Evaluation of the TAPCO Sequential Dynamic Curve Warning System

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16. Abstract Implementing safety countermeasures on rural horizontal curves to address speeding can improve the safety performance for those locations. State safety and traffic engineers are faced with making decisions on what type of technology to use and which sites to use the technology on in a fiscally constrained environment. The research conducted for this project will evaluate a Sequential Dynamic Curve Warning System (SDCWS) that could be an additional tool for these engineers to use either separately or in combination with other countermeasures to address horizontal curve locations with a history of safety concerns.		
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SI* (MODERN METRIC) CONVERSION

FACTORS APPROXIMATE CONVERSIONS TO SI UNITS

SYMBOL	WHEN YOU KNOW	MULTIPLY BY	TO FIND	SYMBOL
		LENGTH		
in	inches	25.4	millimeters	mm
ft	feet	0.305	meters	m
yd	yards	0.914	meters	m
mi	miles	1.61	kilometers	km
		AREA		
in^2	square inches	645.2	square millimeters	mm^2
ft^2	square feet	0.093	square meters	m^2
yd^2	square yard	0.836	square meters	m^2
ac	acres	0.405	hectares	ha
mi^2	square miles	2.59	square kilometers	km^2
		VOLUME		
fl oz	fluid ounces	29.57	milliliters	mL
gal	gallons	3.785	liters	L
ft^3	cubic feet	0.028	cubic meters	m^3
yd^3	cubic yards	0.765	cubic meters	m^3
		NOTE: volumes greater than 1000 L shall be shown in m^3		
		MASS		
oz	ounces	28.35	grams	g
lb	pounds	0.454	kilograms	kg
T	short tons (2000 lb)	0.907	megagrams (or "metric ton")	Mg (or "t")
		TEMPERATURE (exact degrees)		
^oF	Fahrenheit	5 (F-32)/9 or (F-32)/1.8	Celsius	^oC
		ILLUMINATION		
fc	foot-candles	10.76	lux	lx
fl	foot-Lamberts	3.426	candela/m^2	cd/m^2
		FORCE and PRESSURE or STRESS		
lbf	poundforce	4.45	newtons	N
lbf/in^2	poundforce per square inch	6.89	kilopascals	kPa

APPROXIMATE CONVERSIONS FROM SI UNITS

SYMBOL	WHEN YOU KNOW	MULTIPLY BY	TO FIND	SYMBOL
		LENGTH		
mm	millimeters	0.039	inches	in
m	meters	3.28	feet	ft
m	meters	1.09	yards	yd
km	kilometers	0.621	miles	mi
		AREA		
mm^2	square millimeters	0.0016	square inches	in^2
m^2	square meters	10.764	square feet	ft^2
m^2	square meters	1.195	square yards	yd^2
ha	hectares	2.47	acres	ac
km^2	square kilometers	0.386	square miles	mi^2
		VOLUME		
mL	milliliters	0.034	fluid ounces	fl oz
L	liters	0.264	gallons	gal
m^3	cubic meters	35.314	cubic feet	ft^3
m^3	cubic meters	1.307	cubic yards	yd^3
		MASS		
g	grams	0.035	ounces	oz
kg	kilograms	2.202	pounds	lb
Mg (or "t")	megagrams (or "metric ton")	1.103	short tons (2000 lb)	T
		TEMPERATURE (exact degrees)		
^oC	Celsius	1.8C+32	Fahrenheit	^oF
		ILLUMINATION		
lx	lux	0.0929	foot-candles	fc
cd/m^2	candela/m^2	0.2919	foot-Lamberts	fl
		FORCE and PRESSURE or STRESS		
N	newtons	0.225	poundforce	lbf
kPa	kilopascals	0.145	poundforce per square inch	lbf/in^2

*SI is the symbol for the International System of Units. Appropriate rounding should be made to comply with Section 4 of ASTM E380.

