arranged to facilitate peaking characteristics comparisons between locations.

### **Occupancy**

**Figures D3, D6 and D9** indicate that occupancy levels at the **Wisconsin Avenue** detector location, 250 ft downstream from the location of **WZ1** remained virtually unchanged between **Normal**, **WZ1** and **WZ2** conditions, peaking at about 12% during the am peak. However, occupancies were much higher under Work Zone conditions at the **S of Zoo** location, rising from a maximum of approximately 19% under **Normal** conditions to a maximum of 52% during **WZ1** and 40% during **WZ2**. The high occupancy at this location during **WZ1** was due to congestion at the **Wisconsin Avenue** taper, located 5,400 ft downstream; during **WZ2** it was due to the taper located 1,130 ft downstream of the detectors.

Significant occupancy increases extended to **Lincoln Avenue**, with minor effects extending to **Cleveland Avenue**. **Howard Avenue** and **Coldspring Road** had lower congestion levels under Work Zone conditions than under **Normal** conditions.

Similar information is presented in **Appendix E, Figures E3, E6 and E9**, arranged to facilitate peaking characteristics comparisons between locations.

## Corridor 24-Hour Normal traffic 4/4, 4/5, 5/16, 5/17, 5/18, 5/19

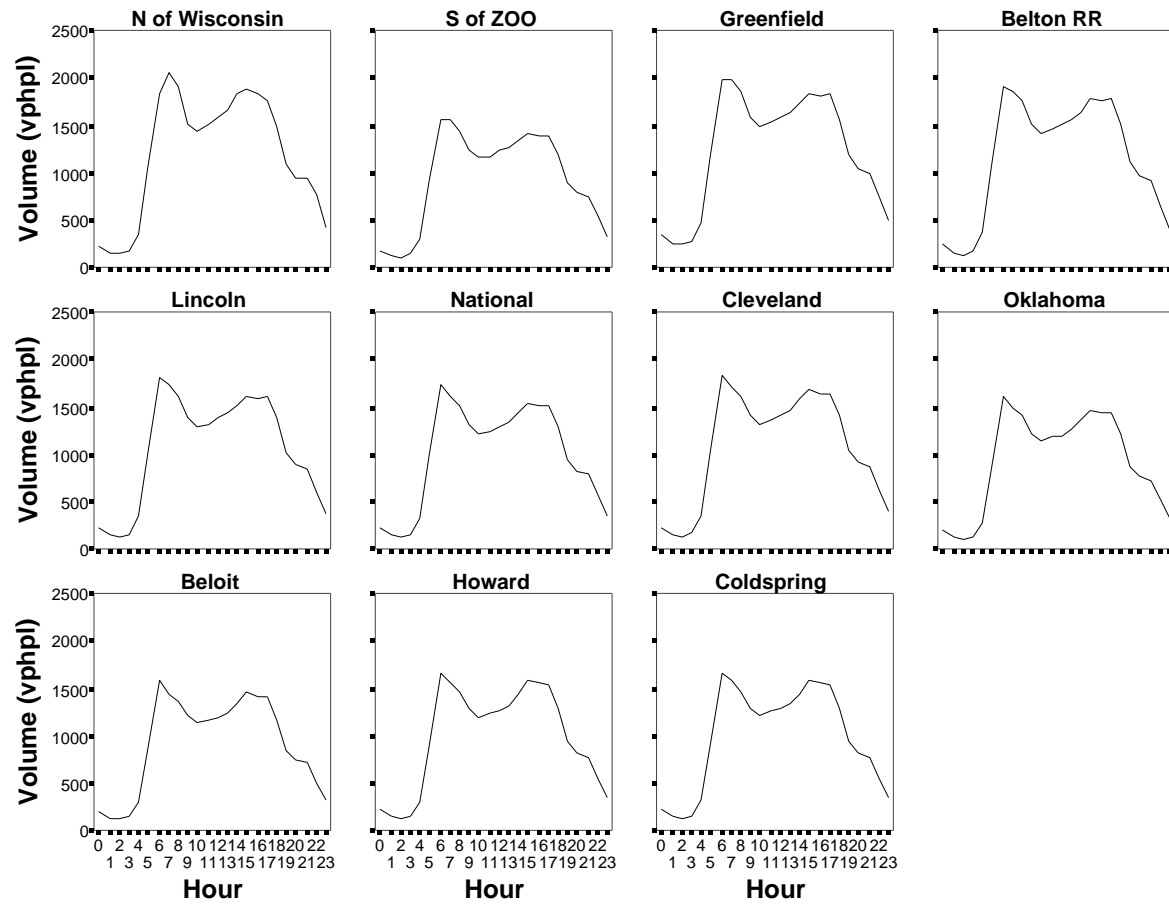


Figure D1. Corridor 24-Hour Normal traffic volume per lane.

## Corridor 24-Hour Normal traffic 4/4, 4/5, 5/16, 5/17, 5/18, 5/19

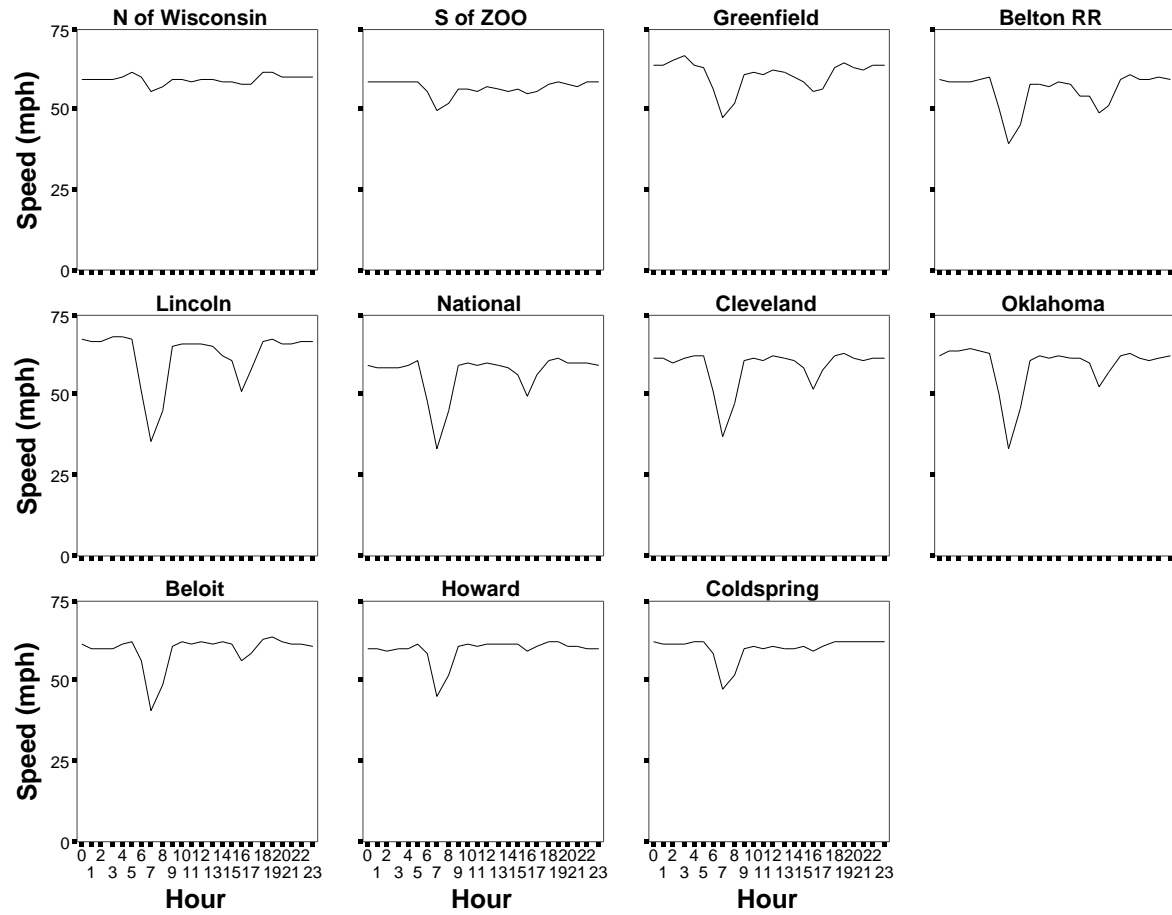


Figure D2. Corridor 24-Hour Normal traffic average speed.

## Corridor 24-Hour Normal traffic 4/4, 4/5, 5/16, 5/17, 5/18, 5/19

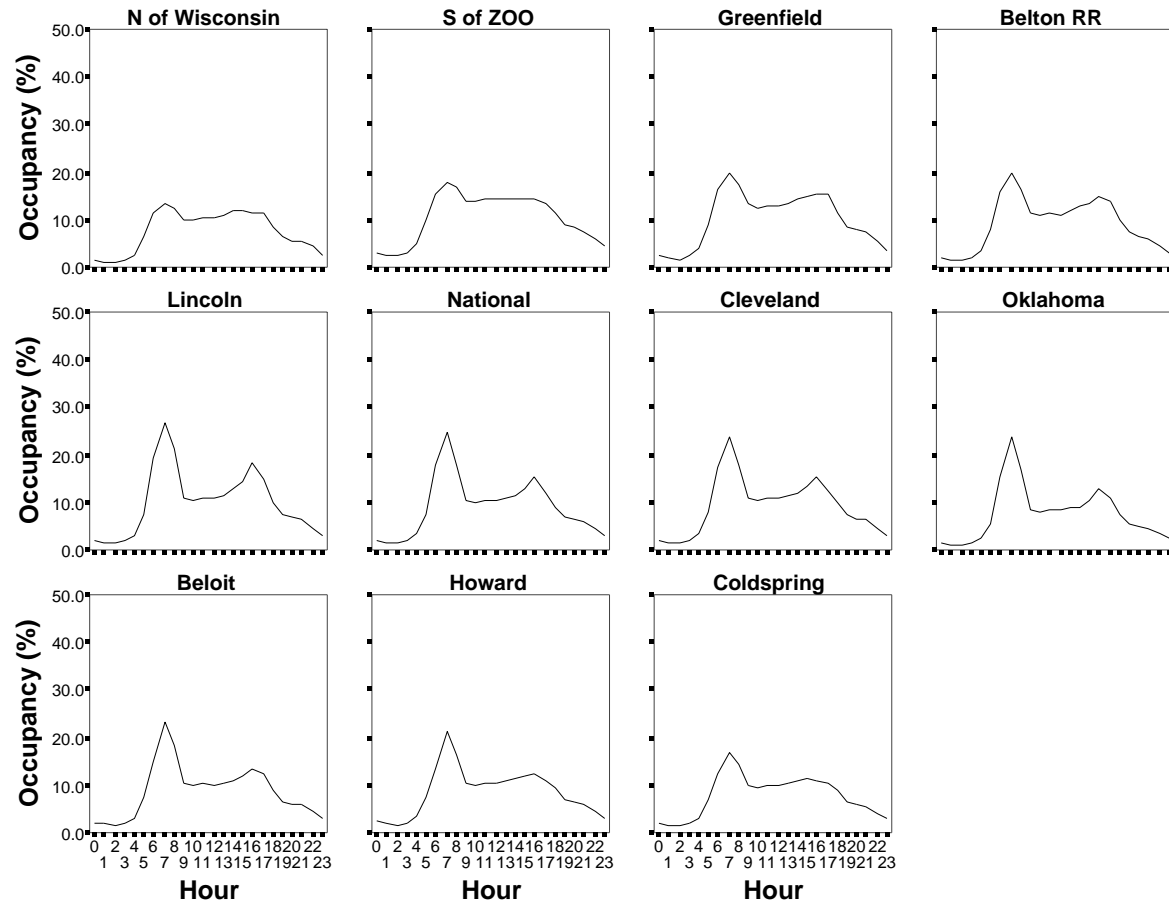


Figure D3. Corridor 24-Hour Normal traffic average occupancy.



## Corridor 24-Hour WZ1 4/11 ,4/14, 4/17, 4/18, 4/19, 4/20

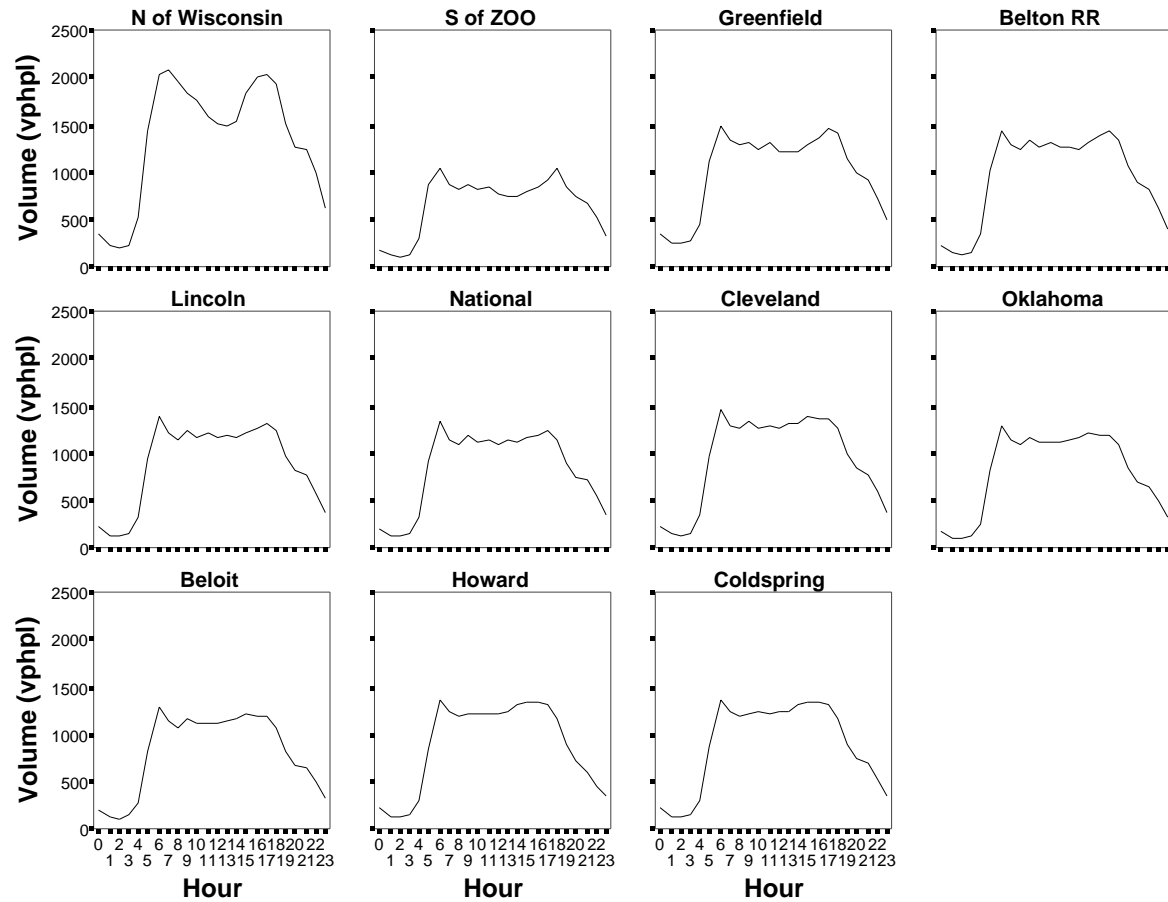


Figure D4. Corridor 24-Hour WZ1 traffic volume per lane.

**Corridor 24-Hour WZ1 4/11 ,4/14, 4/17, 4/18, 4/19, 4/20**

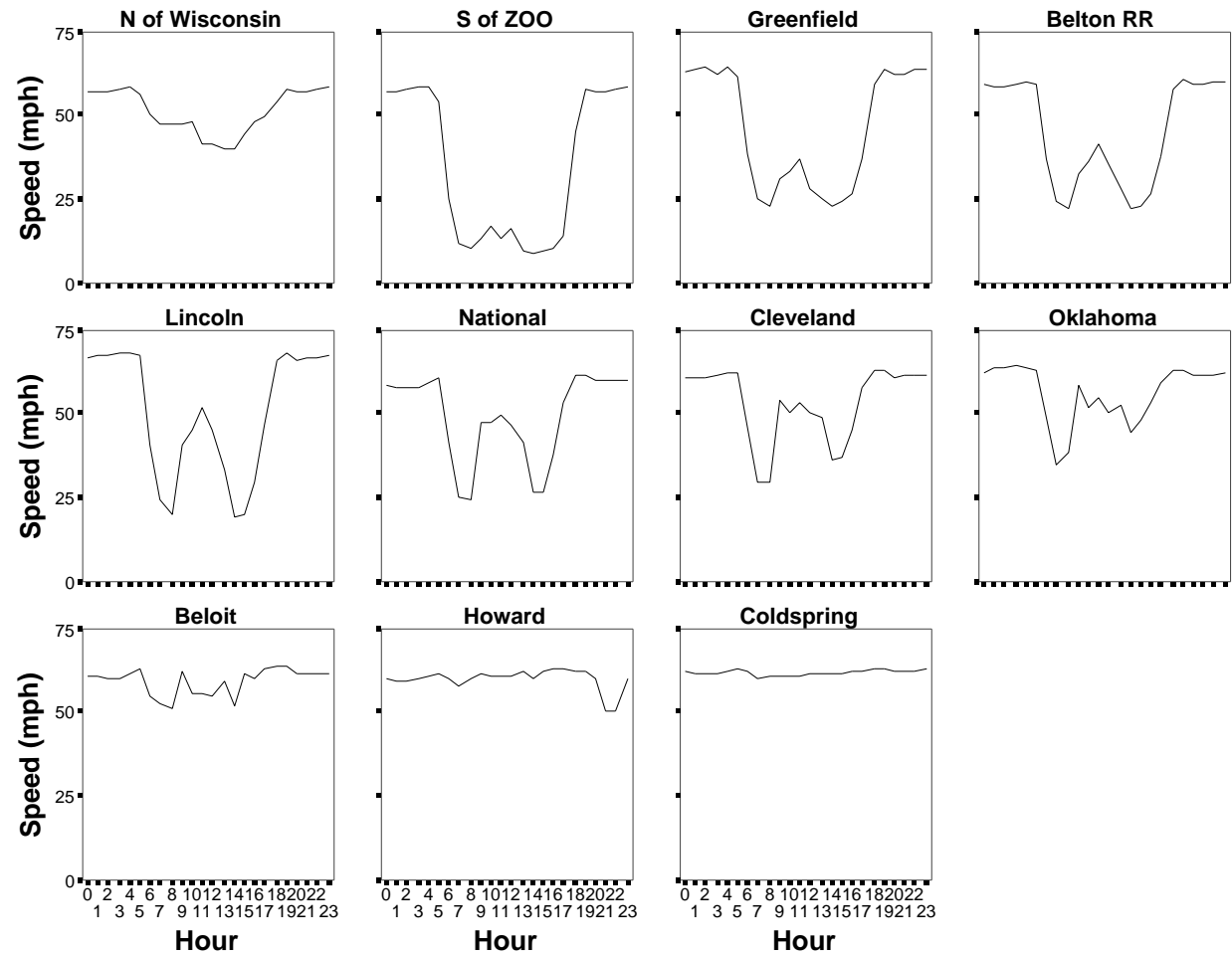


Figure D5. Corridor 24-Hour WZ1 average speed.

## Corridor 24-Hour WZ1 4/11 ,4/14, 4/17, 4/18, 4/19, 4/20

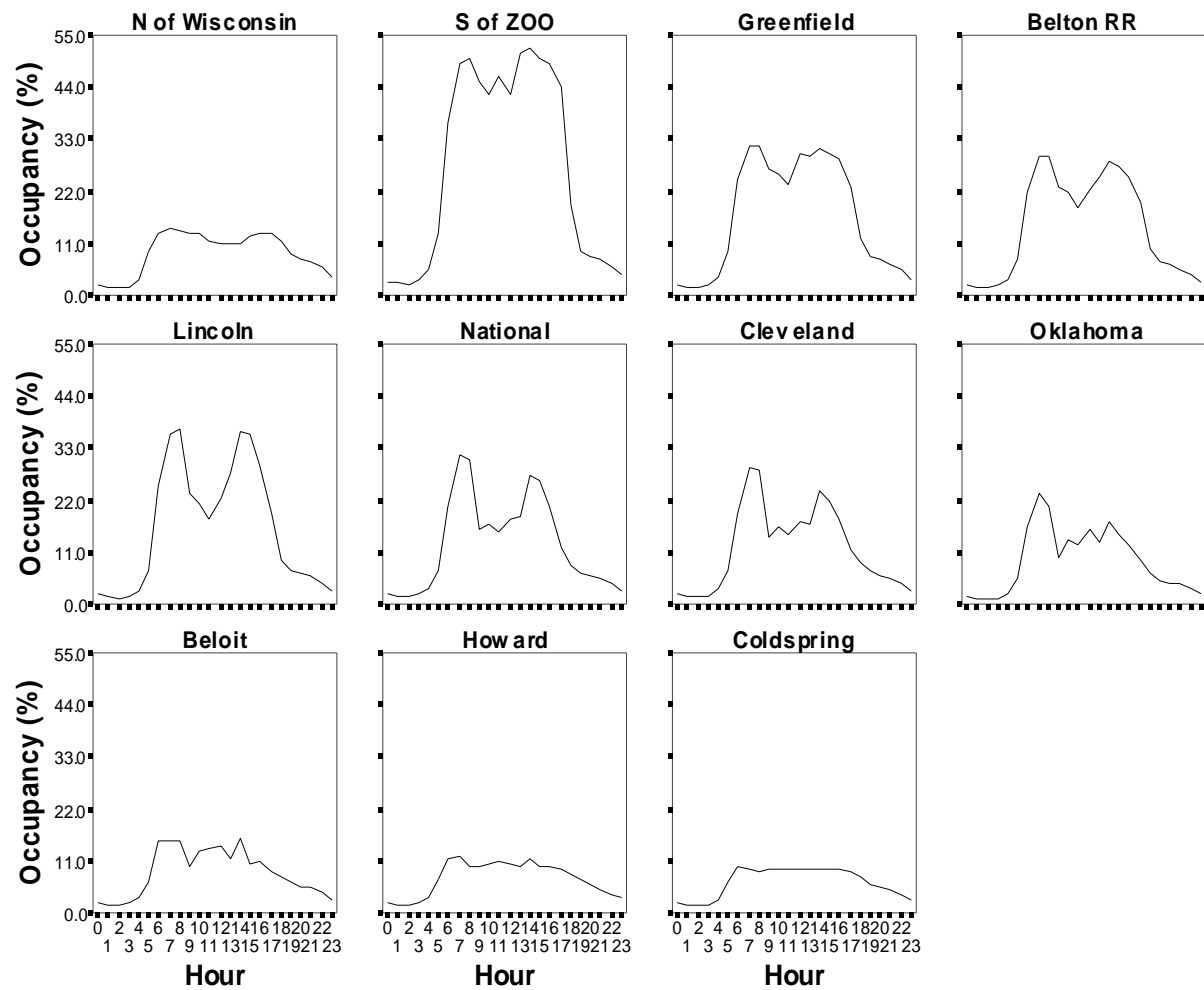


Figure D6. Corridor 24-Hour WZ1 average occupancy.

## Corridor 24-Hour WZ2 5/1, 5/3, 5/4, 5/5, 5/9

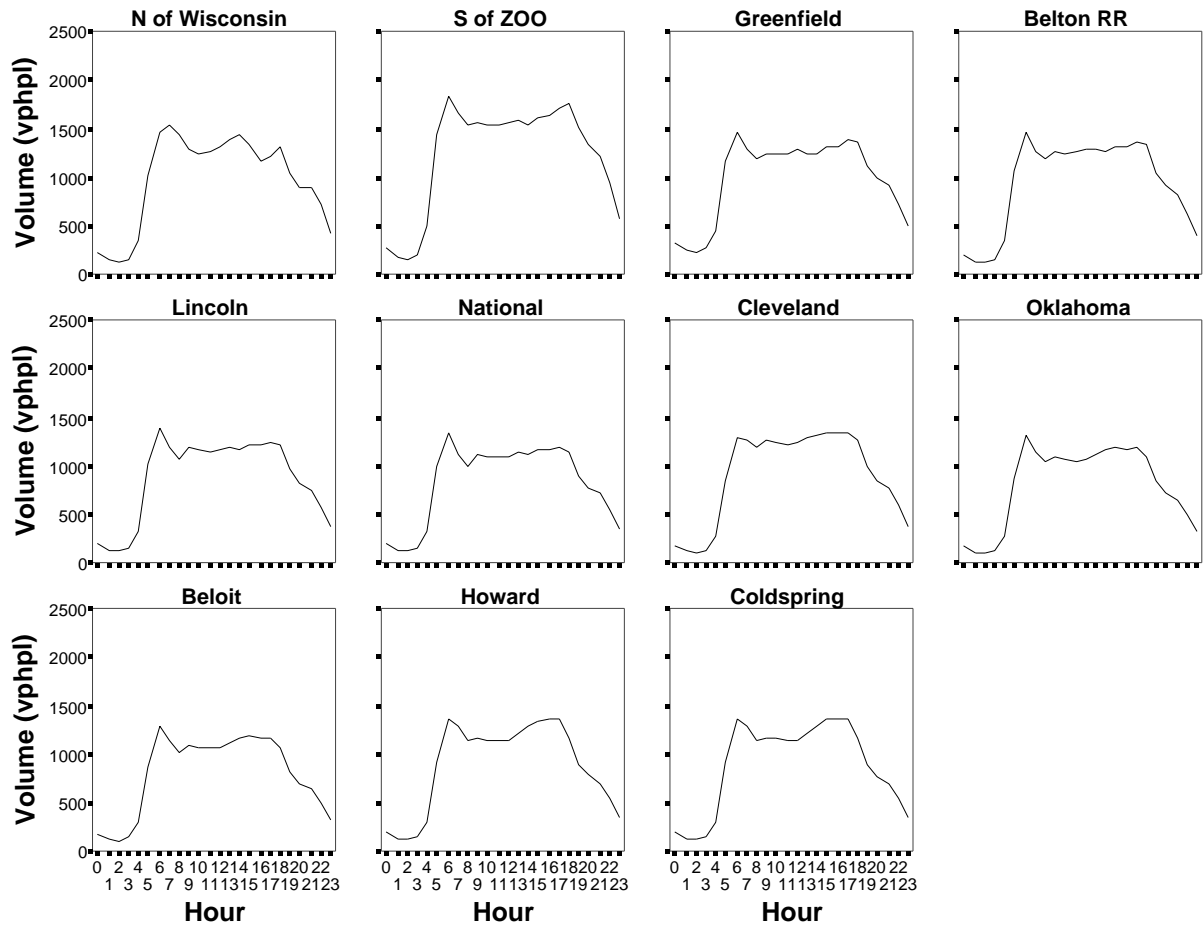


Figure D7. Corridor 24-Hour WZ2 traffic volume per lane.

## Corridor 24-Hour WZ2 5/1, 5/3, 5/4, 5/5, 5/9

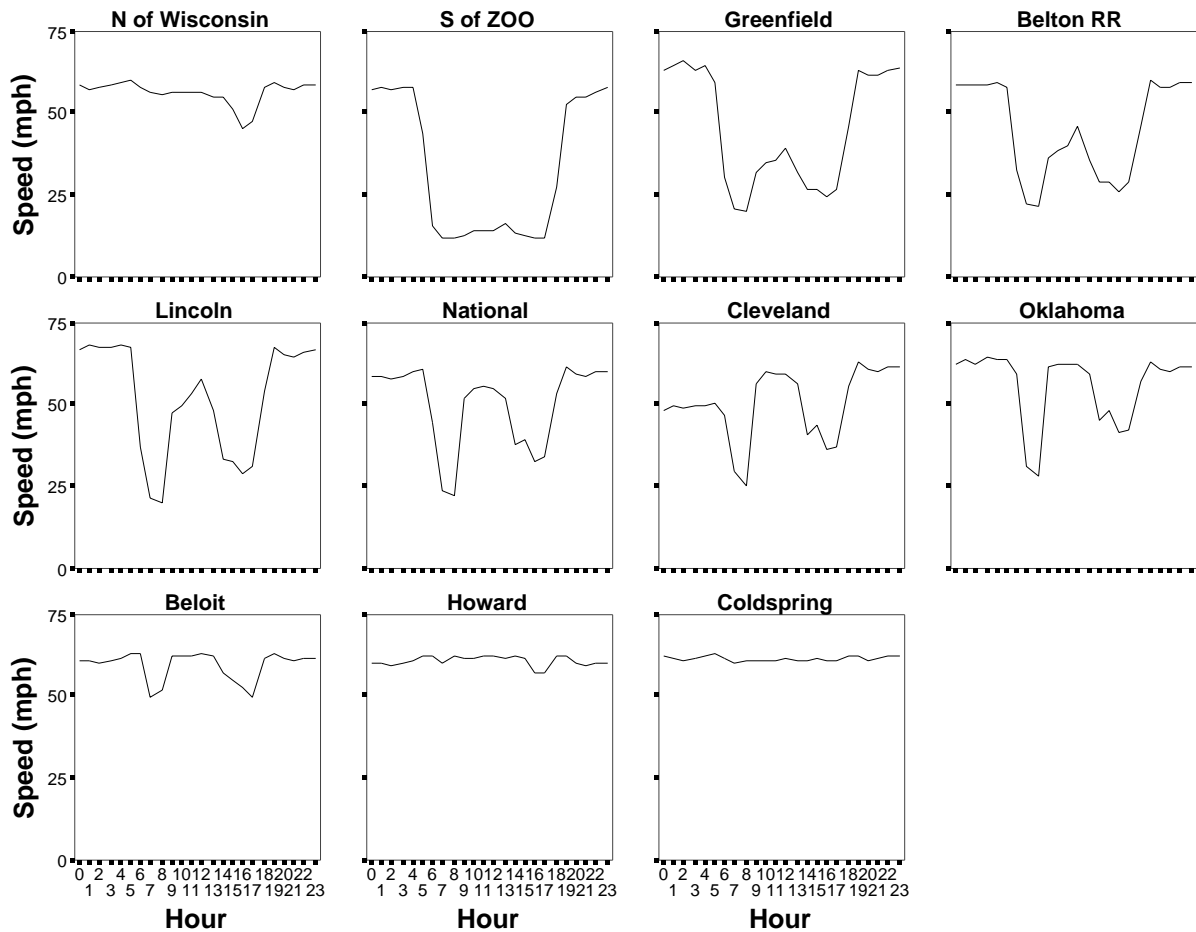


Figure D8. Corridor 24-Hour WZ2 average speed.

## Corridor 24-Hour WZ2 5/1, 5/3, 5/4, 5/5, 5/9

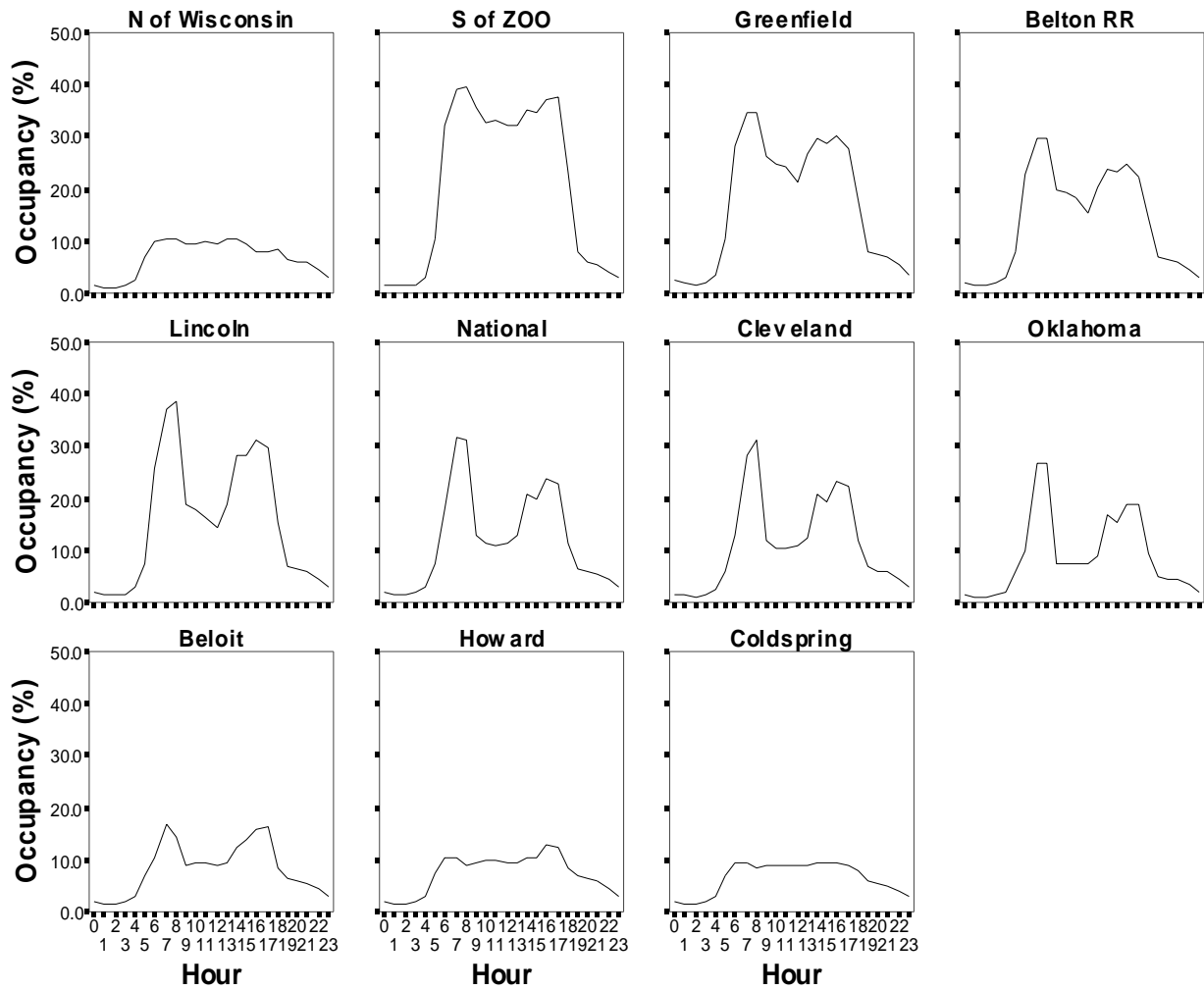


Figure D9. Corridor 24-Hour WZ2 average occupancy.

# **APPENDIX E**

**CORRIDOR VOLUME SPEED AND OCCUPANCY DURING:**

**NORMAL CONDITIONS**

**WZ1 CONDITIONS**

**WZ2 CONDITIONS**

**PARALLEL PRESENTATION**

## INTRODUCTION

**Appendix E** presents detector-based average per-lane hourly volume, speed and occupancy diagrams for each of eleven mainline locations. Facilities crossing the mainline are listed in a North-to-South sequence (left-to-right in each Figure). Facility locations can be found in aerial photos in **Appendix A** and **Figure C1** in **Appendix C**. Detector location information can be found in **Figure C2**. Work zone traffic control plans can be found in **Appendix H**.

Figures in this Appendix provide for easy comparisons of peak period traffic characteristics along the entire corridor. A more detailed presentation of hourly traffic characteristics fluctuations can be found in **Appendix D**.

## GENERAL OBSERVATIONS

### Volume

**Figures E1, E4 and E7** present volume information along the corridor under **Normal, WZ1** and **WZ2** conditions. Per-lane peak volumes dropped compared to **Normal** conditions during **WZ1** along the entire corridor, with the exception of **Wisconsin Avenue**. Changes were more pronounced during the am peak, especially near the North end of the corridor. Mid-day lowest volumes did not change appreciably, especially between **Cleveland Avenue** and **Coldspring Road**. Similar changes, compared to **Normal** conditions, occurred during **WZ2** with notable exceptions at the **Wisconsin Avenue** and **S of Zoo** locations: Per-lane traffic volumes were lower at **Wisconsin Avenue** and appreciably higher at the **S of Zoo** location. This higher volume was assumed to be the **WZ2** capacity.

Similar information is presented in **Appendix D, Figures D1, D4 and D7**, arranged to facilitate hour-by-hour traffic characteristics changes comparisons between locations.

### Speed

**Figures E2, E5 and E8** present speed information along the corridor under **Normal, WZ1** and **WZ2** conditions, respectively. Compared to **Normal** traffic conditions, morning peak speeds were much lower at the North end of the corridor, between **Wisconsin Avenue** and **Lincoln Avenue** during **WZ1**. They remained unchanged at **National** and **Cleveland Avenues**, and were higher at the South end of the corridor, between **Oklahoma Avenue** and **Coldspring Road**. However, afternoon peak speeds were universally lower during **WZ1**, with the exception of **Coldspring Road**.

Similar observations apply to **WZ2**, however **Wisconsin Avenue** speeds were lower only during the afternoon peak. Here again, morning peak speeds were higher during **WZ2** at the South end of the corridor, between **Beloit Road** and **Coldspring Road**.



Similar information is presented in **Appendix D, Figures D2, D5 and D8**, arranged to facilitate hour-by-hour traffic characteristics changes comparisons between locations.

### **Occupancy**

**Figures E3, E6 and E9** present occupancy information along the corridor under **Normal, WZ1** and **WZ2** conditions, respectively. Compared to **Normal** conditions, morning peak occupancy remained unchanged at **Wisconsin Avenue** during **WZ1**. A dramatic increase, from 20% to 52% was observed at the **S of Zoo** location. Diminishing increases were observed as far South as **National Avenue**; **Cleveland Avenue** remained unchanged; occupancy decreases were observed from **Oklahoma Avenue** to **Coldspring Road**.

Occupancies followed similar trends during **WZ2**, however the morning peak increase at the **S of Zoo** location was only to 40%.

Similar information is presented in **Appendix D, Figures D3, D6 and D9**, arranged to facilitate hour-by-hour traffic characteristics changes comparisons between locations.

**Corridor 24-Hour Normal traffic 4/4, 4/5, 5/16, 5/17, 5/18, 5/19**

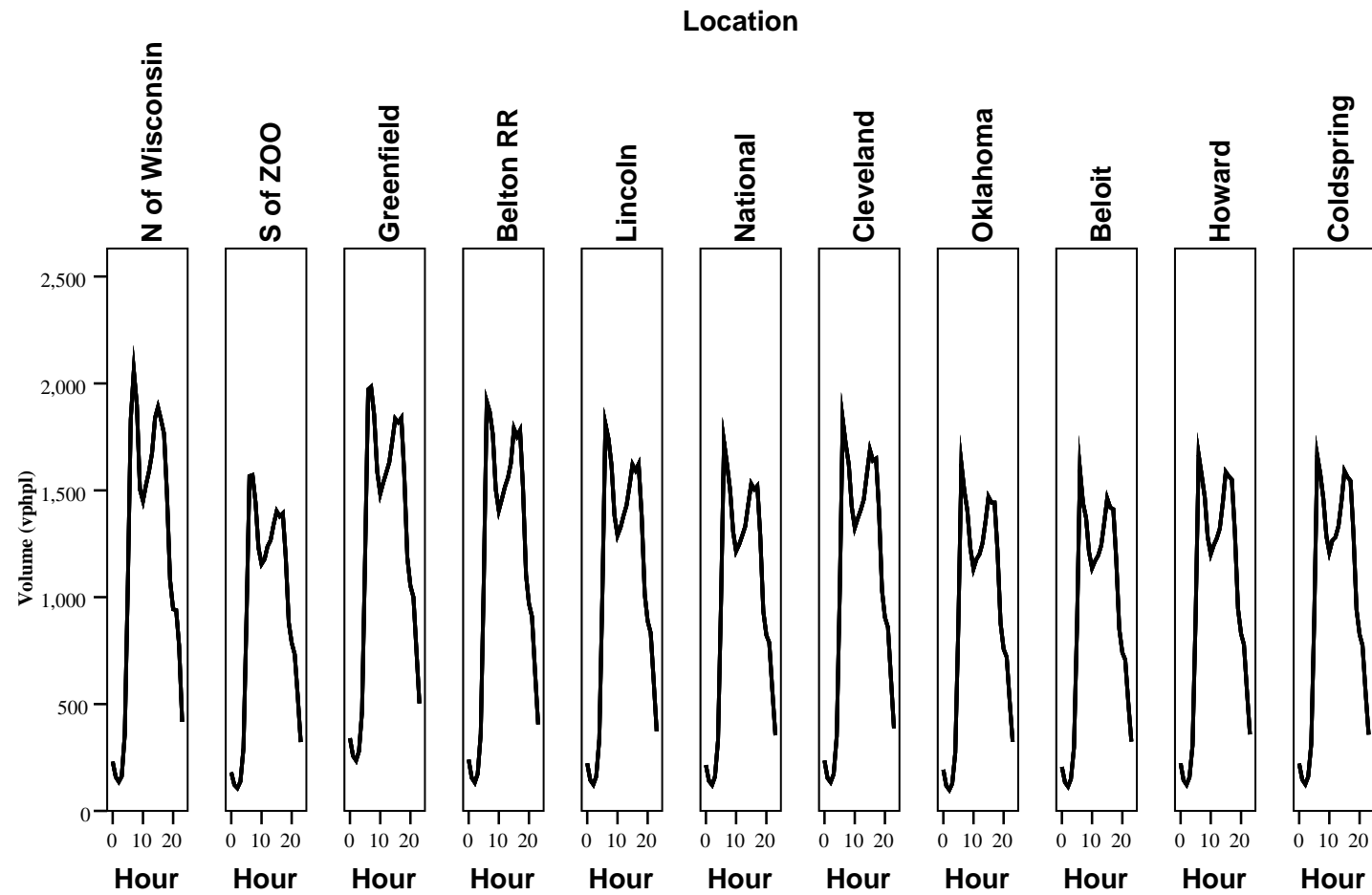


Figure E1. Corridor 24-Hour Normal traffic volume per lane.