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LIST OF ABBREVIATIONS AND ACRONYMS

AADT	Annual average daily traffic
Caltrans	California Department of Transportation
CC	Center of curve
DOT	Department of Transportation
DSFS	Dynamic speed feedback sign
FARS	Fatality Analysis Reporting System
GES	General Estimates System
HSIS	Highway Safety Information System
LIDAR	Light detection and ranging
MUTCD	Manual on Uniform Traffic Control Devices
PC	Point of curvature
SD	Standard deviation
SDCWS	Sequential Dynamic Curve Warning System
TE	True effect
vpd	Vehicles per day

INTRODUCTION

Horizontal curves make up a small percentage of total road miles, yet account for one-quarter of all highway fatalities. The majority of curve-related crashes are attributed to speeding and driver error and involve lane departures. There are a number of low-cost countermeasures traditionally used to help keep vehicles on the road and in their lane; however, the impacts of their application can be limited, which leads to the need for additional research and testing on more dynamic devices to assist traffic engineers in managing speed and safety across their diverse roadway network.

Project Scope

More than 25 percent of fatal crashes are associated with a horizontal curve, and the vast majority of these crashes involve a roadway departure. The average crash rate for horizontal curves is about three times that of other highways segments. About three-quarters of curve-related fatal crashes involve a single vehicle leaving the roadway and striking trees, utility poles, rocks, or other fixed objects, or overturning. The majority of these crashes are speed related.

Implementing safety countermeasures on rural horizontal curves to address speeding can improve the safety performance for those locations. State safety and traffic engineers are faced with making decisions on what type of technology to use and which sites to use the technology on in a fiscally constrained environment. The research conducted for this project will evaluate a Sequential Dynamic Curve Warning System (SDCWS) that could be an additional tool for these engineers to use either separately or in combination with other countermeasures to address horizontal curve locations with a history of safety concerns.

Project Objectives

The objective of this project is to test and evaluate the effectiveness of TAPCO's SDCWS in reducing vehicle speed as well as the frequency and severity of speed-related crashes on horizontal curves on rural roadways. With 12 treatment sites and 24 control sites having been identified in Missouri, Texas, Washington, and Wisconsin, speed data will be collected before and immediately after the installation, as well as at 12 and 18 months post installation.

Report Overview

The information in this interim report includes a summary of the literature on speed-activated display practices, details on the locations of existing treatments, site selection methodology, a list of potential and final new treatment sites, the type and amount of data to be collected, data collection procedures and equipment, and the schedule for analyses to be performed. The report also includes a summary of baseline data including roadway, traffic, and crash data and data analysis and results from the 1-month post installation data collection effort. Guidelines and recommendations for implementing SDCWS displays for curves will be included in the final report.

LITERATURE REVIEW

This section discusses the relationship between roadway geometry, vehicle speeds, and crashes on horizontal curves and reviews the effectiveness of various applications of Dynamic Speed Feedback Sign (DSFS) systems installed to date. This research effort will test the effectiveness of the SDCWS and its impact on safety. Even though several dynamic curve sign systems have been tested in the past, this system is unique in terms of including guidance not just before or at the curve, but also throughout the curve with the blinking chevrons. The results from this research will add to the body of knowledge and provide safety engineers with another tool to address curve crashes.

Relationship between Curve Crash Rate and Geometry

Curves have about three times the crash rate of tangent sections.[(1)] Preston and Schoenecker reported that 25 to 50 percent of the severe road departure crashes in Minnesota occurred on curves, even though curves account for only 10 percent of the total system mileage.[(2)] Shankar et al. evaluated divided State highways without median barriers in Washington State and found a relationship between the number of horizontal curves per kilometer and median crossover crashes.[(3)] Farmer and Lund evaluated single-vehicle fatal and injury rollover crashes using Fatality Analysis Reporting System (FARS) data and data from Florida, Pennsylvania, and Texas.[(4)] Using logistic regression, they found that the odds of having a rollover on a curved section were 1.42 to 2.15 times the odds of having a rollover on a straight section.

The majority of crashes on curves involve lane departures. A total of 76 percent of curve-related fatal crashes are single vehicles leaving the roadway and striking a fixed object or overturning. Another 11 percent of curve-related crashes are head-on collisions.[(5)]

The frequency and severity of curve-related crashes have been correlated to a number of geometric factors, including radius, degree of curve, length of curve, type of curve transition, lane and shoulder widths, preceding tangent length, and required speed reduction.