Corridor 24-Hour Normal traffic 4/4, 4/5, 5/16, 5/17, 5/18, 5/19

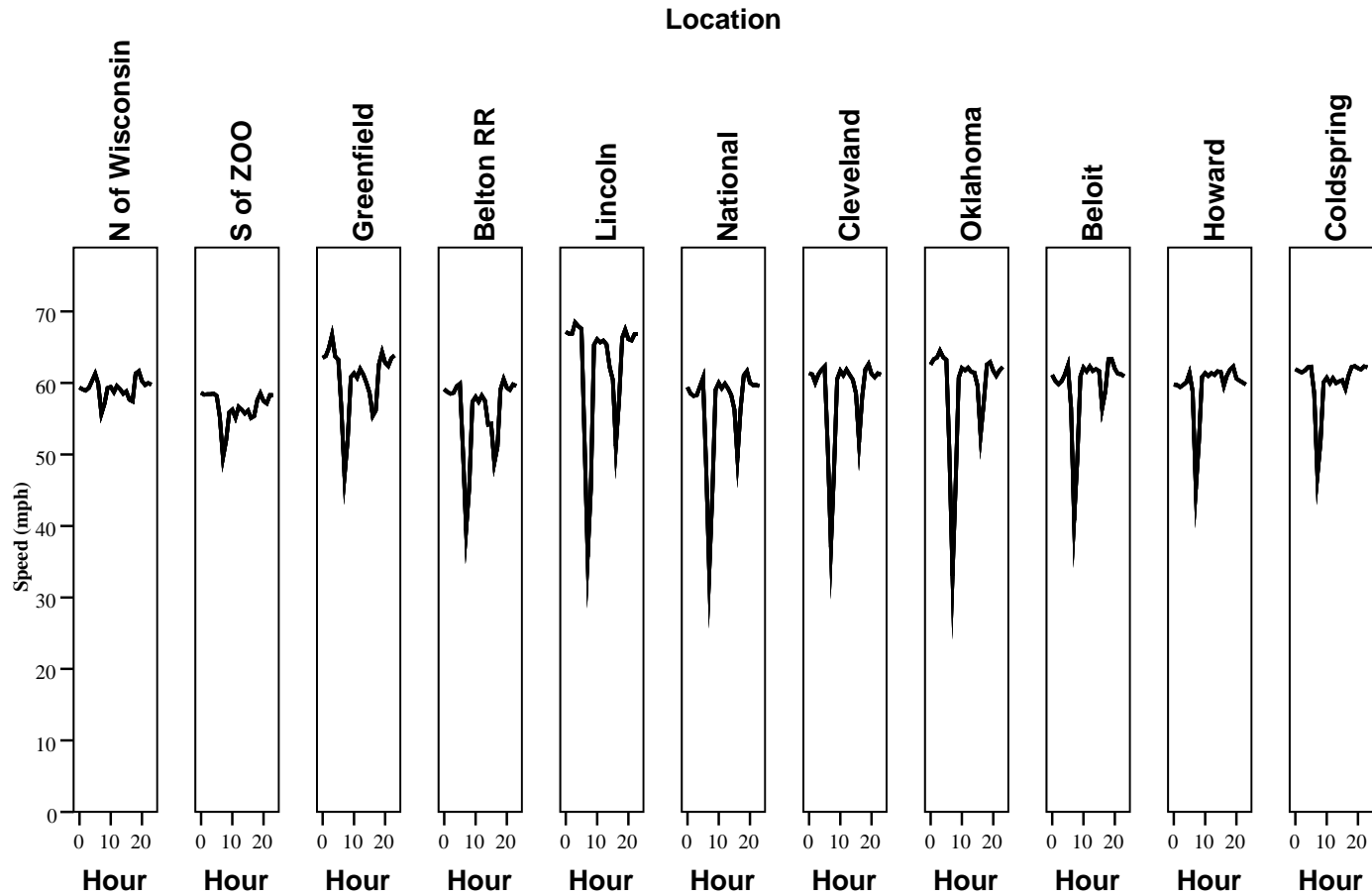


Figure E2. Corridor 24-Hour Normal traffic average speed.

Corridor 24-Hour Normal traffic 4/4, 4/5, 5/16, 5/17, 5/18, 5/19

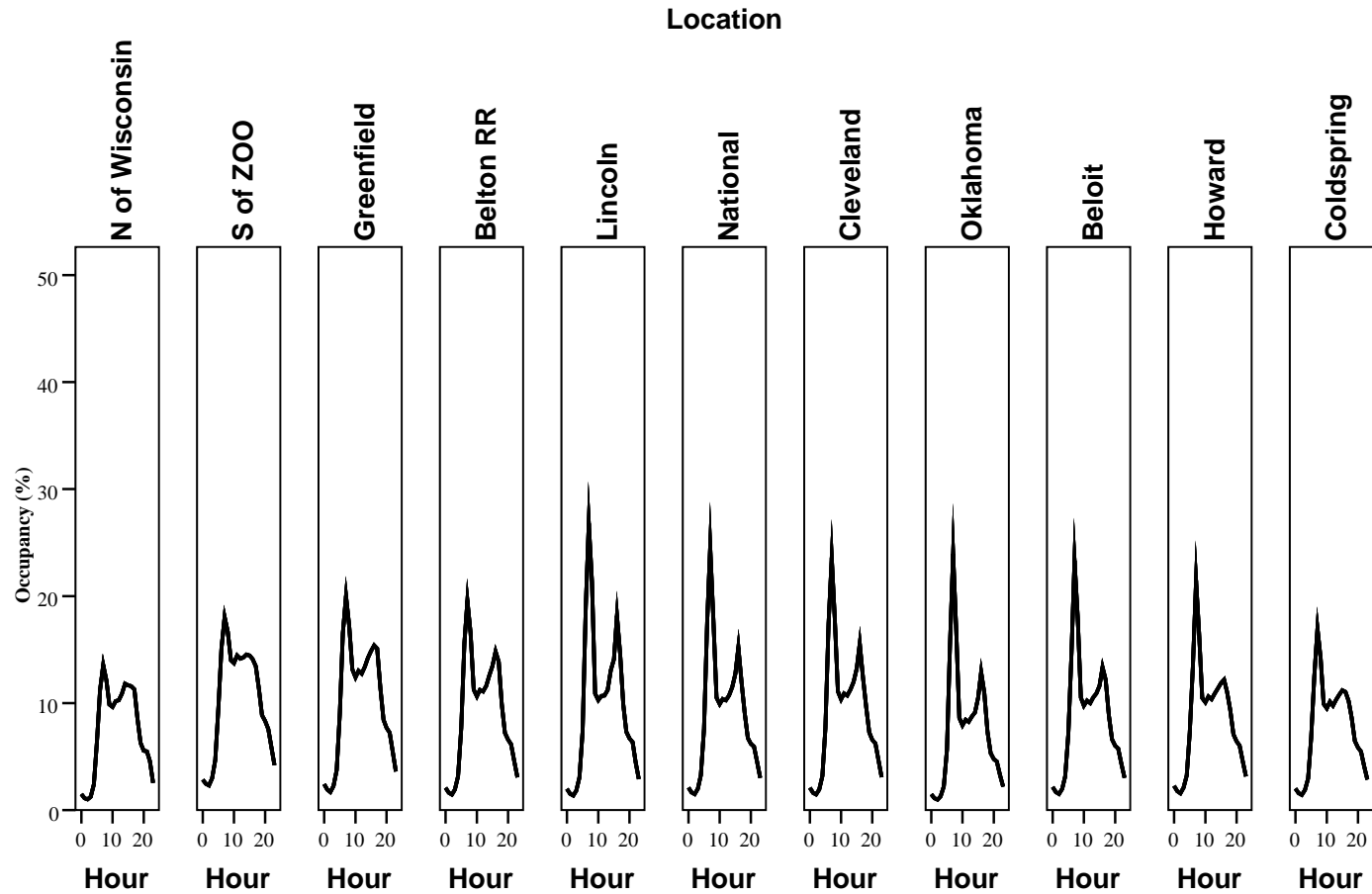


Figure E3. Corridor 24-Hour Normal traffic average occupancy.

Corridor 24-Hour WZ1 4/11 ,4/14, 4/17, 4/18, 4/19, 4/20

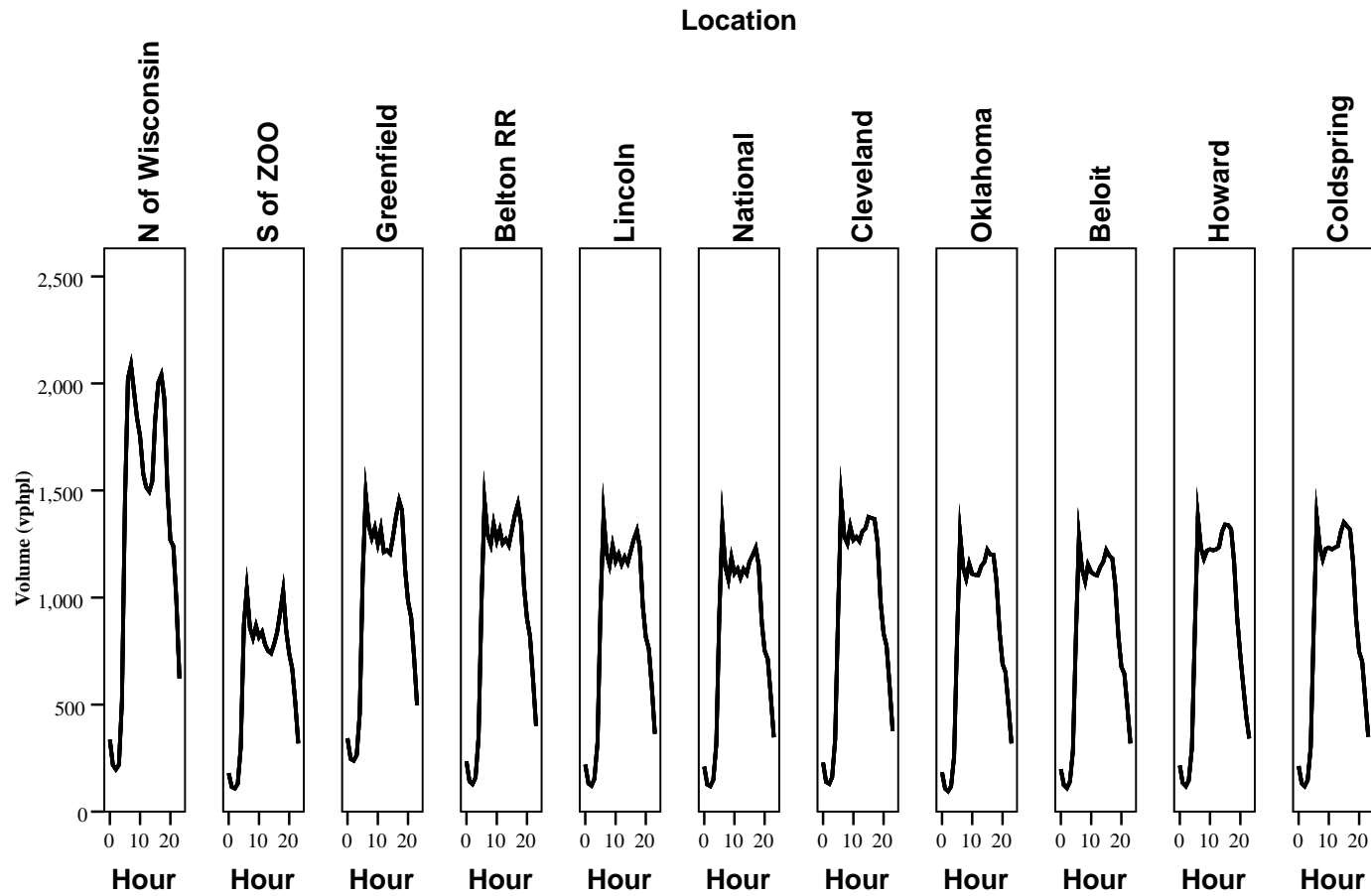


Figure E4. Corridor 24-Hour WZ1 traffic volume per lane.

Corridor 24-Hour WZ1 4/11 ,4/14, 4/17, 4/18, 4/19, 4/20

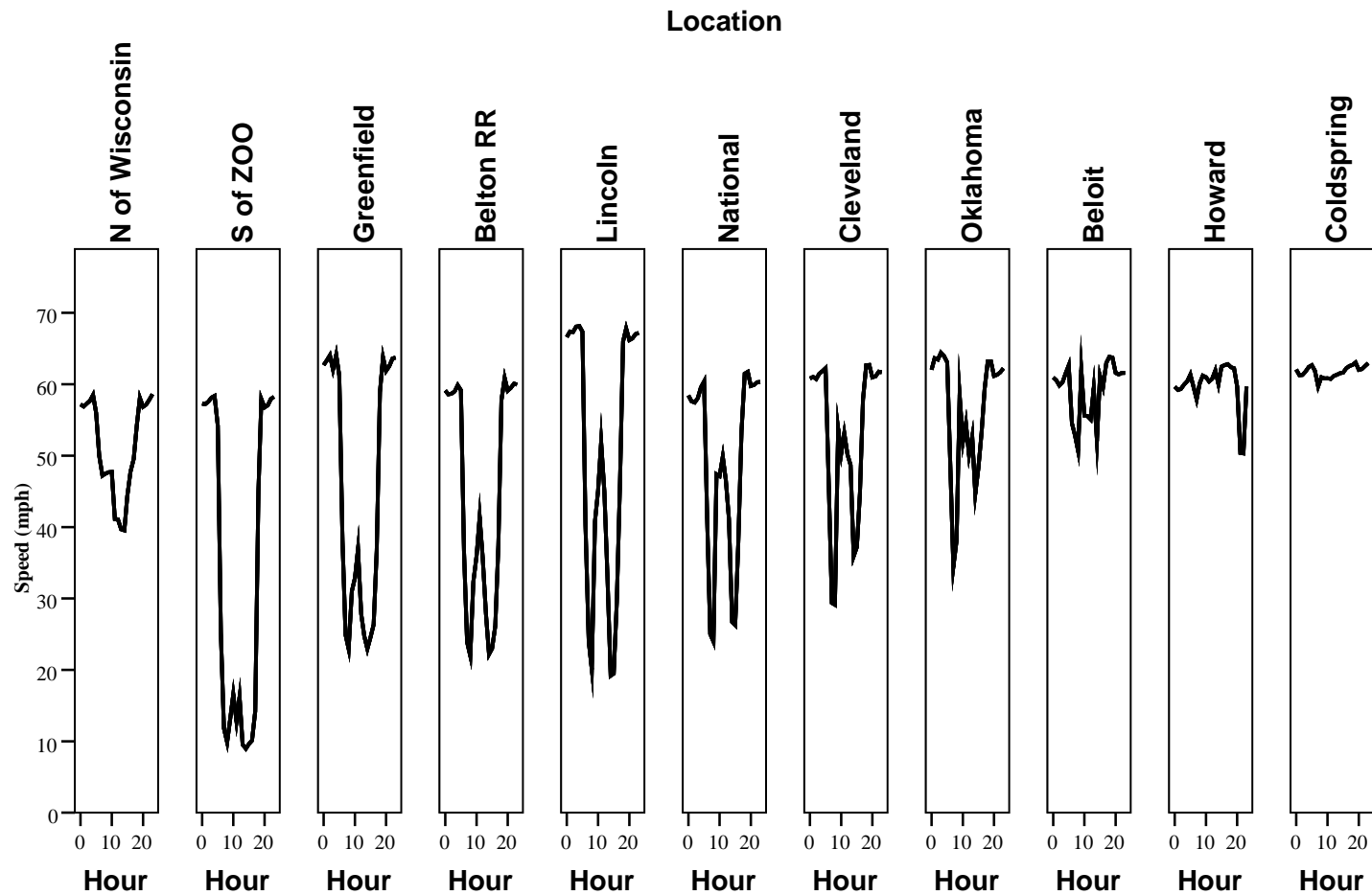


Figure E5. Corridor 24-Hour WZ1 average speed.

Corridor 24-Hour WZ1 4/11 ,4/14, 4/17, 4/18, 4/19, 4/20

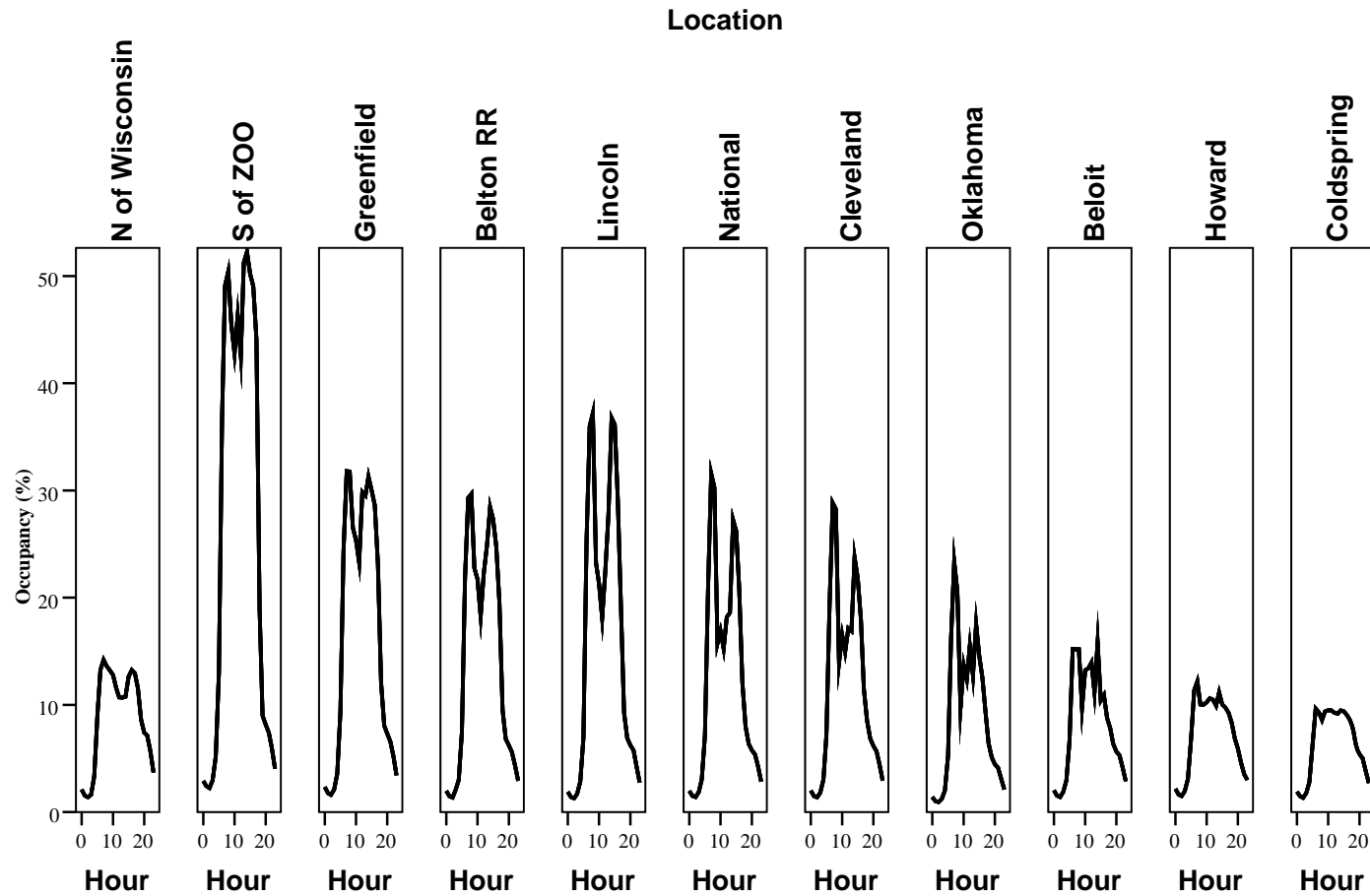


Figure E6. Corridor 24-Hour WZ1 average occupancy.