Luediger et al. found that crash rates increase as the degree of curve increases, even when traffic warning devices are used to warn drivers of the curve.[(6)] Miaou and Lum found that truck crash involvement increases as horizontal curvature increases, depending on the length of curve.[(7)] Council found that the presence of spirals on horizontal curves reduced crash probability on level terrain but did not find the same effect for hilly or mountainous terrain.[(8)] Vogt and Bared evaluated two-lane rural road segments in Minnesota and Washington State using Highway Safety Information System (HSIS) data and found a positive correlation between injury crashes and degree of horizontal curve.[(9)]

Zegeer et al. evaluated curves on two-lane roads in Washington State using a linear regression model.[(10)] The researchers found that the degree of curve was positively correlated with crashes, while total surface width and presence of spirals were negatively correlated. They also evaluated 10,900 horizontal curves on two-lane roads in Washington State using a weighted linear regression model and found that crash likelihood increases as the degree and length of curve increases.[(10)] Mohamedshah et al., however, found a negative correlation between crashes and degree of curve for two-lane roadways.[(11)]

Preston and Schoenecker examined severe roadway departure crashes and found that 90 percent of fatal crashes and 75 percent of injury crashes occurred on curves with a radius of less than 1,500 ft.(2) Milton and Mannering evaluated 2,725 miles of highway in Washington State using a negative binomial model and reported that an increase in radius was associated with decreases in crash frequency.(12) They also found that a shorter tangent length between horizontal curves was associated with decreases in crash frequency. They speculated that drivers may be traveling at lower speeds and are therefore more likely to be paying attention when tangent lengths between curves are short.

In contrast, Deng et al. evaluated head-on crashes on 729 segments of two-lane roads in Connecticut using an ordered probit model.(13) They included geometric characteristics in the analysis but did not find that the presence of horizontal or vertical curves was significant.

Taylor et al. evaluated the relationship between speed and crashes on rural single-carriageway roads in England.(14) The authors collected data from 174 road sections with 60 mph speed limits with a wide range of conditions. Data collected included injury crash data, traffic volume, speed data, and roadway geometry. Speed and flow were measured at each site for 1 or 2 days, and various speed metrics were calculated, including mean speed, 85th percentile speed, and standard deviation of speed. The authors found that crashes were more highly correlated with mean speed than any other speed metric. They also found that crash frequency increased with mean speed. In general, a 10 percent increase in mean speed resulted in a 26 percent increase in the frequency of injury crashes.

More recently, Khan et al. analyzed curves in Wisconsin to determine the relationship between safety, horizontal curve signs, and geometry.(15) Compared to previous research, a larger data set with greater detail was used to develop a model showing the relationship of the horizontal curves. The data showed that crashes increased with an increase in annual average daily traffic (AADT), posted speed, and curve length; they also increased with a decrease in curve radius. In addition, an analysis of traffic control signs indicated that sites with curve signs (W1-2) had fewer crashes than sites with turn signs (W1-1). Sharper curves, however, showed no significant correlation to sign type in reducing crashes because of other, more substantial influencing factors.

Relationship between Curve Crash Rate and Speed of Curve Negotiation

Although curve-related crashes are correlated to geometric factors, driver factors such as speed selection also contribute to curve-crash frequency and outcome. Driver factors include driver workload, driver expectancy, and speed selection.

Speeding, defined by FHWA as "exceeding the posted speed limit or driving too fast for conditions," is generally problematic. Council et al. evaluated FARS, General Estimates System (GES), and HSIS data to assess the impact of speeding on fatal crashes.(16) Using 2005 FARS data, they found that 29.5 percent of fatal crashes were speed-related. They conducted several different types of analyses and found the single-vehicle run-off-road crashes are more likely to be speed-related than are multi-vehicle crashes. Crashes on curves were more likely to be speed-related as compared to tangent sections and nighttime crashes. Additionally, FARS data indicated that 54 percent of speed-related rollover/overturn, jackknife, or fixed object crashes were on curves.(16)

FHWA estimates that approximately 56 percent of run-off-road fatal crashes on curves are speed-related.[6] The vehicle speed reduction from the tangent section required for traversing a curve has an impact on the frequency and severity of crashes in curves. Abrupt changes in operating speed resulting from changes in horizontal alignment are suggested to be a major cause of crashes on rural two-lane roadways.[6]

Anderson and Krammes developed a model comparing mean speed reduction and mean crash rate for 1,126 horizontal curves on rural two-lane roadways.[17] They reported that the relationship between mean crash rate and required speed reduction to negotiate the curve is roughly linear. This finding is also supported by Fink and Krammes, who indicated that curves requiring no speed reduction did not have significantly different mean crash rates than their preceding roadway tangent.[18]

Driver errors on horizontal curves are often due to the inappropriate selection of speed and the inability to maintain lane position. Drivers' speed selection at curves depends on both explicit attentional cues and implicit perceptual cues.[19] A driver's speed prior to entering a curve has a significant effect on his or her ability to negotiate the curve successfully.[2] Inappropriate speed selection and lane positioning can be a result of a driver failing to notice an upcoming curve or misperceiving the roadway curvature.

Driver workload plays an important role in driver speed maintenance. Distracting tasks such as radio-tuning or cell phone conversations can draw a driver's attention away from speed monitoring, detection of headway changes, lane keeping, and detection of potential hazards.[19] Other factors include sight distance issues, fatigue, or complexity of the driving situation.[19,20]

Preston and Shoenecker evaluated vehicle paths through a curve on a two-lane rural roadway as part of an evaluation of a dynamic curve message sign.[2] The roadway had a posted speed limit of 55 mph and AADT of 3,250 vehicles per day (vpd). The researchers collected data over a 4-day period and randomly selected and evaluated 589 vehicles. A total of 340 of the vehicles (58 percent) were traveling over 55 mph, and the rest were traveling at or below the speed limit. The authors evaluated whether each vehicle successfully negotiated the curve. Vehicles that crossed a left or right lane line on one or more occasions were defined as "not successfully navigating the curve."

A logistic regression model was developed to determine the relationship between initial speed and the probability of a vehicle unsuccessfully navigating the curve. The researchers found that there was a 20 percent better chance for vehicles that were traveling at or below the speed limit to successfully navigate the curve than for vehicles that were traveling over the speed limit, with the difference being statistically significant at 99 percent. They found that 45 percent of vehicles traveling at or above 65 mph were unable to negotiate the curve compared to 30 percent for vehicles that were traveling under 65 mph, with the difference being statistically significant at the 90 percent confidence interval.

Hassan and Easa found that driver misperception of curvature was greatest when vertical curvature was combined with horizontal curvature.[21] This was particularly a problem when a crest vertical curve was superimposed on a severe horizontal curve, or when a sag vertical curve was combined with a horizontal curve, causing the horizontal curve to appear less severe and resulting in drivers underestimating the curve.

Charlton conducted a simulator study and evaluated driver speed adjustments on several types of curves with several types of signing.[20] Charlton found that, in general, drivers approached and entered curves at higher speeds when engaged in cell phone tasks than when in non-distraction scenarios.

Effectiveness of DSFS Systems

DSFS systems have been used in only a few cases to reduce speeds and warn drivers of upcoming curves. They have been used more extensively for a number of other related applications. A summary of information about the application of DSFS on curves and in related situations is provided below.

Bertini et al. studied the effectiveness of a DSFS system on Interstate 5 near Myrtle Creek, Oregon.[22] The system consisted of two displays that provided different messages to drivers based on the speed detected, as shown in table 1.

Table 1. Advisory message for Interstate 5 dynamic speed-activated feedback sign system.