Corridor 24-Hour WZ2 5/1, 5/3, 5/4, 5/5, 5/9

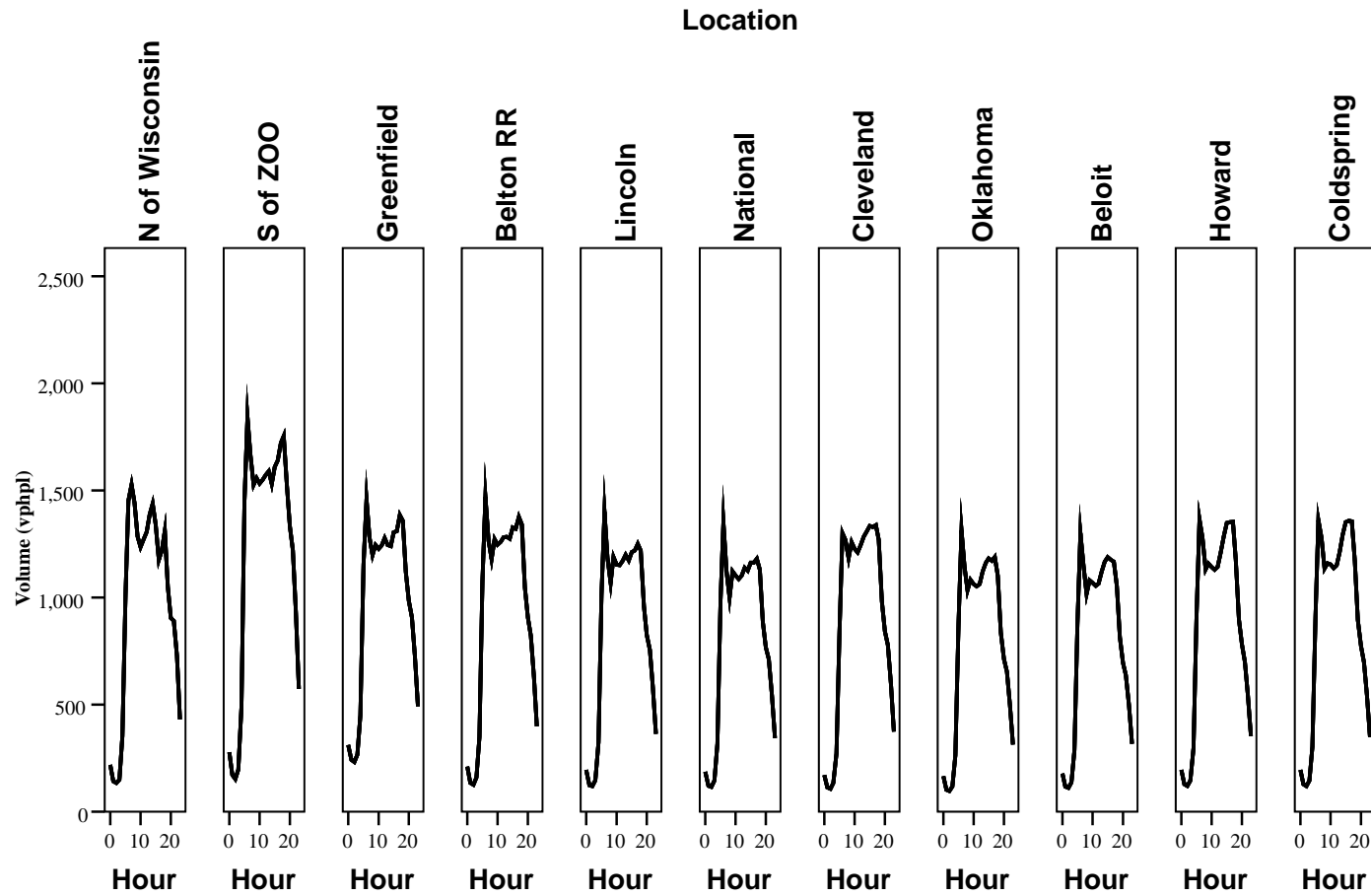


Figure E7. Corridor 24-Hour WZ2 traffic volume per lane.



Corridor 24-Hour WZ2 5/1, 5/3, 5/4, 5/5, 5/9

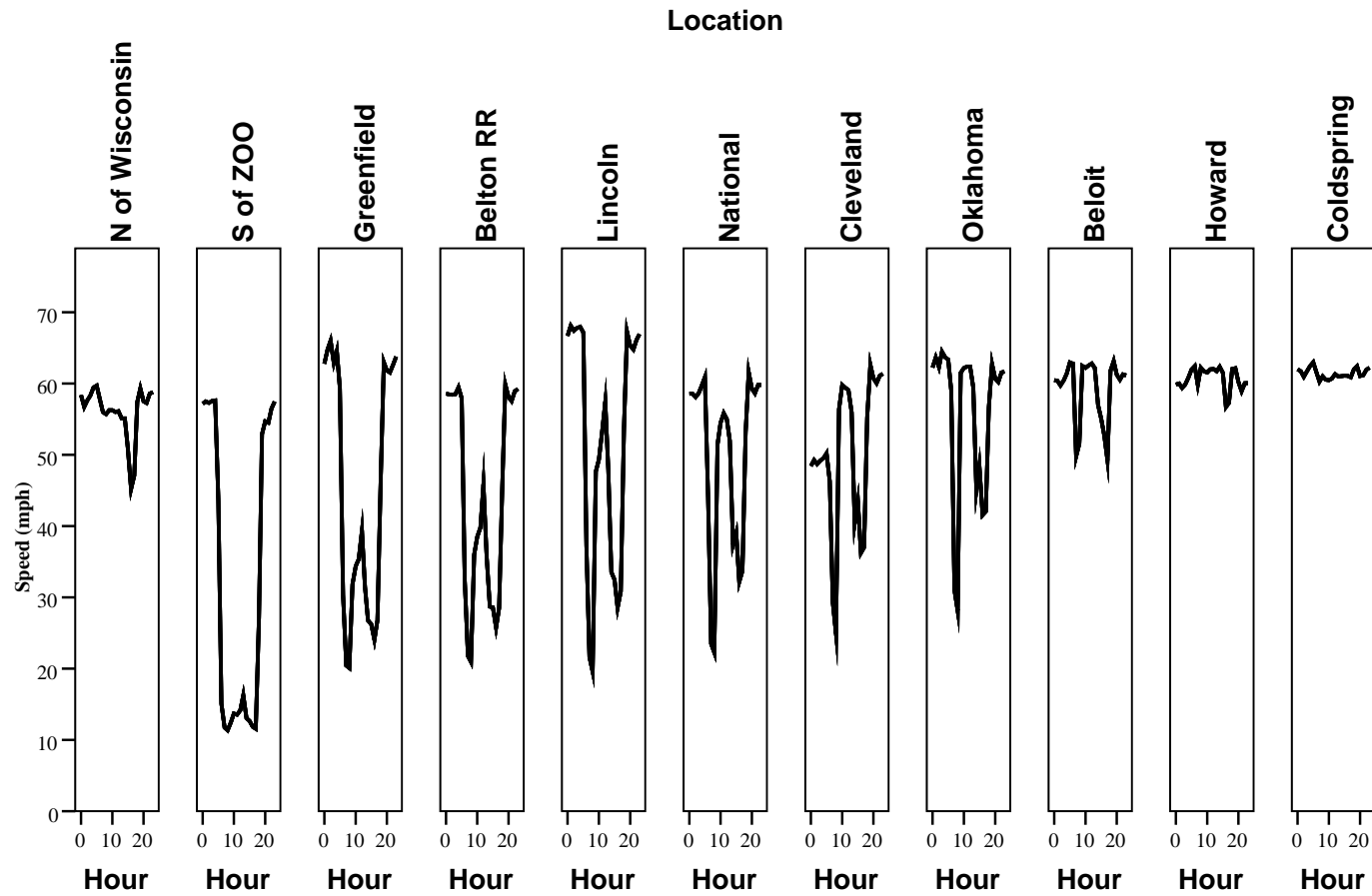


Figure E8. Corridor 24-Hour WZ2 average speed.

# Corridor 24-Hour WZ2 5/1, 5/3, 5/4, 5/5, 5/9

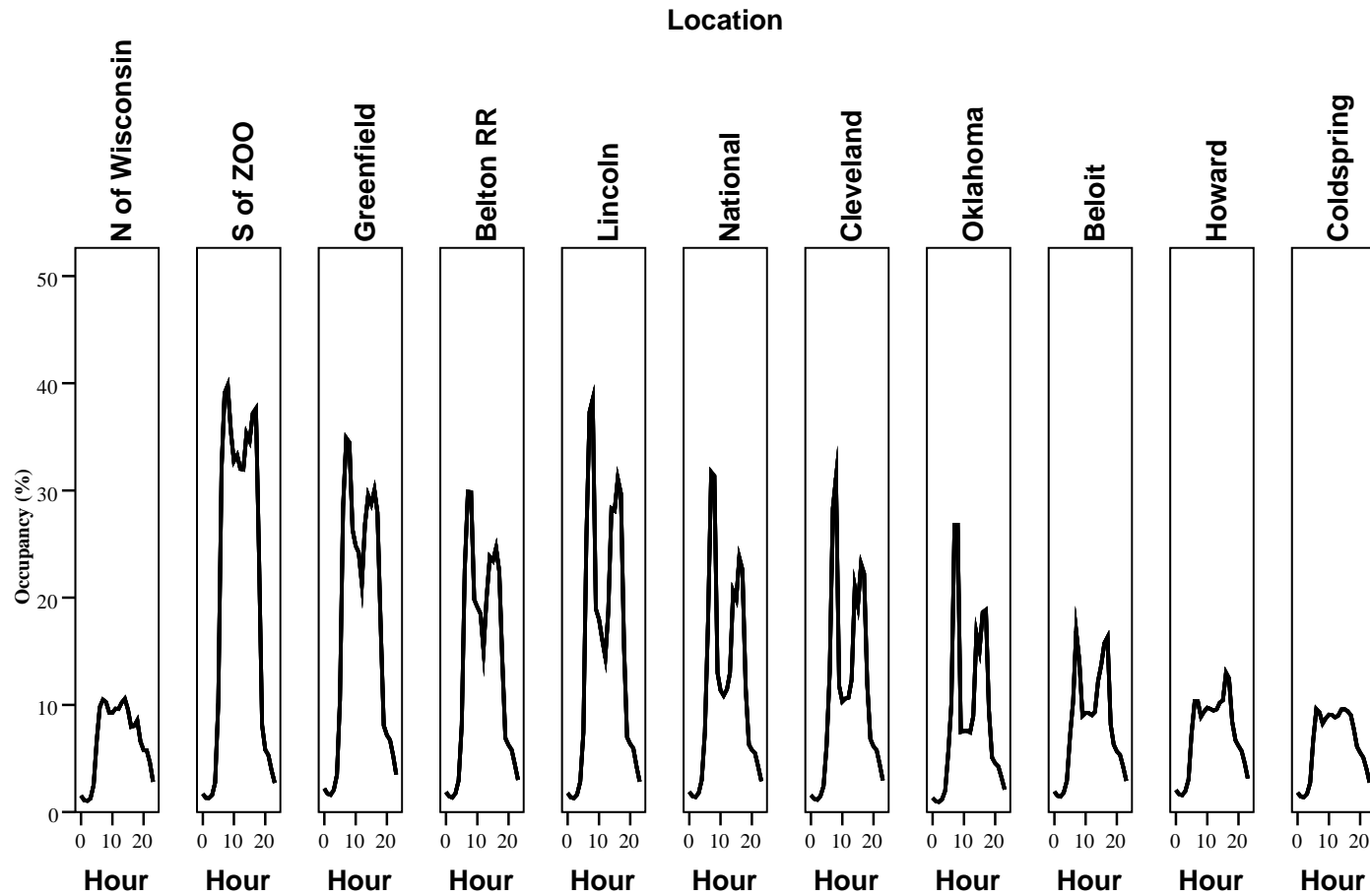


Figure E9. Corridor 24-Hour WZ2 average occupancy.

# **APPENDIX F**

## **THROUGHPUT AND SPEED AT WZ1 & WZ2 LOCATIONS**

**DURING NORMAL AND WZ CONDITIONS**

## INTRODUCTION

**Appendix F** focuses on speeds and throughputs in the vicinity of the two Work Zones. Figures in this Appendix present:

1. **Normal** traffic conditions in terms of speeds and throughputs at the locations where the Work Zones were established.
2. Speeds and throughputs under Work Zone 1 (**WZ1**) and Work Zone 2 (**WZ2**) conditions.

Volumes are provided in terms of throughput (all mainline lanes together) in order to allow exact conclusions about the number of diverted trips at any time of the day. Shifts in the starting and ending hours of peak periods are also easily identifiable.

The Figures can be used to establish a working definition of Work Zone capacity, whether one is interested in a maximum throughput value, as is observed, for example, at 6:30 am during **WZ2** (**Figure F6**), or a throughput value sustainable over the course of an entire day, as is observed between 9:00 and 19:00 hours on the same Figure.

## IMPORTANT FIGURE INFORMATION

Speed and throughput information was compiled from 5-minute detector observations. Lines in the Figures comprise of points, each point representing summarized information over the preceding 12 five-minute observations. Thus, a point with x-coordinate 8:00:00 represents average speed/total traffic between 7:00 am and 8:00 am.<sup>14</sup>

Appendix information is based on detectors located:

- For **WZ1** Detector location name: “**Wisconsin**.” Located 250 feet downstream from the Wisconsin Avenue overpass (refer to distances in **Figures C1** and **C2**). The detectors were placed within **WZ1** (past the end of the taper).
- For **WZ2** Detector location name “**S of Zoo**.” Located 1,130 feet from mile point 0.0 established where the South-to-North ramp (**S-N**) crosses over the West-to-East (**W-E**) ramp at the Zoo interchange (refer to distances in **Figure C2** and aerial photograph page **A4**). The detectors were placed upstream of **WZ2**.

The distance between the two detectors was 5,650 feet.<sup>15</sup>

Lane configurations during each time period are shown in **Figures B1–B3**; also in **Appendix H**.

Table F1. Number of open mainline lanes.

		Time period		
		Normal conditions	WZ1	WZ2
Location	WZ1	3	2	3
	WZ2	2	2	1

<sup>14</sup> See Figure footnote “60 min period ENDING at a given time.”

<sup>15</sup> Figure C2: 4,250 ft + 1,130 ft = 5,650 ft.

## FIGURE DESCRIPTIONS

### Wisconsin Avenue Normal conditions

**Figure F1** presents normal conditions at the **Wisconsin** detector location (250 feet downstream from the **Wisconsin Avenue** overpass). A free-flow speed of 60 mph was present most of the day; the lowest average speed of 52 mph occurred during the morning peak between 7:30 and 8:30 hrs. During that time throughput peaked at 6,500 vph over three mainline lanes. Peak occupancy (**Figures D3 and E3**) was 15%. Average speed dropped to 56 mph toward the end of the afternoon peak.

Between peak periods throughput dropped to as low as 4,500 vph over the three mainline lanes. Speeds were very close to the free-flow speed levels observed in the late night/early morning hours.

**Figure F2** presents throughput information from the **Wisconsin** detector location and speed information from the **S of Zoo** detector location (5,650 feet upstream) under **Normal** traffic conditions. Free-flow speed at the **S of Zoo** location was 59 mph. Average speed dropped during the morning peak to 42 mph, coincident with **Wisconsin Avenue** throughput peaking. Average speeds at this location remained at 56 mph between the morning and the afternoon peaks.

### South-of-Zoo Normal conditions

**Figure F3** presents volume and speed measurements at the **S of Zoo** location under **Normal** conditions. Speed observations were presented in the previous paragraph. It is interesting to note here that the lowest average speed observed during the morning peak did not coincide with the highest throughput at the **S of Zoo** location, but rather with that of the **Wisconsin** location, as shown in **Figure F2**.

### Wisconsin Avenue WZ1 conditions

**Figure F4** presents volume and speed measurements from the **Wisconsin** detector location under **WZ1** conditions (two open mainline lanes at the **Wisconsin** overpass). Maximum throughput was reduced from 6,500 vph over three lanes to 4,250 vph over two lanes. Thus, per-lane volumes were approximately equal in the two periods. However, average speed during the morning peak was 47 mph (5 mph lower than under normal conditions) and remained at that level until after the afternoon peak. It should be mentioned that speed measurements were taken 250 feet downstream of the **WZ1** taper. Drivers were in the process of accelerating within the Work Zone.

### **South-of-Zoo WZ 1 conditions**

**Figure F5** presents the correspondence between throughput at the **Wisconsin** location and average speed at the **S of Zoo** location. A very significant drop in average speeds at the **S of Zoo** location corresponded with peaking throughput at the **Wisconsin** location. Free-flow speeds of 58 mph before the morning peak dropped to 9 mph during the peak throughput at **Wisconsin**. When throughput at **Wisconsin** dropped to 3,500 vph between 10:00 and 11:00 hrs, average speeds at the **S of Zoo** location rose to 17 mph. This Figure establishes that significant queues were present throughout the day upstream of **WZ1**.

### **South-of-Zoo WZ 2 conditions**

**Figure F6** presents volume and speed conditions at **WZ2**, when only one lane was open. A freeflow speed of 58 mph dropped to 17 mph when flow peaked in the morning between 5:50 and 6:50 hrs. Speeds remained between 12-17 mph until 18:15 hrs. Speeds during the peak afternoon period were similar to those in the morning period; free-flow speeds resumed around 20:15 hrs.

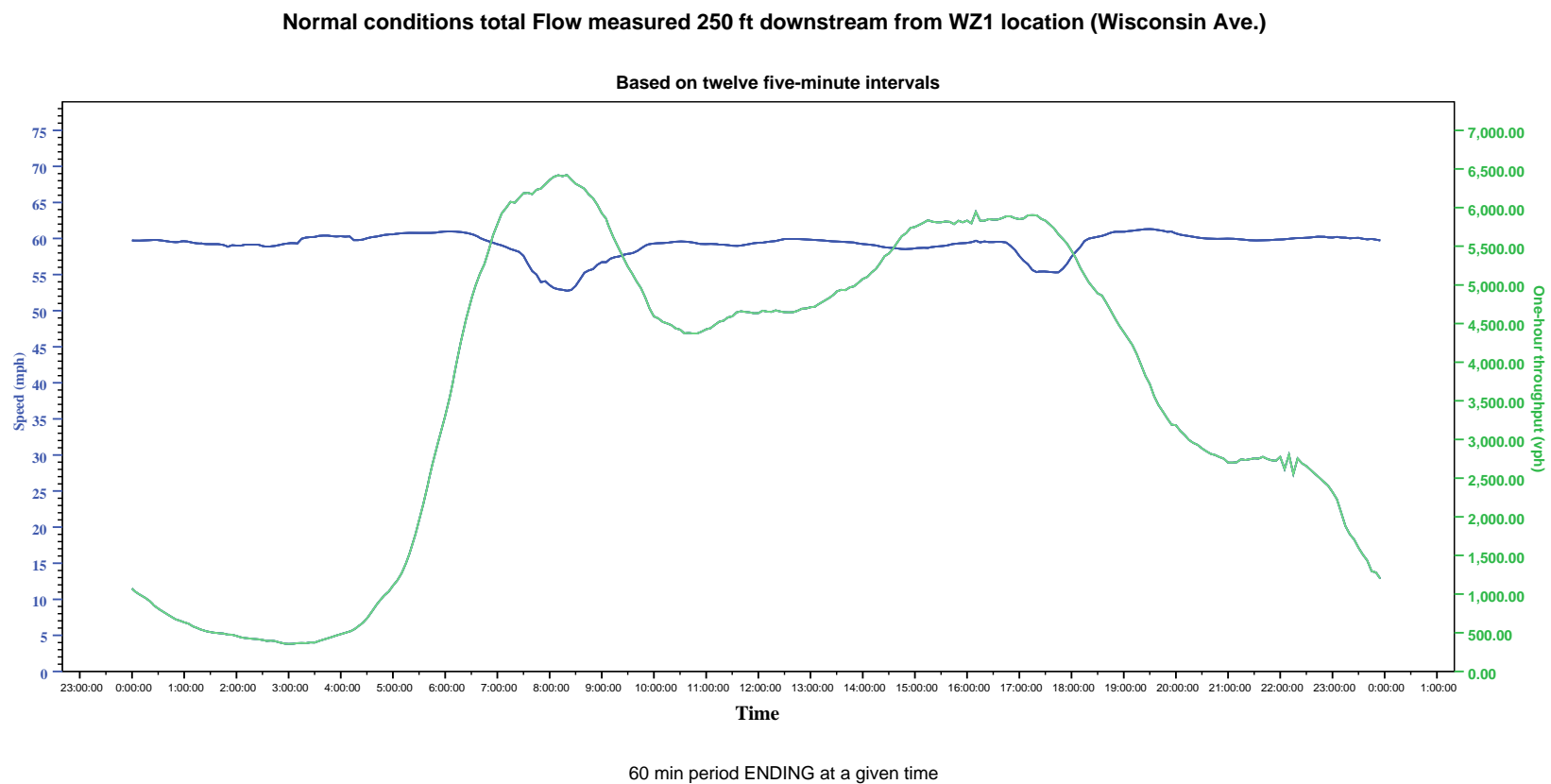


Figure F1. Normal conditions total Flow measured 250 ft downstream from WZ1 location (Wisconsin Avenue).