Sign Panel	Sign Messages		
	Detected Vehicle Speeds Less than 50 mph	Detected Vehicle Speeds 50–70 mph	Detected Vehicle Speeds over 70 mph
1	CAUTION	SLOW DOWN	SLOW DOWN
2	SHARP CURVES AHEAD	YOUR SPEED IS XX MPH	YOUR SPEED IS OVER 70 MPH

The curve has an advisory speed of 45 mph with an AADT of 16,750 vpd. Before the DSFS system was in place, there was what the authors termed “dual overhead horizontal alignment/advisory speed combination sign assemblies with 4 flashing beacons.” The DSFS system was put in place alongside one of the existing signs in both the northbound and southbound directions. Each system consisted of the actual dynamic message sign, a radar unit, a controller unit, and computer software. Figures 1 and 2 show the system.

The researchers collected speed data using a laser gun. Results indicated that, after installation of the DSFS system, passenger vehicle speeds were reduced by 2.6 mph and commercial truck speeds were reduced by 1.9 mph, with the results being statistically significant at the 95 percent confidence level. The distribution of speeds shifted to the left after installation of the signs, and the differences were found to be statistically significant based on a 95 percent confidence level using the chi-square test.

Results of a driver survey indicated that 95 percent of drivers surveyed noticed the DSFS system, and 76 percent said they slowed down due to the system.

Figure 1. Photo. Northbound Interstate 5 DSFS systems in Oregon.[22]

Figure 2. Photo. Southbound Interstate 5 DSFS systems in Oregon.[22]

Another type of DSFS system, a vehicle-activated curve warning sign, was tested on curves in the United Kingdom.[23] Three curve warning signs were placed on two-lane roads in Norfolk, Wiltshire, and West Sussex. The signs, shown in figure 3, were placed 165 to 330 feet before the apex of a curve.

Figure 3. Photo. DSFS system in Norfolk.(23)

The signs were blank when the driver was under a specified speed threshold and displayed the curve sign when a driver exceeded the threshold. The speed threshold was set at the 50th percentile speed for the sign location because the researchers wanted to target the upper half of driver speeds. Once activated, the bend warning display was shown for 4 seconds. Based on previous research, the researchers had calculated this time as being sufficient for drivers to register and understand the message.

Speed data were collected for a minimum of 7 days before the signs were installed, and again 1 month and 1 year after installation. Data were collected at the 1-year period to determine if habituation occurs—in other words, whether drivers become immune to treatments and stop responding. Data were collected using pneumatic tubes at two sites and a radar gun at the third. Mean speeds were reduced by 2.1 mph at West Sussex, 3.0 mph at Wiltshire, and 6.9 mph at Norfolk.

Crash data were available for two sites, and the researchers found that crashes decreased 54 percent at the Norfolk bend site and 100 percent at the Wiltshire bend site. A public survey found that drivers approved of the signs.

The City of Bellevue Washington installed and evaluated 31 DSFS systems, including two used as curve advisory warnings (see figure 4). Both were on urban arterials with 35 mph speed limits and 25 mph advisory speeds. Speeds were collected before and between 18 months and 2 years after installation of the signs. One sign showed a 3.3 mph reduction in 85th percentile speed and the other showed a 3.5 mph reduction.

Figure 4. Photo. DSFS system in Bellevue, Washington.[24]

Preston and Shoenecker also evaluated the safety effect of a DSFS system on County Highway 54 in Minnesota, which is a two-lane rural roadway with a speed limit of 55 mph and an AADT of 3,250 vpd.[2] The curve has an advisory speed of 40 mph. The DSFS system had a changeable message sign and radar unit. A field test was conducted over a 4-day period with a unit that consisted of a closed circuit TV camera, a VCR, and a personal computer. A portable trailer housed the entire system.

The sign displayed the following:

- From 6 a.m. to 10 a.m., 11 a.m. to 2 p.m., and 4 to 7 p.m.: CURVE AHEAD.
- No message during other times of the day unless activated.

During all times of the day, when the radar unit detected a vehicle traveling 53 or more mph, the camera would activate and record the vehicle for 18 seconds. Using a random number generator and depending on the time of day, the computer would either continue displaying the CURVE AHEAD message, display the CURVE AHEAD – REDUCE SPEED message, or display no message.

The team randomly selected 589 of the vehicles captured during data collection and evaluated whether each vehicle successfully negotiated the curve. Successful negotiation was defined as a vehicle remaining within the lane lines as it traversed the curve. Vehicles that crossed a left or right lane line on one or more occasions were defined as "not successfully navigating the curve."

The team found that approximately 35 percent of the drivers who received the message were unable to successfully negotiate the curve. Vehicles that received the CURVE AHEAD sign were more likely to negotiate the curve successfully, but the difference was not statistically significant. Only 26 percent of vehicles that received the CURVE AHEAD – REDUCE SPEED sign were unable to negotiate the curve successfully, and the difference was statistically significant at the 90 percent level of confidence.

Mattox et al. looked at the effectiveness of a DSFS system on secondary highways in South Carolina.[25] This system consisted of a radar device and a 4-ft by 4-ft yellow sign with 6-inch lettering reading YOU ARE SPEEDING IF FLASHING. In addition, there were two 1-ft by 1-ft orange flags and a type B flashing beacon light. Teams collected data in a before-and-after study upstream of the sign, at the sign, and then downstream of the sign. Results showed a significant reduction in speed at the sign and downstream of the sign. Overall mean speed and 85th percentile speeds were reduced by approximately 3 mph.

A report by the California Department of Transportation (Caltrans) provided a summary of the effectiveness of safety treatments in one California district.[26] A changeable message sign was installed at five locations along Interstate 5 to reduce truck collisions. Caltrans reported that truck crashes decreased from 71 percent to 91 percent at four of the sites, while truck crashes increased by 140 percent at one site.

A study by the 3M Company evaluated driver speed feedback signs, which display the approaching drivers' speeds, in the United Kingdom. Signs were tested at various locations in Doncaster, including semi-rural roadways. The sites had speed limits of 40 mph, and reductions up to 7 mph in 85th percentile speeds were noted.[27]

Tribbett et al. evaluated dynamic curve warning systems for advance notification of alignment changes and speed advisories at five sites in the Sacramento River Canyon on Interstate 5.[28] The roadway has high traffic volumes (7,650 to 9,300 vpd), mountainous terrain, and a number of heavy vehicle crashes. The signs were a 10-ft by 7-ft full matrix LED panel that could be programmed to display a variety of messages. Messages used by the researchers included curve warning (shown in figure 5) and driver speed feedback.

Figure 5. Photo. Speed warning sign in the Sacramento River Canyon.[26]

The researchers collected speed data using stopwatches. Data were collected before installation of the signs and at several points after the signs were installed; the researchers did not indicate when these after periods were, however. Speed results at the point of curvature (PC) include the following:

- Site 1: statistically significant decreases in mean truck speeds from 2.4 to 5.4 mph and decreases in mean passenger car speeds from 3.0 to 4.5 mph.
- Site 2: no statistically significant changes in truck or passenger car speeds for any time

periods.

- Site 3: statistically significant decreases in mean truck speeds from 1.9 to 3.7 mph and increases in passenger cars from 5.2 to 7.8 mph.
- Site 4: no statistically significant change in mean truck speed and a 1.4 mph decrease for passenger cars for one time period that was statistically significant.
- Site 5: a statistically significant change in mean truck speed of 4.5 for one time period and decrease in mean passenger car speeds from 2 to 3 mph.

The researchers also compared 5 years of crash data before installation of the signs and 6 months after. However, due to the very short after period, the results were determined to be unreliable.

The Texas Transportation Institute evaluated the use of a portable speed display trailer in work zones.(29) They found that passenger vehicle speeds were reduced by 7 to 9 mph at one site and 2 to 3 mph at another. Truck speeds were reduced 3 to 10 mph at both sites.

Hallmark et al. also analyzed the installation of DSFS on curves throughout the country to determine the safety benefits.(30) Seven States participated, installing curve warning signs as well as speed feedback signs, which can be seen in figure 6. For the analysis, the mean speed, 85th percentile speed, and the percentage of vehicles going over the speed limit were compared.