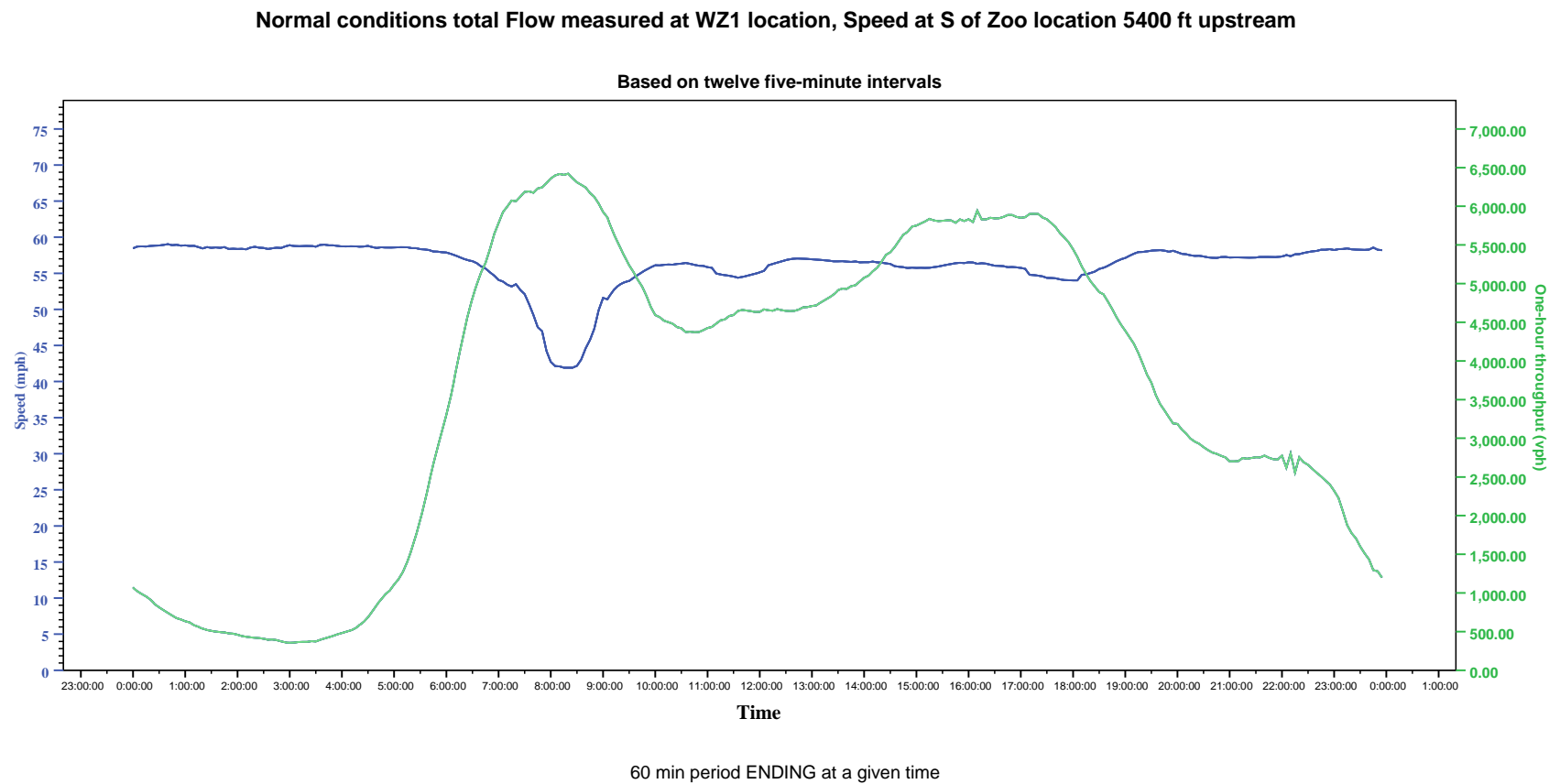


Figure F2. Normal conditions total Flow measured at WZ1 location, Speed measured at S of Zoo location 5,400 ft upstream.



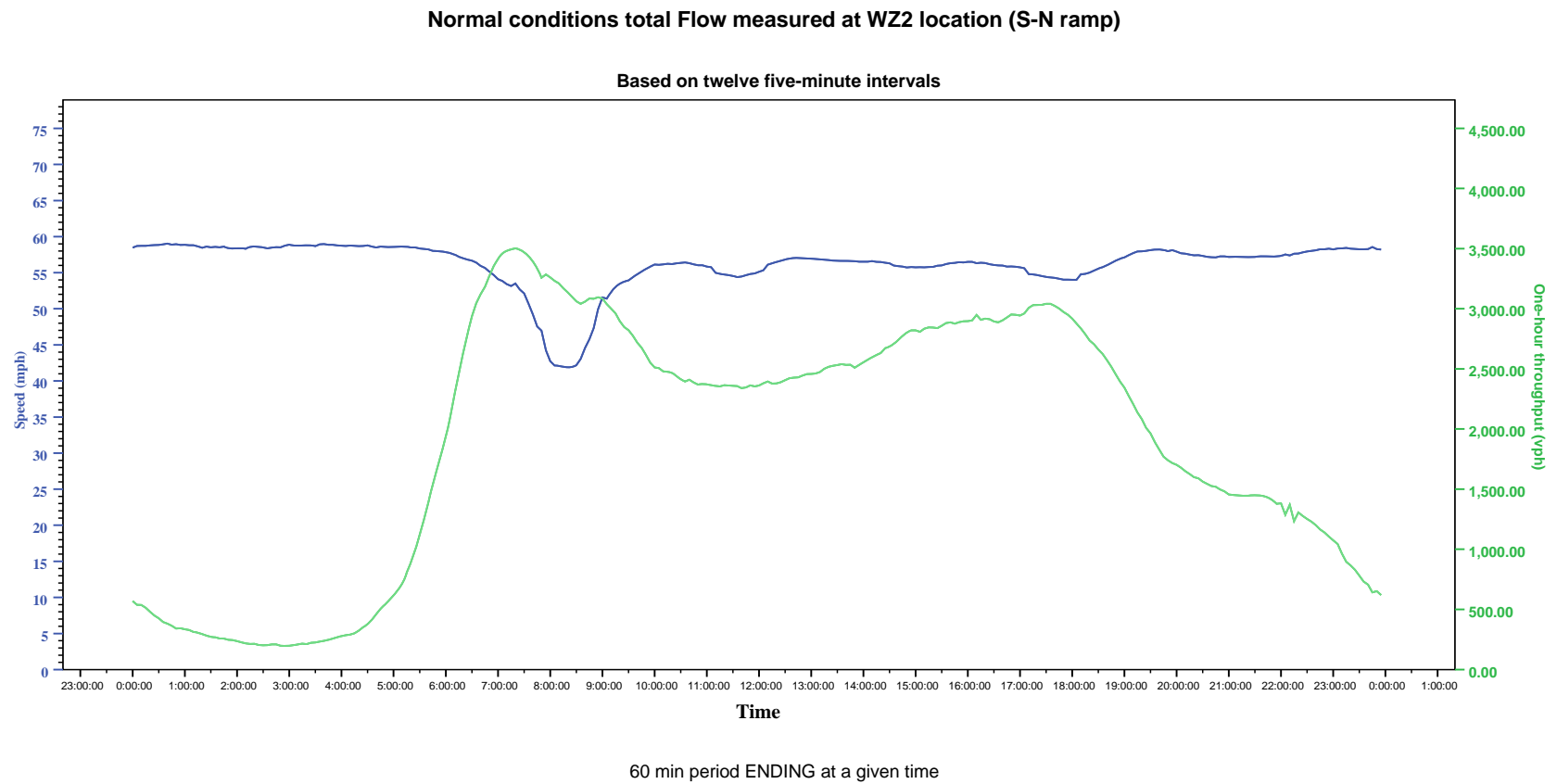


Figure F3. Normal conditions total Flow measured at WZ2 location (S-N ramp).

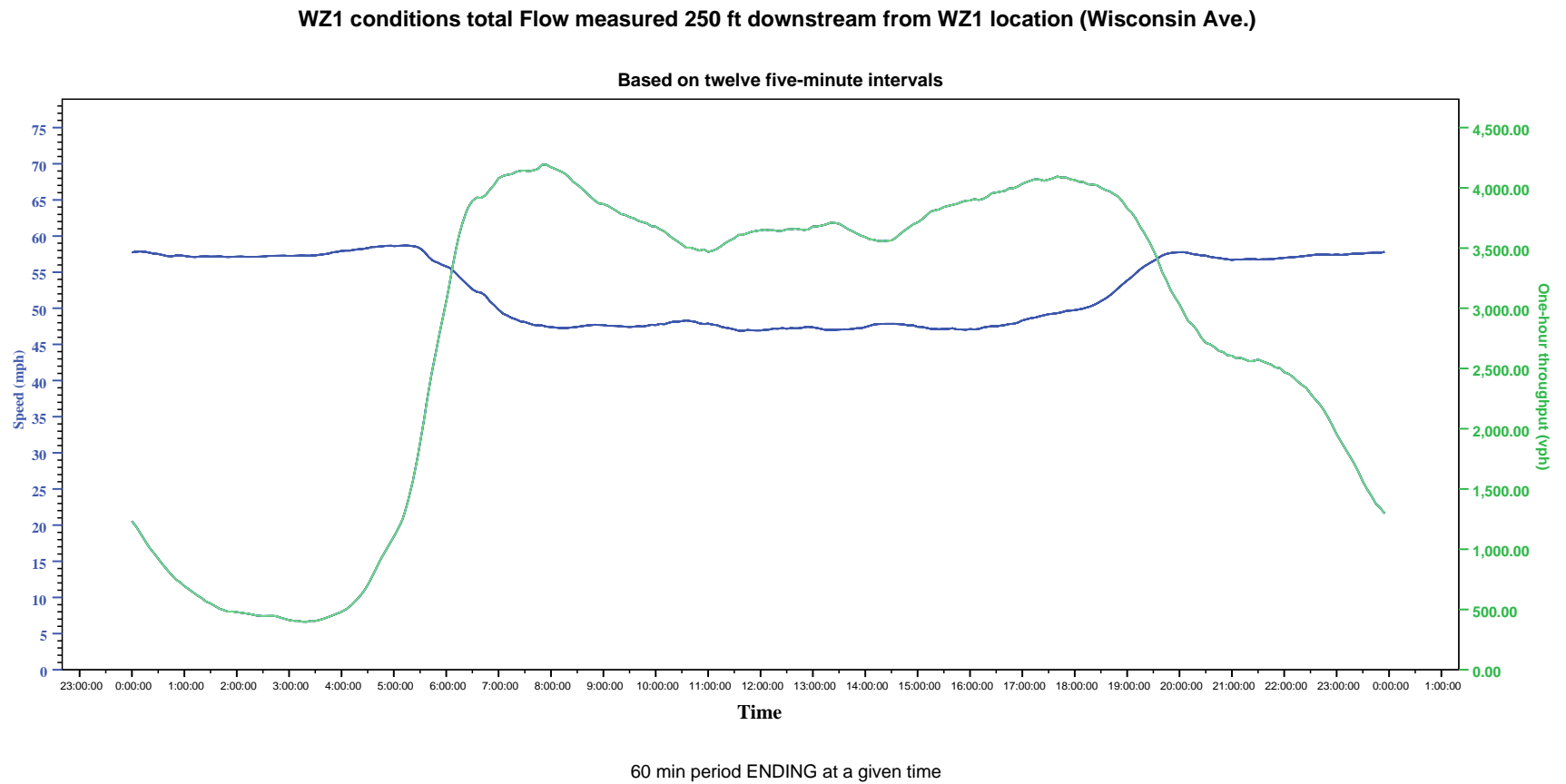


Figure F4. WZ1 conditions total Flow measured 250 ft downstream from WZ1 location (Wisconsin Avenue).

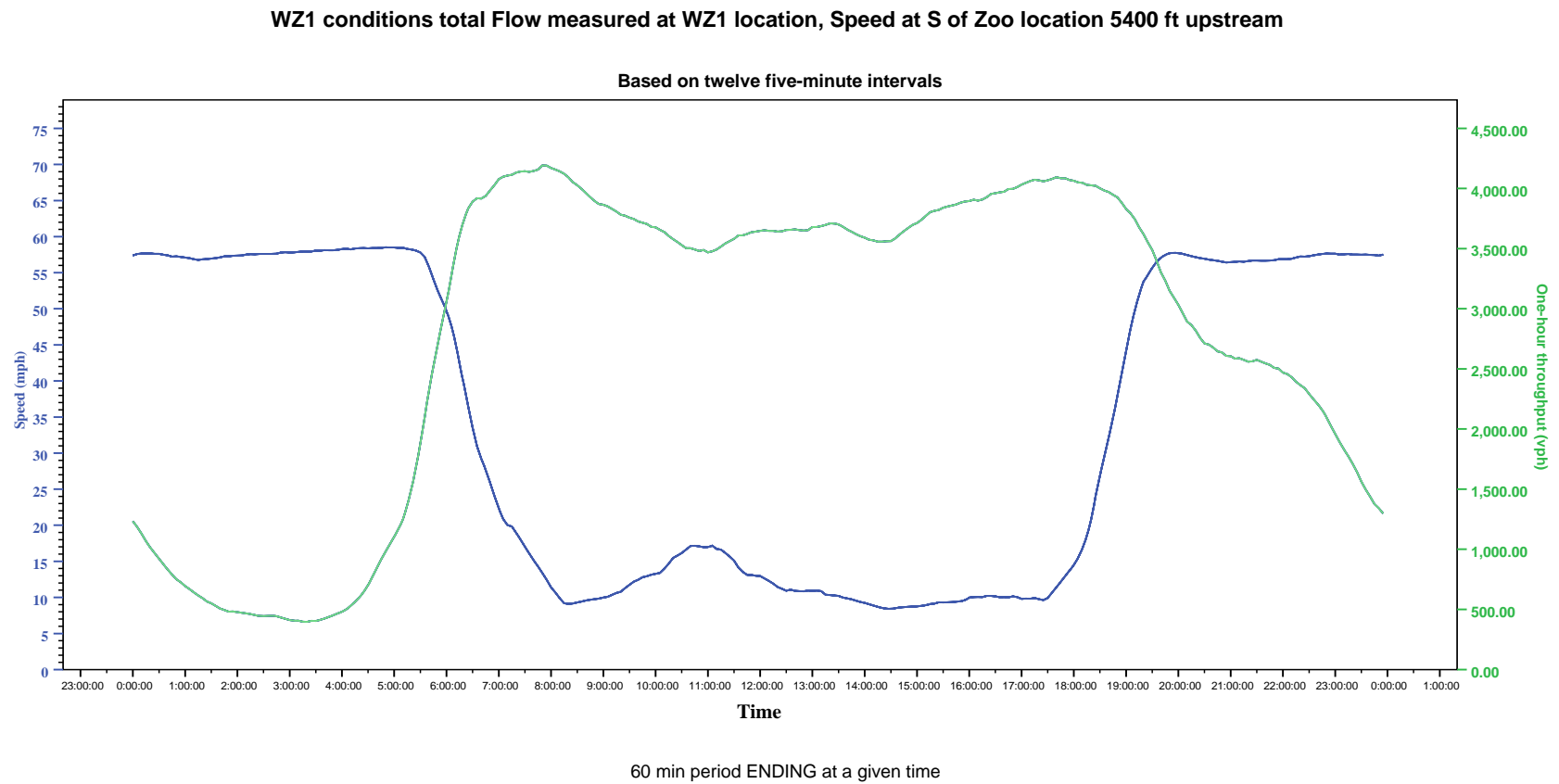
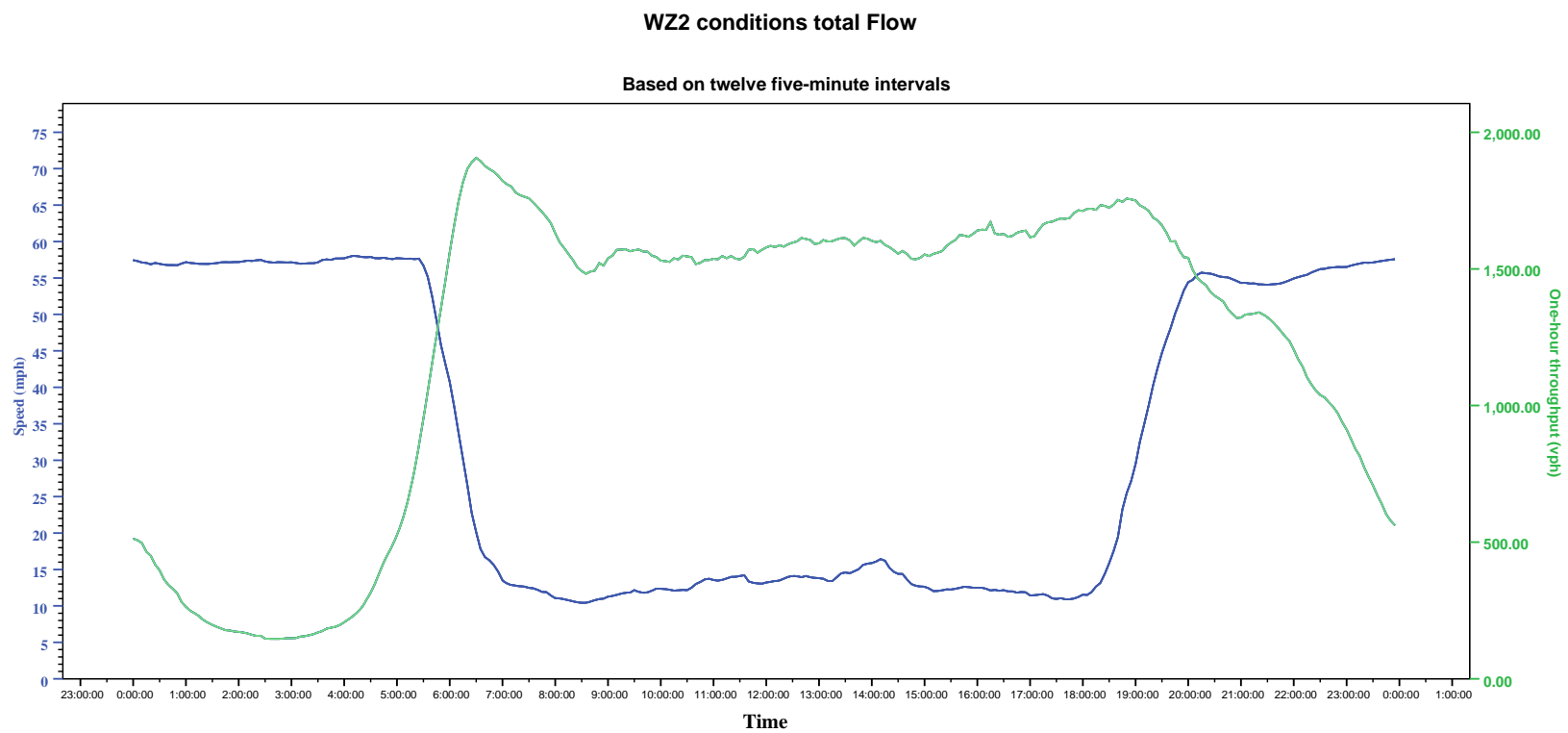


Figure F5. WZ1 conditions total Flow measured 250 ft downstream from WZ1 (Wisconsin Avenue), Speed at S of Zoo location.



60 min period ENDING at a given time

Figure F6. WZ2 conditions total Flow.

## **APPENDIX G**

### **TRAFFIC CONDITIONS IN THE VICINITY OF WORK ZONE LOCATIONS**

## INTRODUCTION

**Appendix G** tables present traffic characteristics statistics for each of the two analyzed Work Zone locations under **Normal**, Work Zone 1 (**WZ1**) and Work Zone 2 (**WZ2**) conditions, including traffic composition (percent heavy vehicles). Information presented herein, can be cross-referenced with **Appendix F** Figures.

Volume, speed and occupancy findings are presented based on information from two detector locations:<sup>16</sup>

1. **Wisconsin** (250 feet downstream of where the **WZ1** taper was established).
2. **S of Zoo** (5,400 feet upstream of where the **WZ1** taper was established which was also 1,130 feet upstream of where the **WZ2** taper was established).

Aerial photos of the general **WZ1** and **WZ2** locations are shown on pages **A3** and **A4**, respectively. Lane configurations under **Normal**, **WZ1** and **WZ2** conditions can be found in **Appendix B**. Distances to crossing facilities, detector location names and distances can be found in **Figures C1** and **C2**. Work Zone traffic control plans can be found in **Appendix H**.

A separate aerial photo file (**Corridor.pdf**) is provided and can be reviewed on a computer monitor, or printed in a plotter.

## IMPORTANT TABLE INFORMATION

- Hourly statistics in **Tables G1-G4** are based on twelve consecutive five-minute periods (sum of observed volumes, averaged observed speeds and occupancies). These hourly statistics were calculated from five-minute summaries. Visual representations of volumes and speeds can be found in **Appendix F** Figures.
- Highest one-hour throughput: based on average hourly volumes over all analysis days.<sup>17</sup>
- Min and max one-hour values: the highest/lowest values reported in any analyzed day.
- Number of observations N: the number of calculated one-hour averages (one for every five-minute period), times the number of analyzed days.
- AM and PM peak period duration: when volumes were greater than or equal to 90% of the peak hourly volume for a given peak period.<sup>18</sup> Mid-day period: the period between AM and PM peak periods.

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<sup>16</sup> See Figures C1 and C2 for distances.

<sup>17</sup> Analysis dates: see Table 1 in the body of this report, “WZ vicinity” column.

<sup>18</sup> Example: AM peak period duration Table G1: period when hourly volumes exceed 90% of maximum hourly volume ( $6422 \times 0.90 = 5780$  vph).

## TABLE DESCRIPTIONS

### Normal traffic conditions

**Normal** traffic conditions at the Work Zone 1 (**WZ1**) location are presented in **Table G1**. Under **Normal** conditions, all three mainline lanes were open at the Wisconsin Avenue overpass (see **Figure B1**). Volume information is from the **Wisconsin** detector location. Speed and occupancy information from the **Wisconsin** location (250 feet downstream of where the **WZ1** taper was established), and the **S of Zoo** location (4,500 feet upstream from the **WZ1** taper) is provided.

**Normal** traffic conditions at the Work Zone 2 (**WZ2**) location are presented in **Table G2**. Under **Normal** conditions both South-to-North (**S-N**) lanes at the Zoo interchange were open (see **Figure B1**). Volume, speed and occupancy findings are presented based on information provided from the **S of Zoo** detector location (1,130 feet upstream of where the **WZ2** taper was established).

### Work Zone 1 traffic conditions

**Table G3** provides traffic conditions during the **WZ1** period, when the median mainline lane was closed and the remaining two mainline lanes were open at the **Wisconsin Avenue** overpass (**Figure B2**). Information was acquired from the **Wisconsin** (250 feet downstream of the **WZ1** taper) and **S of Zoo** (5,400 feet upstream) locations.

### Work Zone 2 traffic conditions

**Table G4** provides traffic conditions during the **WZ2** period, when the right **S-N** lane was closed and the left lane was open (**Figure B3**). Information was acquired from the **S of Zoo** location (1,130 feet upstream of the **WZ2** taper).