Figure 6. Photo. Comparison of curve warning sign (left) and speed feedback sign (right).(30)

The average for all of the sites showed a 1.8 mph reduction in mean speed at 1 month, a 2.6 mph reduction in mean speed at 1 year, and a 2.0 mph reduction in speed at 2 years; all of these reductions occurred at the PC. The 85th percentile speed at the PC was reduced by 2.2 mph at both the 1-month and 2-year data collection period and was reduced by 2.9 mph at the 1-year data collection period. Similar decreases were seen in the percentage of vehicles going over the speed limit. The mean speed and 85th percentile speed were also lower at the center of curve, with the largest speed reductions occurring at the 1-month data collection period.

Between the two types of signs, larger decreases were seen with the speed feedback signs than with the curve warning signs. The signs were proven to be effective over time as well. A crash analysis was also performed for the direction of travel for the DSFS and for both directions combined. The analysis showed that, compared to control sites, crashes were reduced 2 to 4 times more for both directions and in the direction of travel by 1.7 to 6.0 times per quarter. Crash modification factors developed using a full Bayes model were .85 for both directions and .97 for the direction of the DSFS.

Sun et al. researched the effectiveness of sequential warning lights as a method to better define the beginning and taper into nighttime work zones.[31] The sequential lights were evaluated in Missouri along Interstate 70 with a right lane closure. Vehicle speeds at the closure were compared in addition to speeds at the point where the vehicle merged and at the lateral position in the taper. Decreases were seen in the mean speed of 2.2 mph and by 1 mph in the 85th percentile speeds, both of which were statistically significant. The lateral position of vehicles in the closed lane increased from 6.2 percent without sequential lights to 7.8 percent with sequential lights. The sequential lights had a negative effect, which could be due to drivers being more aggressive because the taper is illuminated better. The location where vehicles merged was split into eight zones with zone 8 being the zone closest to the taper. With the sequential lights, the total vehicles merging in zones 5 through 7 decreased while the vehicles merging in zones 1 through 4 increased. The exception that occurred was an increase in vehicles merging in zone 8, which further supports the aggressive driver assumption given the lateral position of the driver. Overall, vehicles were merging 20 ft earlier with the sequential lights.

Santiago-Chaparro et al. evaluated the spatial effectiveness of speed feedback signs at a single location along State Highway 164 in Wisconsin.[32] Vehicles were tracked while approaching and receding from the speed feedback signs, and the speeds were monitored to determine when vehicles were slowing down and whether the speed reductions were sustained. The research found that vehicles were reducing their speed the most between 1,200 and 1,400 ft upstream of the speed feedback sign. Speeds began to increase again between 300 to 500 ft downstream of the speed feedback sign, and some vehicles increased speed before even passing the speed feedback sign. The results of the study showed that the speed feedback signs are not adequate for speed reductions at a corridor level but only at the location where the desired speed reduction should occur.

Tracking Vehicles for Data Reduction

Tracking involves monitoring individual vehicles as they traverse multiple data collection points. Limited research has been completed in this area; the literature search revealed only one study that used tracking to reduce data down to only affected vehicles.[33] In this study, tracking was used to determine how much vehicles were slowing down when approaching the sign. This aligns very well with curves, as the speeds of vehicles can be tracked while approaching and through the curve. Vehicles were tracked so that only free-flow passenger vehicles would be analyzed, eliminating vehicles that were influenced by a turning movement. To track the vehicles, the vehicle speed, vehicle length, and time headway were compared at each data collection location.

The standard method was used by determining the mean speed, 85th percentile speed, and percentage of vehicles exceeding the posted speed first in their analysis, but it was not used in determining the effectiveness. Instead, a true effect (TE) was calculated by tracking vehicles and then determining the speed reduction for each vehicle before and after implementation. TE was calculated as shown in figure 7.

$$\text{True Effect}=\Delta V_{1\text{-}2,\ during}-\Delta V_{1\text{-}2,\ before}$$

Figure 7. Equation. True effect.