## OBSERVATIONS AND CONCLUSIONS

### Normal traffic conditions

The highest traffic volumes were observed during the morning peak period, which naturally, then, became the focal point in the pursuit of a Work Zone capacity value.

As shown in **Table G1**, the **WZ1** location operated comfortably under **Normal** conditions (all three mainline lanes open) with an average per-lane volume of 2,061 vph between 6:00 and 9:10 hours. The peak hourly volume of 2,141 vph occurred between 7:25 and 8:25 hrs (this information is reflected in **Figure F1**<sup>19</sup>). Average speed during the peak hour was 52.8 mph and

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<sup>19</sup> Throughput during the hour from 7:25 to 8:25 hrs corresponds to the x-axis value of 8:25:00 in Figure F1.

average occupancy was 15.0% measured 250 feet downstream of the **Wisconsin Avenue** overpass (**WZ1** taper location). Average speed and occupancy at the **S of Zoo** detector location, 5,400 feet upstream of the overpass were 41.9 mph and 23.1%, respectively.

In the absence of significant congestion upstream of the **WZ1** location, and given the relatively high speeds and medium occupancies observed at the **Wisconsin** detector location, it may be concluded that the **WZ1** location operated well below capacity during the morning peak period when normal traffic conditions were present.

**Table G2** statistics indicate that the **WZ2** location (**S-N** ramp lanes) operated well below capacity during the morning peak under **Normal** conditions, with a maximum per-lane volume of 1,750 vph between 6:25 and 7:25 hrs, when average speed was 53.5 mph and average occupancy 12.9%. As shown in **Figure F3**, **WZ2** location speeds reached their minimum values well past the time that volumes reached their maximum values (approximately one hour later). Minimum speed values corresponded to maximum volumes at the downstream **Wisconsin** location, as shown in **Figure F2**.

These observations explain the apparent contradiction of lower average speeds and higher average occupancies outside the peak volume hour, during the morning peak period (5:45-8:20 hrs) at the **WZ2** location.

### **Work Zone 1 traffic conditions**

**Table G3** statistics indicate that, when Work Zone 1 (**WZ1**) was in place, significant changes occurred in traffic flow characteristics compared to Normal conditions. Volume information collected 250 feet downstream from the taper indicated a significant drop in throughput with the median lane closed, to approximately 65% of the **Normal** throughput. The morning peak hour occurred half an hour earlier; peak per-lane volume declined slightly by 45 vph to 2,096 vph, average speed dropped by 5.2 mph to 47.6 mph, and average occupancy decreased by 1.6% to 13.4%. Volumes remained at 90% of the maximum value<sup>20</sup> approximately one hour longer (from 5:25 to 9:30 hrs), during which period an average speed drop of 7.0 mph occurred; average occupancy remained virtually unchanged (dropped by 0.1%). Speed and occupancy statistics reflect conditions within the Work Zone, at a point where drivers were starting to accelerate back to free-flow speeds.

Information collected at the **S of Zoo** detector location (5,400 feet upstream of the **WZ1** taper), however, indicated a very significant speed drop of 32.8 mph during the peak hour, from 41.9 mph to 9.1 mph, and a 24.4% occupancy increase, from 23.1% to 47.5%. Similar significant changes took place during the entire morning peak period: average speeds dropped from 47.5 mph to 16.1 mph and average occupancy increased substantially (from 20.2% to 45.1%). These conditions, as well as speed and occupancy conditions at upstream locations (**S of Zoo**,

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<sup>20</sup> Working definition of “peak period:” time period when hourly volumes are within 90% of the peak hour volume.



**Greenfield, Belton RR and Lincoln**—see **Figures D8, D9 and E8, E9**) indicated the existence of a substantial queue throughout the morning peak period and provided assurance that the measured maximum traffic volume at the **Wisconsin** location represented the **WZ1** capacity.<sup>21</sup>

It should be noted here that the afternoon peak period ended one hour and ten minutes later, compared to **Normal** traffic conditions (19:15 vs. 18:05 hrs). Average per-lane traffic volumes were comparable under **WZ1** and **Normal** conditions (1,972 vphpl vs. 1,929 vphpl); peak per-lane volume was higher by a modest amount under **WZ1** conditions (2,047 vphpl vs. 1,981 vphpl). The peak hour occurred 25 minutes later. Significant speed and occupancy effects were present: downstream speeds were lower by 10.4 mph at 49.3 mph, upstream speeds were lower by 44.9 mph at 11.4 mph; downstream occupancies were 0.9% higher, upstream occupancies increased by 31.3% to 46.5%.

Hourly volume statistics on **Table G3** are actual counts, aggregated from five-minute counts and can be used in planning work zone traffic mitigation measures. Average and highest throughput values are based on five typical weekdays<sup>22</sup> that provided stable statistics. A capacity of 2,100 vph and a sustained average throughput of 2,000 vph over nearly four hours provide a range of values that the Engineer can rely on for Work Zone planning purposes. These values are further supported by the observed highest one-hour afternoon peak throughput of 2,050 vph. The freeway cross-section was reduced from four approaching lanes to two lanes at the **WZ1** taper.

### **Work Zone 2 traffic conditions**

**Table G4** statistics indicate significant traffic characteristic changes at the **S of Zoo** detector location with Work Zone 2 (**WZ2**) in place, when the **S-N** ramp was reduced from two to one lane. Volume information indicated a significant throughput drop to 54% of that under **Normal** conditions. The morning peak hour occurred 55 minutes earlier, between 5:30 and 6:30 hrs. Per-lane volume increased by 156 vph, to 1,906 vph during this hour, average speed declined by 33.2 mph to 20.1 mph; average occupancy increased by 13.0% to a value of 25.9%. Volumes remained to 90% their peak values<sup>23</sup> for two hours and thirty-five minutes under both **Normal** and **WZ2** conditions. However, average volumes during **WZ2** were 150 vph higher. The morning peak period started 35 minutes earlier during **WZ2**.

These conditions, as well as speed and occupancy conditions at upstream locations (**Greenfield, Belton RR and Lincoln**—see **Figures D11, D12 and E11, E12**), indicated the existence of a substantial queue throughout the morning peak period and provided assurance that the measured maximum volume at the **WZ2** location represented the **WZ2** capacity.

It should be noted that the afternoon peak period ended one-and-a-half hour later, compared to **Normal** traffic conditions (19:50 vs. 18:20 hrs). Average volumes were higher compared to

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<sup>21</sup> Defined as the maximum volumes that could be accommodated under queuing conditions.

<sup>22</sup> See **Table 1** right column in the body of this report.

<sup>23</sup> Working definition of peak morning period.

**Normal** conditions by approximately 220 vph under **WZ2** conditions; average speed was 29.4 mph lower, at 25.5 mph and average occupancy was 12.5% higher at 22.4%.

The above statistics suggest a Work Zone 2 (**WZ2**) capacity value of 1,900 vph and a sustained (over two-and-a-half hours) average hourly lane volume of 1,800 vph. These values, based on averages over five weekdays, provide stable statistics for Work Zone planning purposes. The freeway mainline cross-section was reduced from two to one lane at the **WZ2** taper.

## TRAFFIC COMPOSITION

Traffic composition [Heavy Vehicle (**HV**) presence] is an important parameter in assessing the quality of freeway operations. The presence of heavy vehicles adversely affects freeway capacity. The heavy vehicle factor ( $f_{HV}$ ) used in the Highway Capacity Manual analysis of freeway capacity is based on the presence of buses, trucks and recreational vehicles, regardless of prevailing operating speeds. However, an analysis of detailed headway information based on approximately 500,000 individual vehicle headways revealed that heavy vehicle headways vary significantly with speed (longer headways at lower speeds) and the type of leading-trailing vehicle combination (longer headways between heavier vehicles).<sup>24</sup>

Given the importance of **HV** presence, vehicle composition information was desirable for the analyzed Work Zone (**WZ**). However, detailed information on heavy vehicle presence was not available for the analyzed period. **Tables G5-G7** present collected information for the interested reader who would like to apply adjustment factors to the **WZ** capacity information provided in **Tables G3** and **G4** in *vehicles* per hour.

Vehicle classification information for 2004 and 2005 is presented in **Appendix B of the micro-simulation part** of the report. This information is amended herein with available 2006 data collected during April 2006. **Normal** traffic operations were present in the period April 1- 9, **WZ1** operations were present April 10 – 26 and **WZ2** operations were present April 27-30. Only weekday information was analyzed.

April 2006 information was available in daily per-lane summaries for three broad vehicle classes defined based on vehicle length ranges: up to 21 ft, 22-40 ft, and 41 ft or longer vehicles. **Table G5** provides a basic comparison with 2004-2005 vehicle classification information presented in **Table B1 of the micro-simulation part** of this report.

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<sup>24</sup> Drakopoulos, A., Dehman, A., Örnek, E., "Heavy Vehicle Influence Under the Microscope," Mid-Continent Transportation Research Forum 2008, Madison, Wisconsin, August 2008.

A few points that should be kept in mind when comparing 2004-5 information with 2006 data are summarized in the table below:

Daily vehicle classification count differences 2004-5 vs. 2006 data

2004-5 data	2006 data
Bidirectional	Northbound
Yearly	Month of April
FHWA veh classes <ul style="list-style-type: none"> <li>• 1-3</li> <li>• 4-7</li> <li>• 8-13</li> </ul>	Corresponding Vehicle length category <ul style="list-style-type: none"> <li>• Up to 21 ft</li> <li>• 22-40 ft</li> <li>• 41ft +</li> </ul>

**Appendix B of the micro-simulation part** of the report presents 2003 vehicle classification information during two-hour am and pm peaks and during other times of the day. This information can be consulted in evaluating appropriate  $f_{HV}$  values for different times of the day, keeping in mind that a major freeway interchange project (Marquette interchange) started in 2004, approximately five miles due East of the Zoo interchange. This project may have affected **HV** distribution in the vicinity of **WZ1** and **WZ2** due to ramp closures.

## OBSERVATIONS

**Table G6** indicates an overall traffic volume reduction of 12.0% (9,400 vpd) during **WZ1** compared with **Normal** traffic conditions. The reduction was more pronounced among smaller vehicles (passenger cars and pick-up trucks) at 14.4% or approximately 9,800 vpd. Fewer single unit trucks and buses were present (8.3% or 220 vpd) but more combination vehicles (an 8.2% increase or 650 vpd). Thus, most of the traffic volume reduction observed during **WZ1** was due to fewer smaller vehicles using the corridor. These observations may lead to a more generalized conclusion that minor commercial vehicle rerouting may be expected for urban freeway work zones, but measurable passenger car rerouting may take place.<sup>25</sup>

Under **Normal** traffic conditions the middle lane carried the heaviest traffic volumes (35.1%) with the other two lanes evenly dividing the remainder of the traffic. During **WZ1**, all lanes carried lower volumes, but most traffic moved on the shoulder lane (35.4%) with 34.1% on the middle lane and 30.5% on the median lane—a general shift away from the median lane and toward the shoulder lane. The only vehicle class whose presence increased in absolute numbers on the median lane was combination vehicles with an additional 435 vpd (21.9%). This was

<sup>25</sup> For changes in exit ramp volumes during **WZ1** and **WZ2** consult **Figures C5** and **C6**. Substantial increases in exiting volumes and decreases in entering volumes were observed along the entire analysis corridor.

probably due to long-haul combination vehicle drivers wishing to avoid the turbulence due to right-hand-side ramp traffic.

**Table G6** indicates an overall traffic reduction of 12% (9,260 vpd) during **WZ2** compared with **Normal** traffic conditions. The reduction was also more pronounced among passenger cars and pick-up trucks at 15.3% or approximately 10,400 vpd. A smaller number of single-unit trucks and buses diverted (160 vpd or 6.1%), but 16.8% more combination trucks entered the corridor (1,300 vpd). Thus, most of the diverted traffic during **WZ2** was due to fewer smaller vehicles using the corridor. Combination trucks were not likely to divert.

A general shift of traffic toward the shoulder lane was observed during **WZ2** as well, with the exception of combination trucks, whose presence in the median lane increased both in absolute numbers and as a percentage of the vehicles using that lane.

Table G1. **Normal** conditions, Work Zone 1 (WZ1) location. Three lanes open.

	Volume (vph)		Speed (mph)		Occupancy (% time)	
	Total	Per lane	S of Zoo	Wisconsin	S of Zoo	Wisconsin
AM peak period 6:00-9:10						
Average	6184	2061	47.5	55.6	20.2	13.7
Min	5665	1888	37.2	48.9	16.0	11.7
Max	6566	2189	55.0	59.7	25.8	16.3
Std. Dev.	216.3		5.3	2.8	2.8	1.1
N	73		73	73	73	73
Highest one-hour throughput 7:25-8:25	6422	2141	41.9	52.8	23.1	15.0
PM peak period 13:40-18:05						
Average	5788	1929	55.6	58.1	15.1	12.4
Min	4986	1662	50.8	47.1	14.0	11.1
Max	6126	2042	56.7	60.4	16.4	15.9
Std. Dev.	215.0		1.4	3.2	0.58	0.91
N	122		122	122	122	122
Highest one-hour throughput 15:15-16:15	5944	1981	56.3	59.7	15.2	12.1
Mid-Day period 9:10-13:40						
Average	4607	1535	56.0	59.5	14.5	10.1
Min	4258	1419	51.2	58.2	13.3	9.3
Max	5119	1706	57.4	60.3	16.8	11.1
Std. Dev.	170.2		1.4	0.46	0.8	0.36
N	126		126	126	126	129

**NOTE:** Please refer to the **IMPORTANT TABLE INFORMATION** section of this Appendix.

Table G2. **Normal** conditions, Work Zone 2 (WZ2) location. Two lanes open.

	Volume (vph)		Speed (mph)	Occupancy (% time)
	Total	Per lane		
AM peak period 5:45-8:20				
Average	3338	1669	49.3	14.1
Min	2938	1469	37.2	11.0
Max	3553	1777	56.1	18.9
Std. Dev.	165.1		5.8	2.1
N	57		57	57
Highest one-hour throughput 6:25-7:25	3500	1750	53.5	12.9
PM peak period 14:45-18:20				
Average	2910	1455	55.5	10.7
Min	2677	1339	50.8	9.8
Max	3063	1532	57.1	11.7
Std. Dev.	96.0		1.5	0.4
N	128		128	128
Highest one-hour throughput 16:40-17:40	3042	1521	54.9	9.9
Mid-Day period 8:20-14:45				
Average	2496	1248	55.9	10.0
Min	2262	1131	51.2	9.0
Max	2909	1455	57.4	11.9
Std. Dev.	144.1		1.3	0.6
N	195		195	195

**NOTE:** Please refer to the **IMPORTANT TABLE INFORMATION** section of this Appendix.

Table G3. Work zone 1 (**WZ1**) conditions. Two lanes open (four-to-two lane taper).

	Volume (vph)		Speed (mph)		Occupancy (% time)	
	Total	Per lane	S of Zoo	Wisconsin	S of Zoo	Wisconsin
AM peak period 5:25-9:30						
Average	4013	2003	16.1	48.6	45.1	13.6
Min	3437	1719	8.4	44.5	12.0	10.5
Max	4334	2167	57.3	56.5	53.4	15.0
Std. Dev.	170.3		13.4	2.67	11.0	0.82
N	185		185	185	185	185
Highest one-hour throughput 6:55-7:55	4191	2096	9.1	47.6	47.5	13.4
PM peak period 13:55-19:15						
Average	3944	1972	15.8	49.0	44.2	12.9
Min	3249	1625	6.7	46.3	9.7	9.6
Max	4305	2153	57.8	57.4	57.0	14.0
Std. Dev.	173.0		13.4	2.7	11.7	0.8
N	260		260	260	260	260
Highest one-hour throughput <sup>4</sup> 16:40-17:40	4094	2047	11.4	49.3	46.5	13.0
Mid-Day period 9:30-14:55						
Average	3606	1803	12.1	47.4	47.9	13.0
Min	2881	1441	5.6	45.5	23.4	9.7
Max	3908	1954	37.5	52.2	61.0	13.9
Std. Dev.	182.1		5.6	1.4	6.3	0.79
N	265		265	265	265	265

**NOTE:** Please refer to the **IMPORTANT TABLE INFORMATION** section of this Appendix.

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Table G4. Work zone 2 (**WZ2**) conditions. One lane open (two-to-one lane taper).

	Volume (vph)		Speed (mph)	Occupancy (% time)
	Total	Per lane		
AM peak period 5:10-7:45				
Average	One lane open-see next column	1817	17.3	27.5
Min		1603	9.8	12.8
Max		1938	42.0	35.3
Std. Dev.		78.1	7.0	5.37
N		114	114	114
Highest one-hour throughput 5:30-6:30		1906	20.1	25.9
PM peak period 14:25-19:50				
Average	One lane open-see next column	1670	18.7	27.5
Min		1445	9.9	4.8
Max		1899	58.2	35.5
Std. Dev.		110.0	13.7	8.4
N		266	266	266
Highest one-hour throughput 17:50-18:50		1757	25.5	22.4
Mid-Day period 7:45-14:25				
Average	One lane open-see next column	1563	13.3	30.9
Min		1381	9.2	13.5
Max		1704	35.2	37.8
Std. Dev.		61.2	3.8	4.0
N		404	404	404

**NOTE:** Please refer to the **IMPORTANT TABLE INFORMATION** section of this Appendix.



Table G5. Average Daily Classification of Vehicles at Cleveland Avenue.

FHWA Vehicle Class	Year 2004 NB & SB	Year 2005 NB& SB	April 2006 NB only		
			Normal conditions	WZ1 conditions	WZ2 conditions
1 Motorcycles	0.65%	0.75%			
2 Passenger Cars	80.8%	78.4%			
3 Light Trucks	9.19%	11.3%			
4 Buses	0.68%	0.65%			
5 SU, 2 Axles, 6 tires	1.54%	1.60%			
6 SU, 3 Axles	0.56%	0.53%			
7 SU, 4 + Axles	0.24%	0.22%			
8 Single Trailer, 4 or Less Axles	0.96%	0.98%			
9 Single Trailer, 5 Axles	5.03%	5.19%			
10 Single Trailer, 6 + Axles	0.11%	0.09%			
11 Multi-Trailer, 5 or Less Axles	0.18%	0.20%			
12 Multi-Trailer, 6 Axles	0.03%	0.03%			
13 Multi-Trailer, 7 + Axles	0.03%	0.01%			
Total of 1-3 (up to 21 ft)	90.6%	90.5%	86.7%	84.2%	83.3%
Total of 4 to 7 (22-40 ft)	2.92%	2.35%	3.3%	3.5%	3.6%
Total of 8 to 13 (41ft+)	6.34%	6.26%	10.0%	12.2%	13.2%

**Source:** Wisconsin Department of Transportation

Table G6. Weekday daily traffic volumes (vpd) by vehicle length and lane at Cleveland Avenue, April 2006.

	Lane	Vehicle length (ft)			Total
		0-21	22-40	41-90	
<b>Normal</b> conditions	Shoulder	23,117	634	1,636	25,387
	Middle	21,874	1,478	4,184	27,536
	Median	22,961	510	1,982	25,453
	Total	67,952	2,621	7,803	78,376
<b>WZ1</b> conditions	Shoulder	21,919	703	1,819	24,441
	Middle	18,099	1,202	4,207	23,508
	Median	18,138	499	2,417	21,055
	Total	58,157	2,403	8,444	69,004
<b>WZ2</b> conditions	Shoulder	23,001	775	1,832	25,608
	Middle	17,695	1,098	4,213	23,006
	Median	16,843	591	3,068	20,502
	Total	57,539	2,464	9,113	69,115

**Note:** Compare to total 74,400 and 78,100 vpd for **Normal**, 67,700 vpd for **WZ1** and 65,800 vpd for **WZ2** conditions shown in **Figure C4**. Figures are based on different sets of detectors in close proximity to each-other. **Table 1** in the body of the report shows days used for **Figure C4** data.

Table G7. Weekday traffic composition (percentages) by vehicle length and lane at Cleveland Avenue, April 2006.

	Lane	Vehicle length (ft)			Total
		0-21	22-40	41-90	
<b>Normal</b> conditions	Shoulder	91.1%	2.5%	6.4%	32.4%
	Middle	79.4%	5.4%	15.2%	35.1%
	Median	90.2%	2.0%	7.8%	32.5%
	Total	86.7%	3.3%	10.0%	100.0%
<b>WZ1</b> conditions	Shoulder	89.7%	2.9%	7.4%	35.4%
	Middle	77.0%	5.1%	17.9%	34.1%
	Median	86.1%	2.4%	11.5%	30.5%
	Total	84.3%	3.5%	12.2%	100.0%
<b>WZ2</b> conditions	Shoulder	89.8%	3.0%	7.2%	37.1%
	Middle	76.9%	4.8%	18.3%	33.3%
	Median	82.2%	2.9%	15.0%	29.7%
	Total	83.3%	3.6%	13.2%	100.0%

**Note:** Percentages based on **Table G6** vehicle counts.

# **APPENDIX H**

## **WORK ZONE TRAFFIC CONTROL PLANS**

## INTRODUCTION

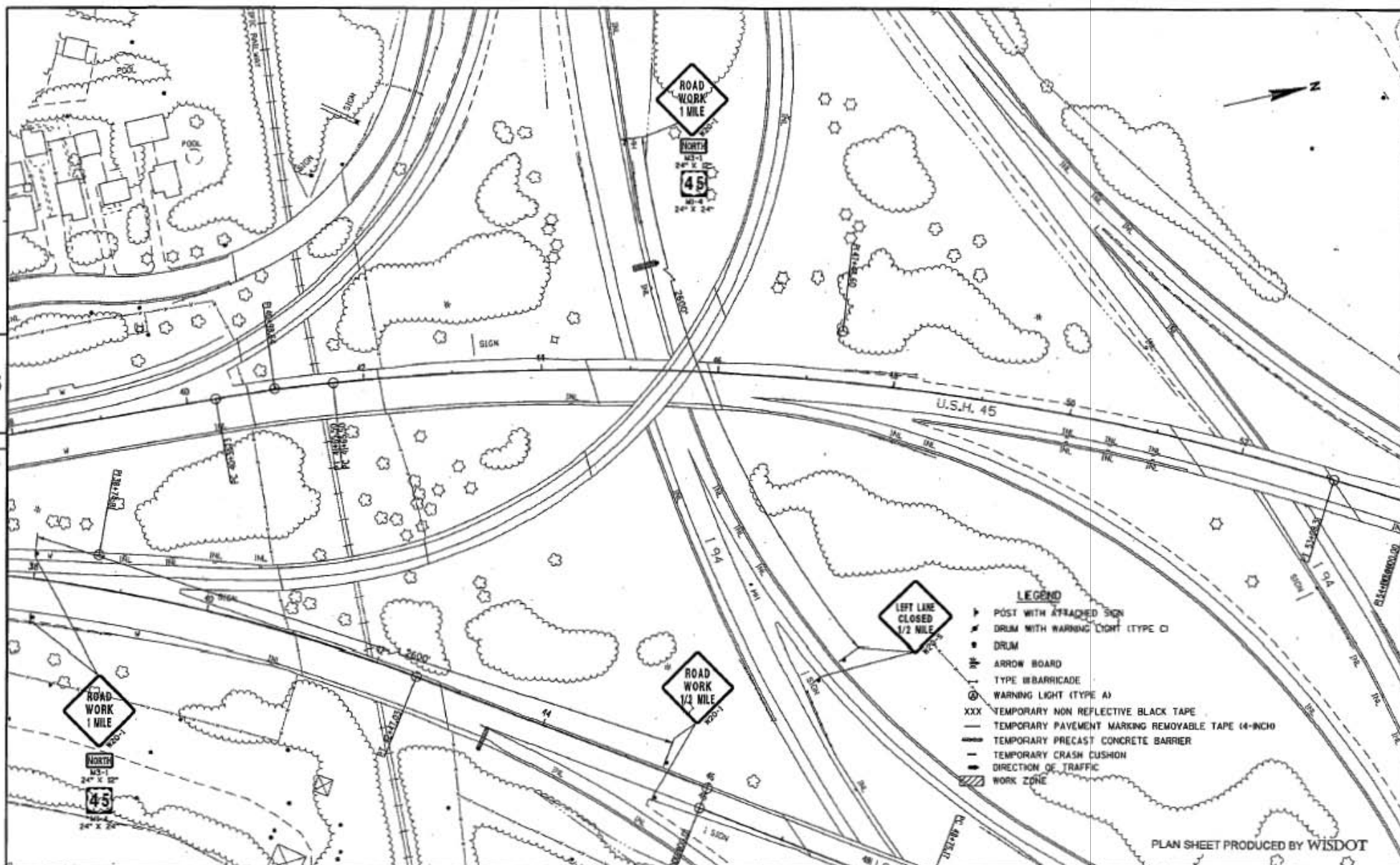
**Appendix H** contains the Work Zone traffic control plans that were implemented in the field during Work Zone 1 (**WZ1**) and Work Zone 2 (**WZ2**).

Aerial photos of the general locations of **WZ1** and **WZ2** are shown on pages **A3** and **A4**, respectively. Lane configuration schematics under **Normal**, **WZ1** and **WZ2** conditions can be found in **Appendix B**. Distances to crossing facilities, detector location names and distances can be found in **Figures C1** and **C2**.

A separate aerial photo file (**Corridor.pdf**) is provided and can be reviewed on a computer monitor, or printed in a plotter.

## IMPORTANT INFORMATION

- **Scale:** Stationing provided on the plans provides guidance for proper scaling.
- The term “**Stage 1**” mentioned in plan legends refers to Work Zone 1 (**WZ1**) located at the Wisconsin Avenue overpass; “**Stage 2**” refers to Work Zone 2 (**WZ2**), located on the South-to-North (**S-N**) two-lane structure.



PROJECT NO: I060-09-70

HWY: USH 45

COUNTY: MILWAUKEE

TRAFFIC CONTROL STAGE 1

SHEET

35

E

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PLOT DATE : 01-SEP-2005 08:13

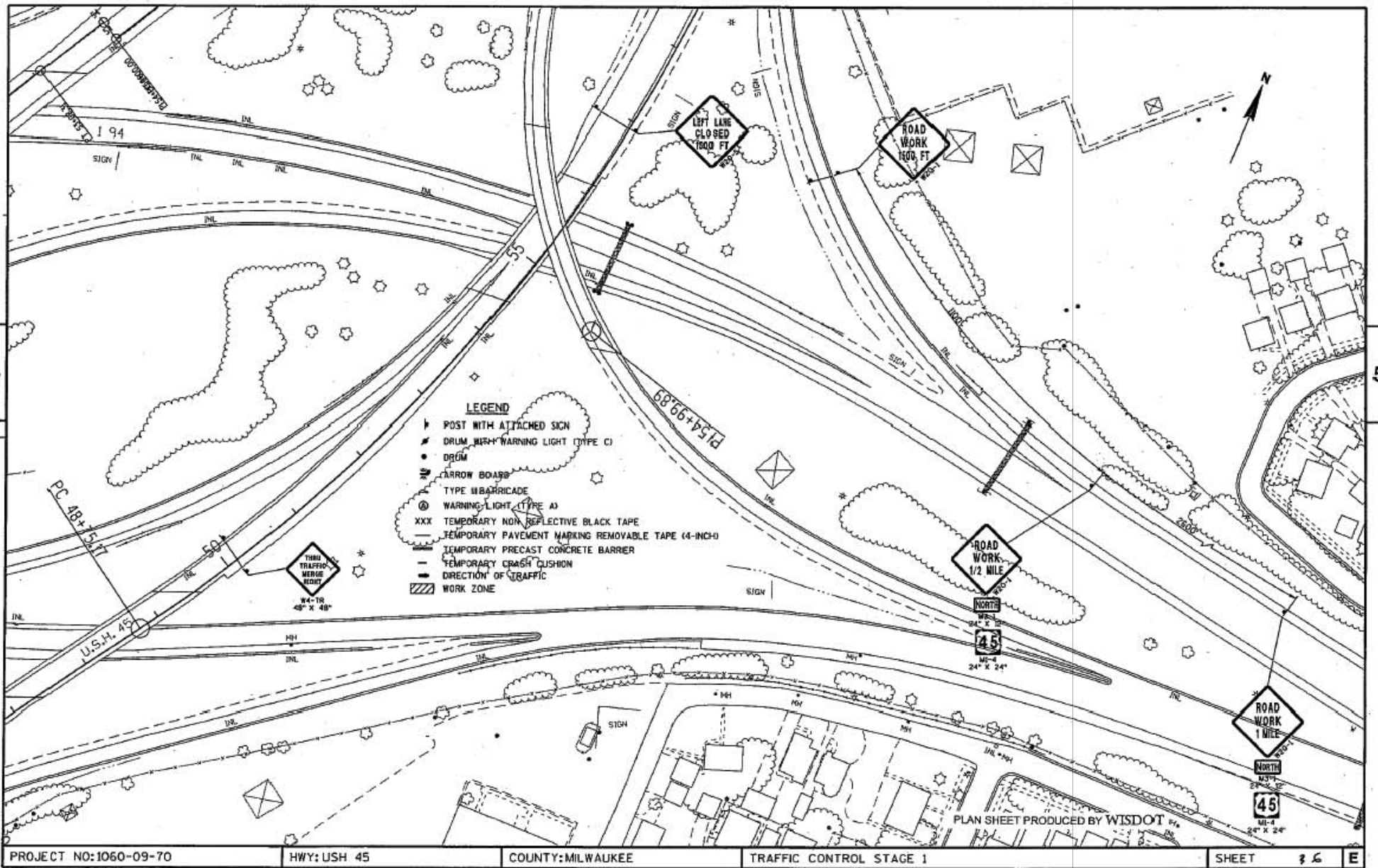
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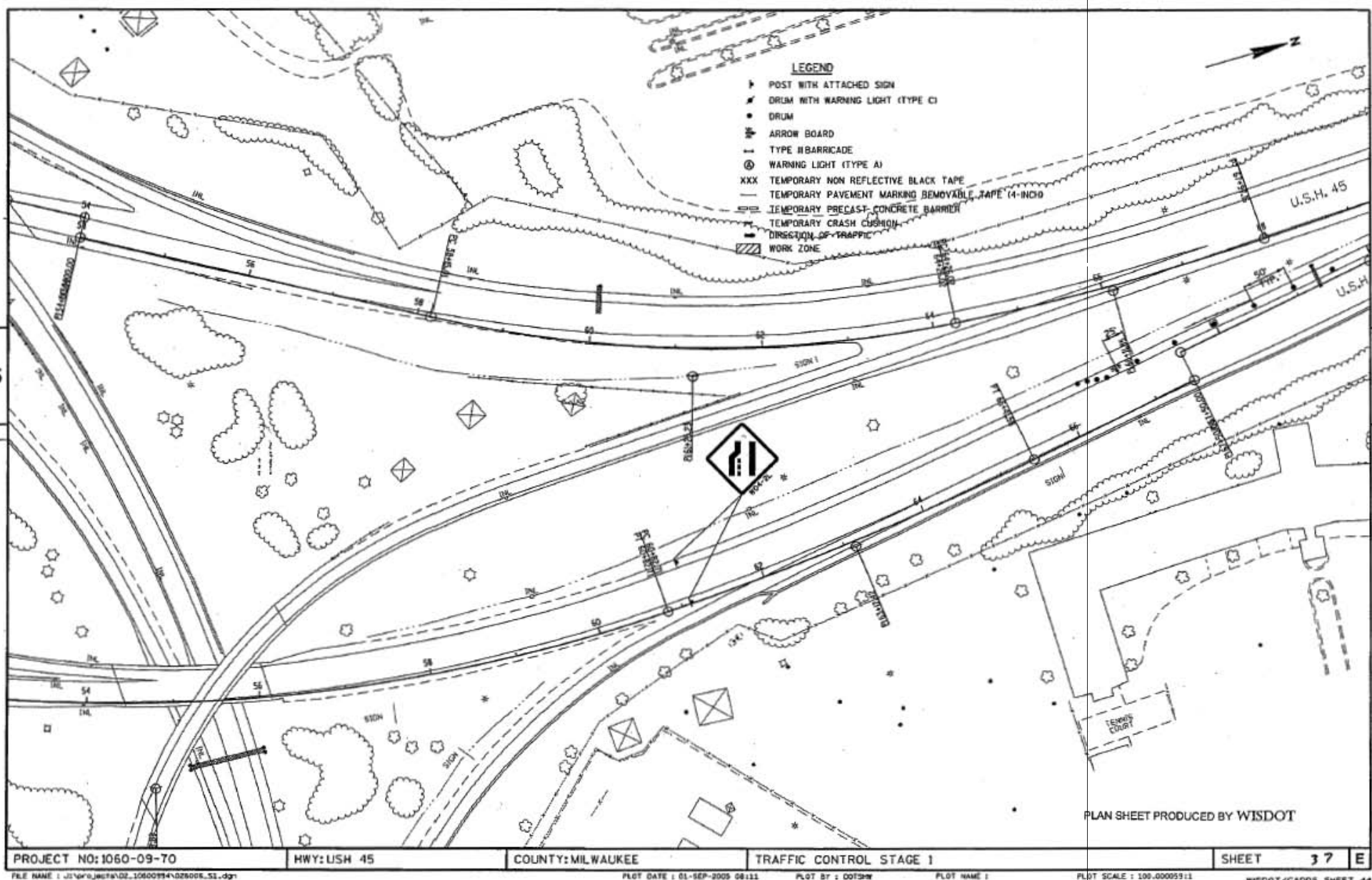
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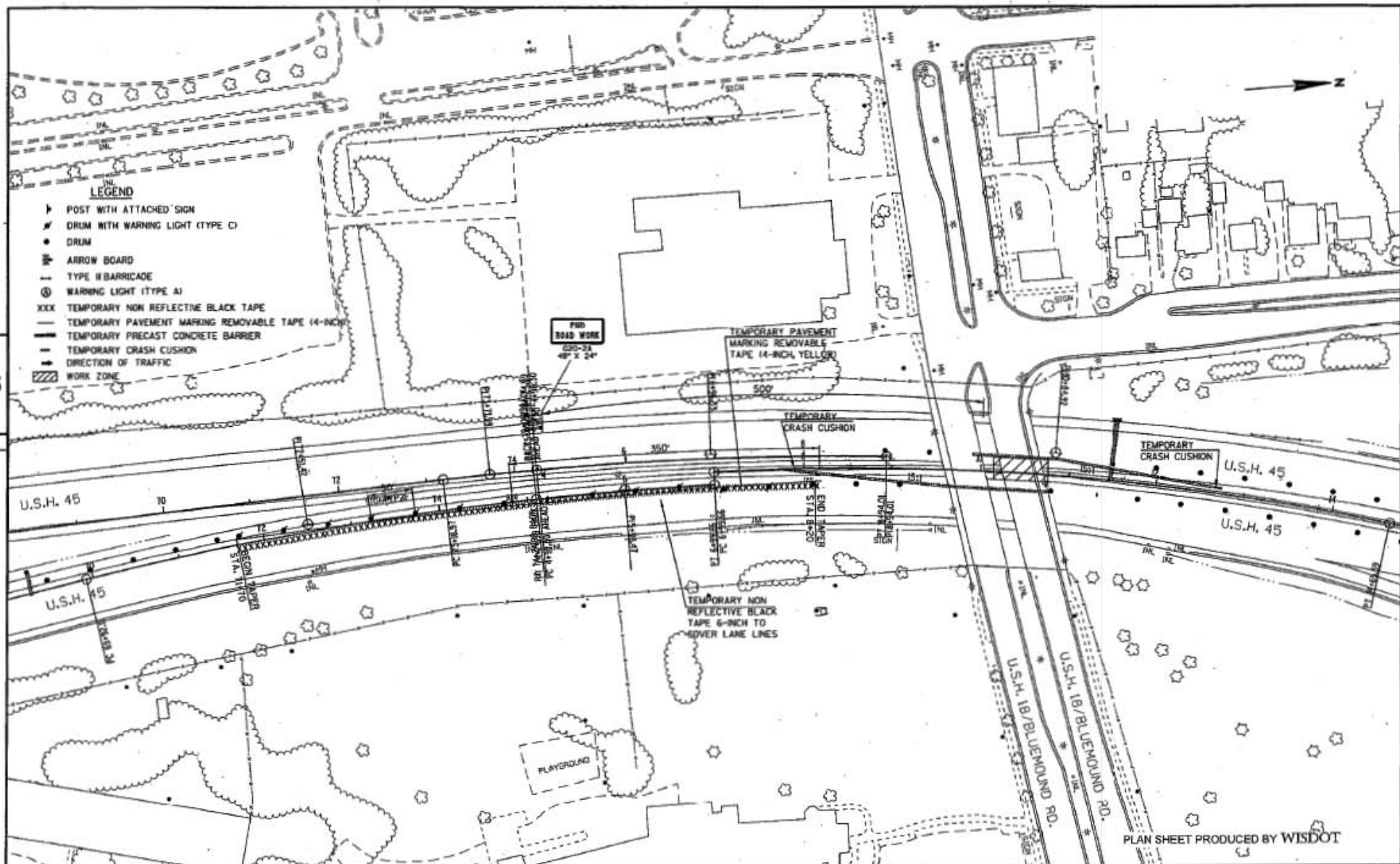
WISDOT/CADDs SHEET 44

H3



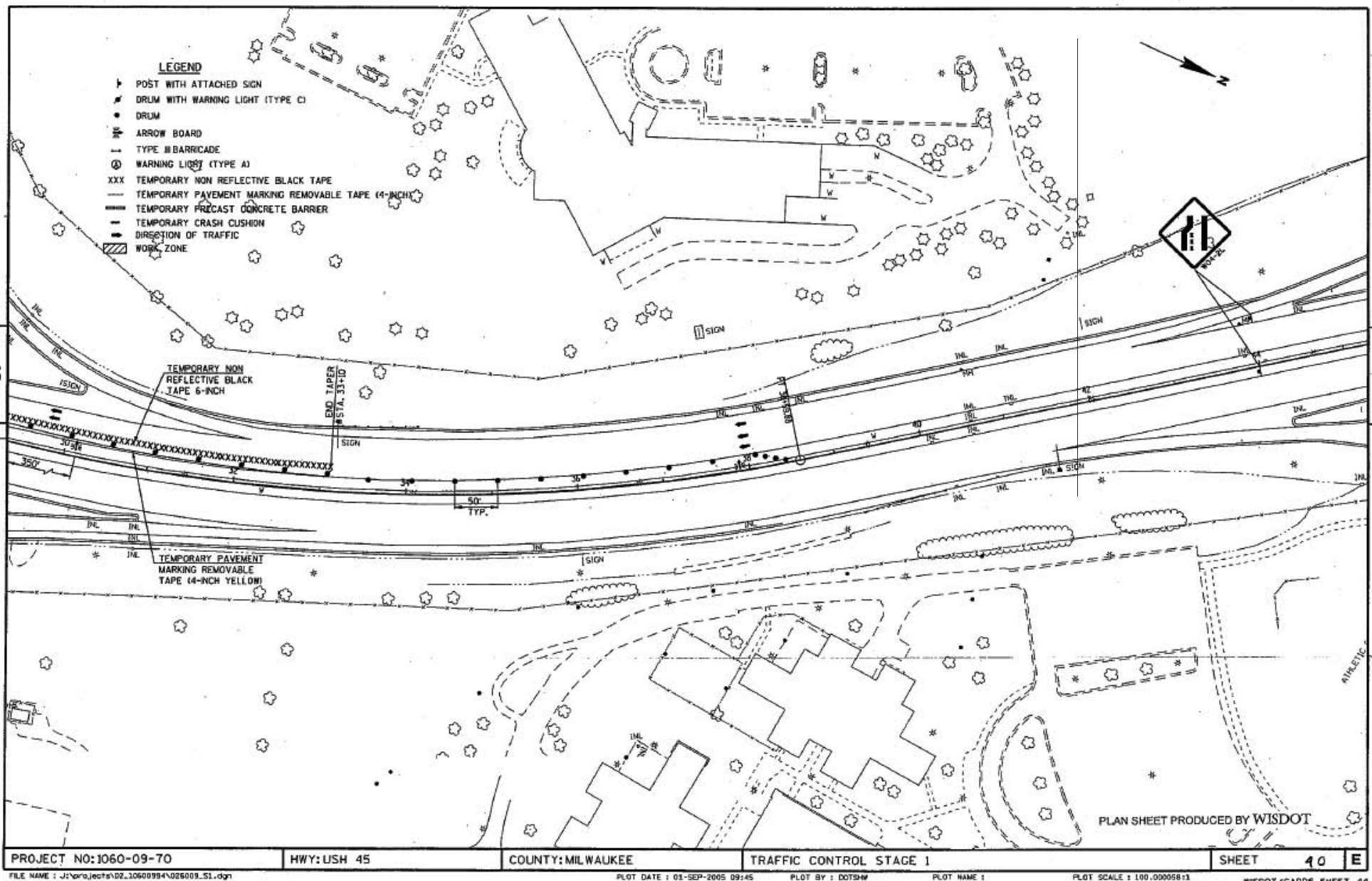


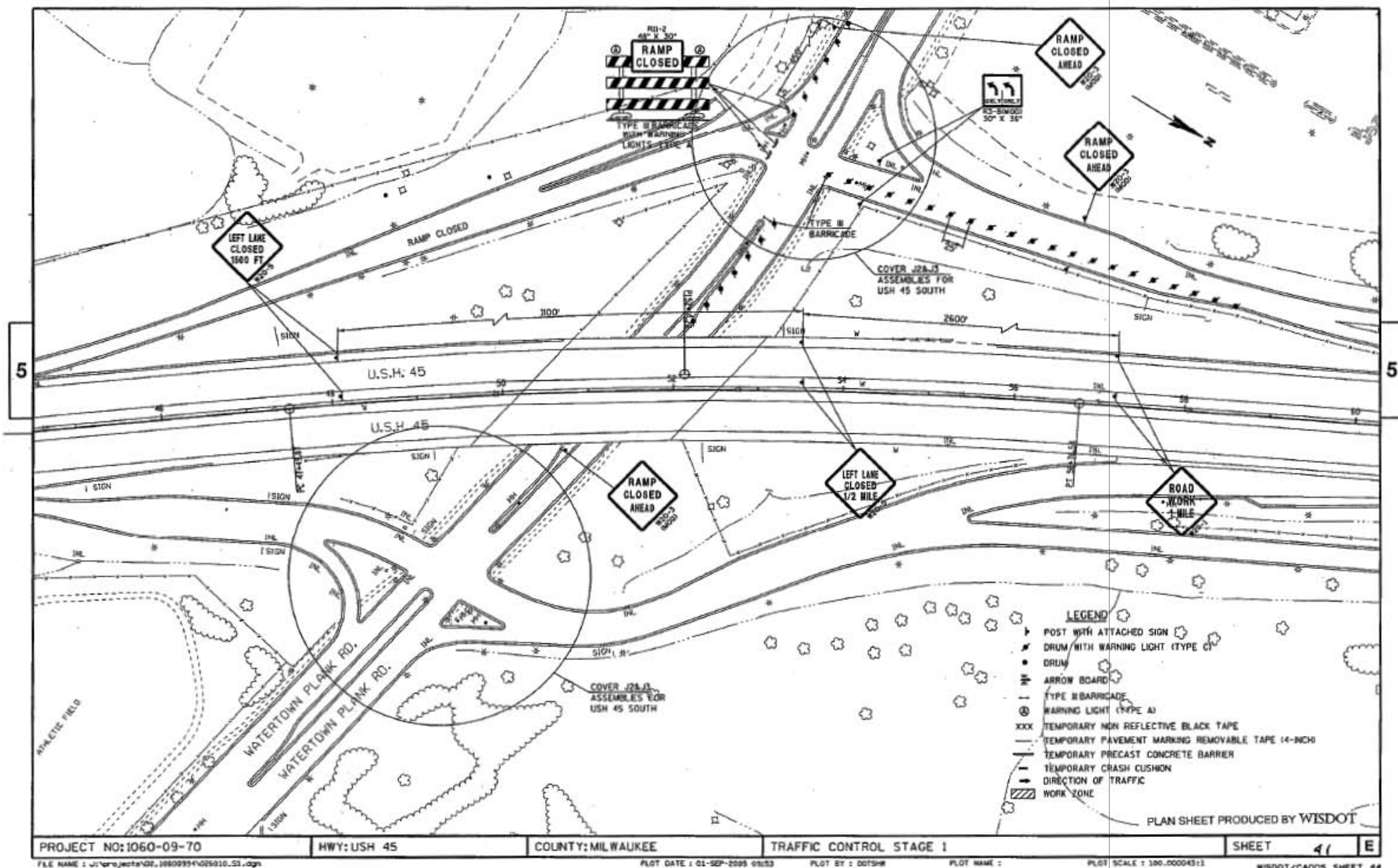
H5

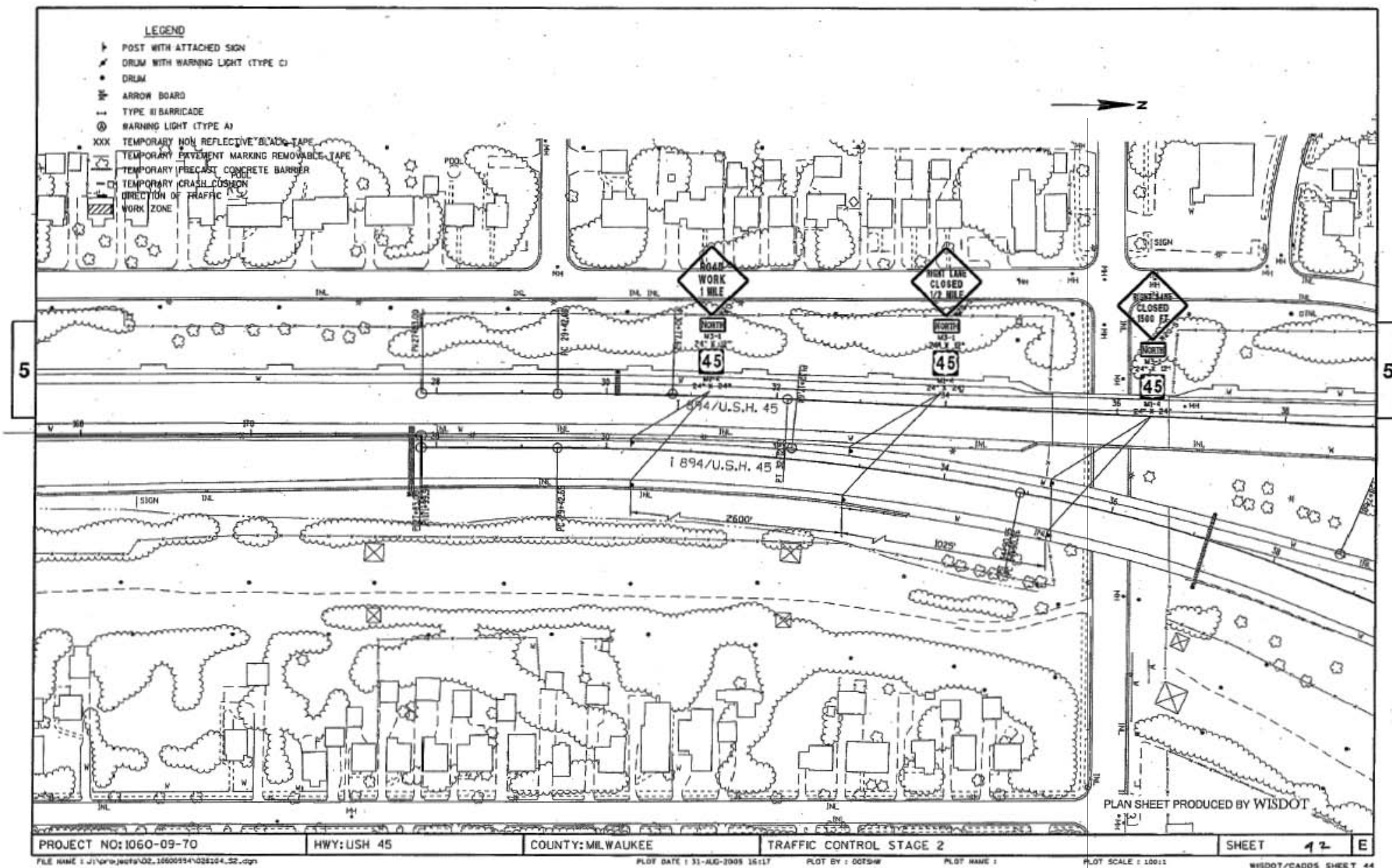


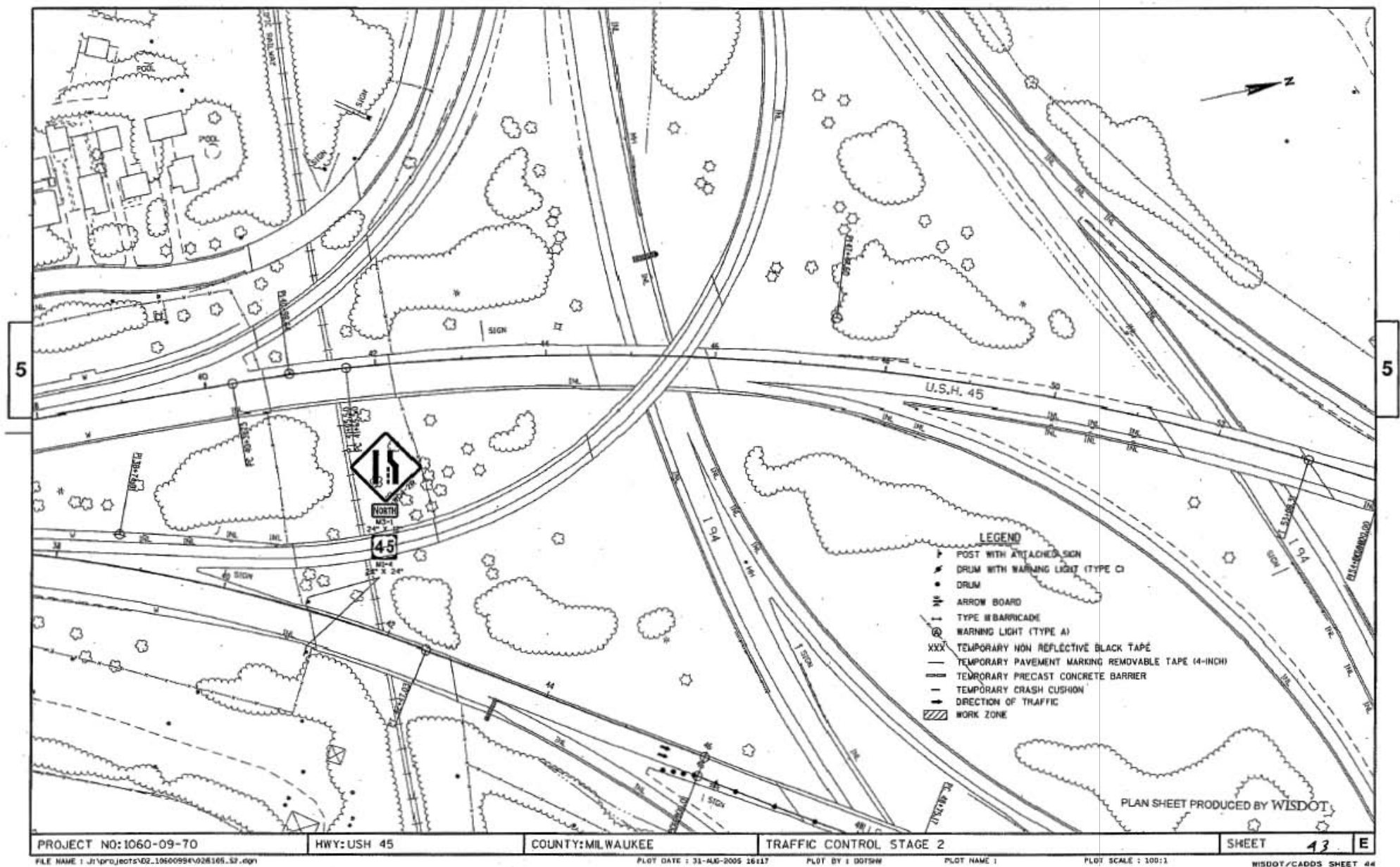






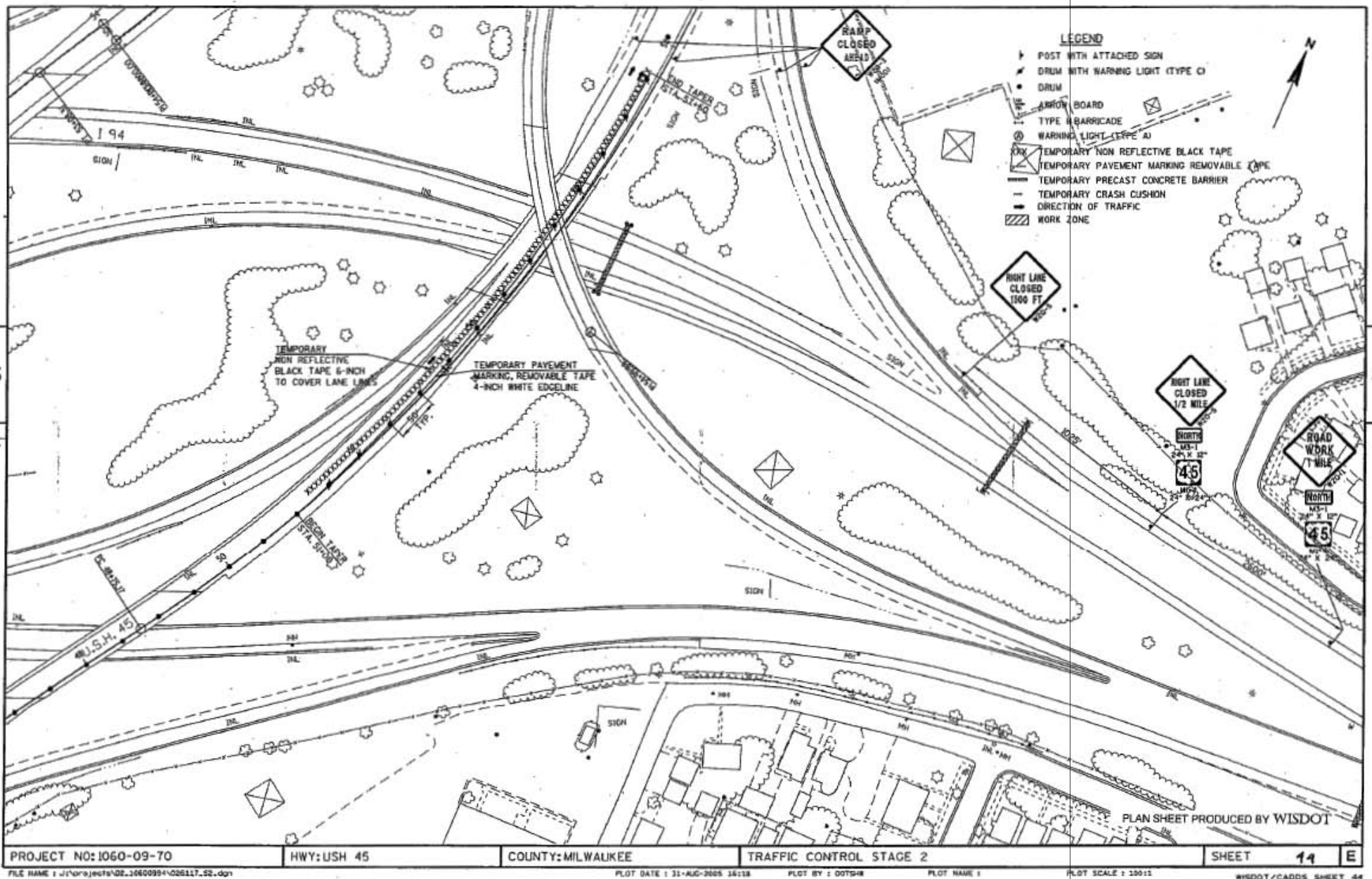




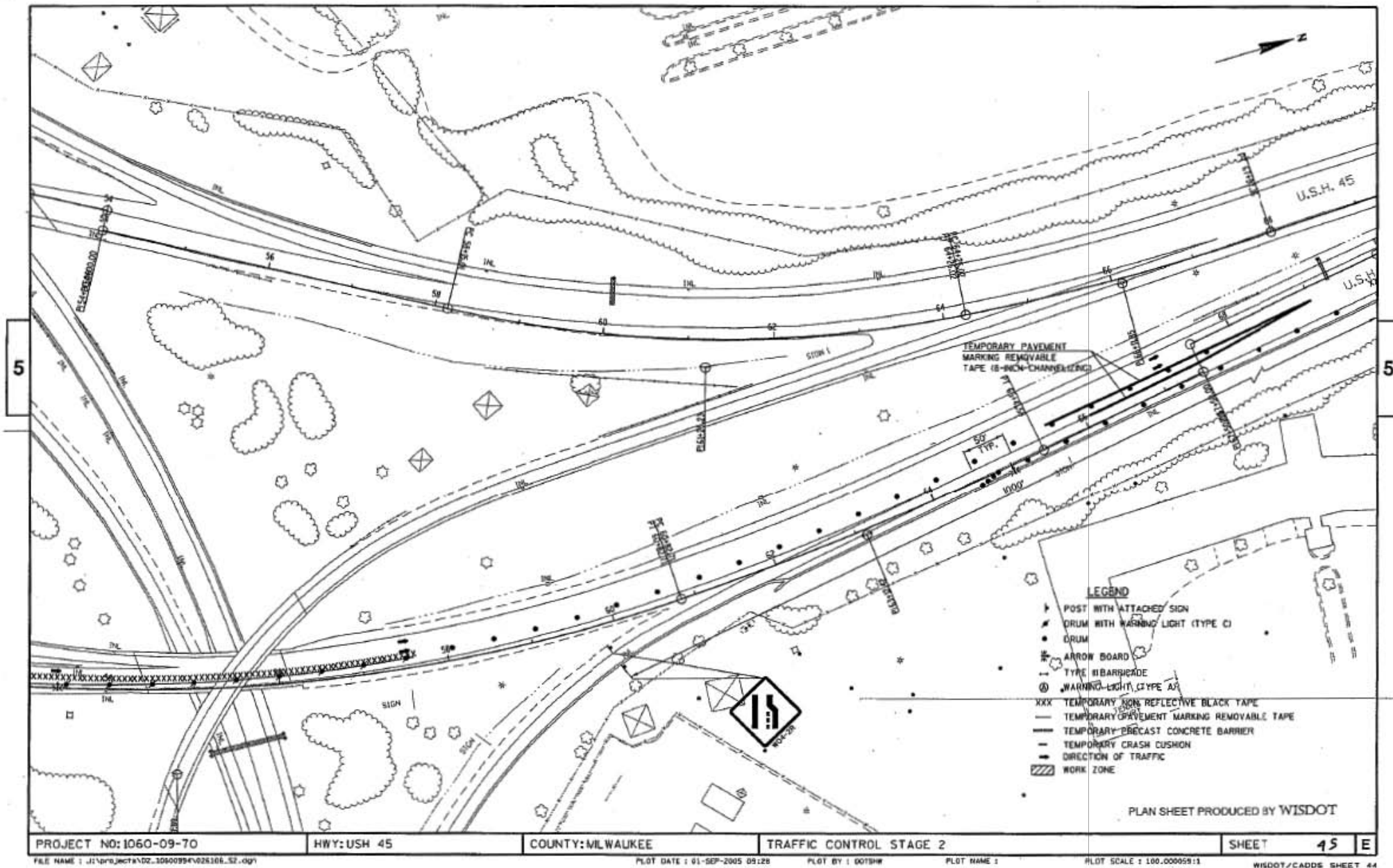


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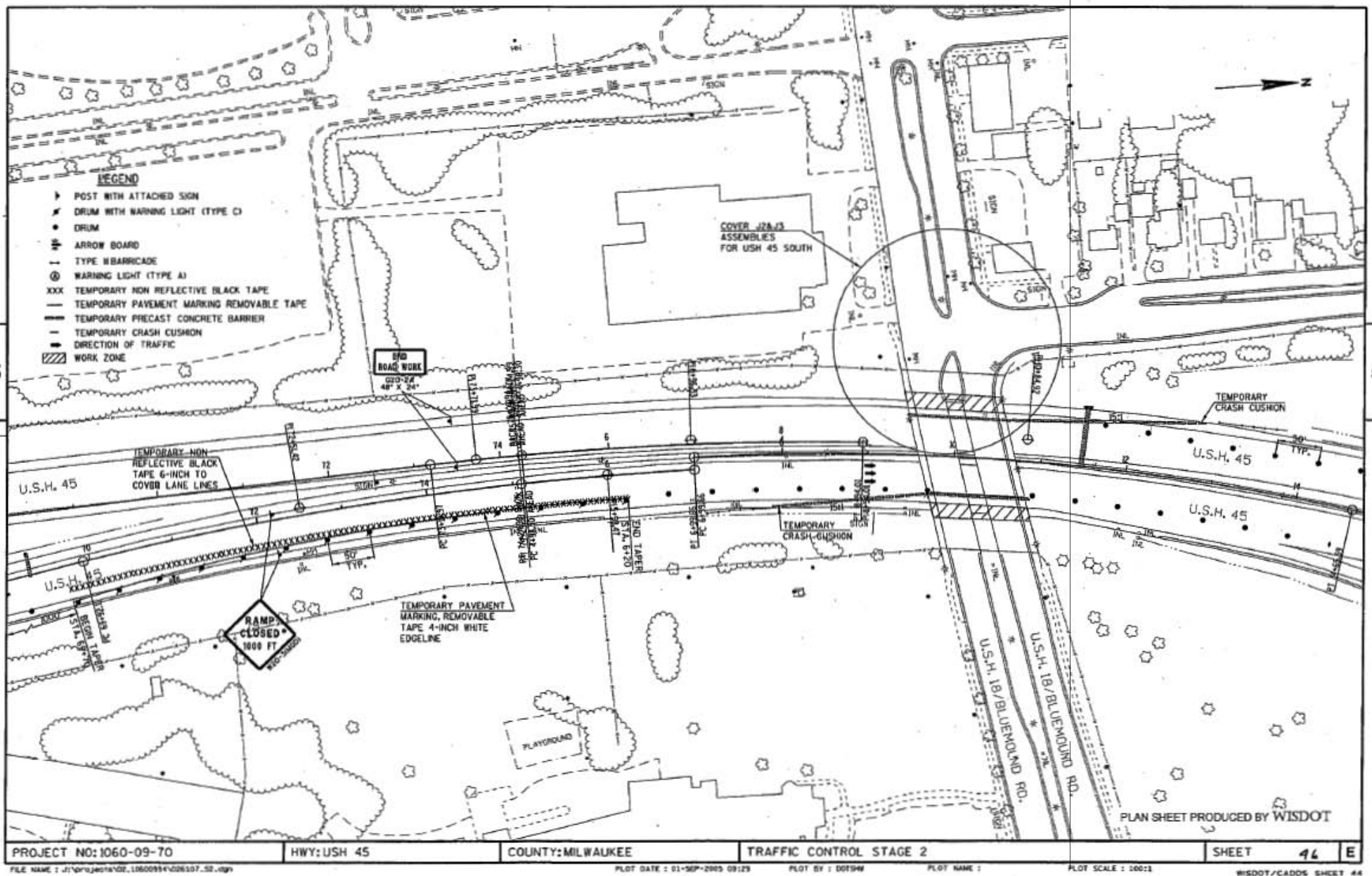




H12



H13



H14