The tracked data were used to determine the statistics $\Delta V_{1\text{-}2,\ during}$, which is the mean speed reduction between sensors 1 and 2 during the study and $\Delta V_{1\text{-}2,\ before}$, which is the mean speed reduction between sensors 1 and 2 before implementation. Cruzado and Donnell briefly discussed that, depending on the upstream data collection, the data may be over- or underestimated by using only the mean speed reduction at the treatment location.(34) TE better reflects any changes in speeds while approaching the curve.

Another form of tracking was performed by McFadden and Elefteriadou, who determined whether calculating the difference of 85th percentile speeds between two points was significantly different than calculating the 85th percentile of speed reduction between the two points.(33) The 85th percentile of the speed reduction requires that individual vehicles be tracked to determine the speed reduction between the two points. This was achieved using light detection and a light detection and ranging (LIDAR) gun. With the tracked data, the 85th percentile speed reduction was significantly different than the change in 85th percentile speed. The change in the 85th percentile speed underestimated the speed reduction of the vehicles traversing the curve. Hirsh (1987) accounted for this with the differences of the distributions of the two locations.(35)

Misaghi and Hassan expanded on this research in Canada, but instead of using LIDAR guns they used counters.(36) The counters were tracked successfully if three criteria were met at both locations: number of axles, wheel base, and the expected time gap between the two locations. Tolerances were used in the tracking because of variance with the counter clock and inconsistencies with the data collected. Once complete, the speed reduction could be calculated between the points and the 85th percentile speed.

SELECTION OF TEST SITES FOR SDCWS

The intent of this project was to evaluate the TAPCO SDCWS in five participant States (Iowa, Missouri, Texas, Washington, and Wisconsin). The research team developed site selection criteria for each and worked with each State to develop a list of candidate locations. The site selection criteria included the following:

- Two-lane rural paved roads.
- Posted speed limit of 50 mph or above.
- Existing chevrons.
- No unusual conditions within the curve (e.g., railroad crossing or major access).
- High crash location (10 or more crashes in the last 5 years, not including animal collisions); speed-related crashes preferred.
- No major rehabilitation/changes in alignment/operations in the last 3 years.
- No major rehabilitation/changes in alignment/operations planned for the next 2 years.

Specific information requested for each candidate site included:

- Curve location (Google map, latitude/longitude, etc.).
- Crash data including the location, direction, type, date, causation, etc.
- Posted speed limit (mph).
- Advisory curve speed, if present (mph).
- AADT.
- Truck traffic data, if available.
- Presence of passing lanes.

After reviewing the information from each State, the team developed a finalized list of potential sites and then conducted site visits. Final test sites were then selected in each State. The general methodology used to select sites in each State is described in the following sections.

Initial Review

A request for initial data was made to each State. The States were asked to provide data on multiple high-crash curve sites on rural two-lane roadways. It was left up to the discretion of each agency to determine what they thought were high-crash locations. Rural was defined as being at least 1 mile outside an incorporated area. Each curve was required to meet the following criteria:

- No rehabilitation or reconstruction activities that change the geometry of the roadway scheduled during the 2-year assessment.
- No geometric or cross-section changes made for 3 years prior to the study.
- Posted speed limit on tangent section 50 mph or greater.

Each State was also asked to provide the following information about the potential sites:

- Crash frequency.
- Traffic volume (AADT and percent trucks).

- Geometry (lane width, shoulder width, and type).
- Speed limit (posted or advisory) in mph.

The research team spatially located each site using Google Earth or the aerial images provided by the agency. The suitability of each curve location was evaluated, and locations that had major developments, railroads, or major points of access, including intersections other than low-volume intersections, were eliminated. Following this, additional information about the remaining sites was requested from each State, including:

- Presence of posted speed advisory on curve.
- Information about crashes (speed-related, severity, etc.).
- Expert opinion about safety and speed problems.
- Existence of unusual traffic or other conditions.

Based on the information received, the sites were ranked in terms of number of crashes with a threshold of at least 5 crashes over a 5-year period being used to define a high-crash location.

Figure 8 shows the 10 candidate curve locations identified by the Washington State Department of Transportation (DOT) for which the team conducted site visits. A similar site visit map of candidate test locations was developed for each State.

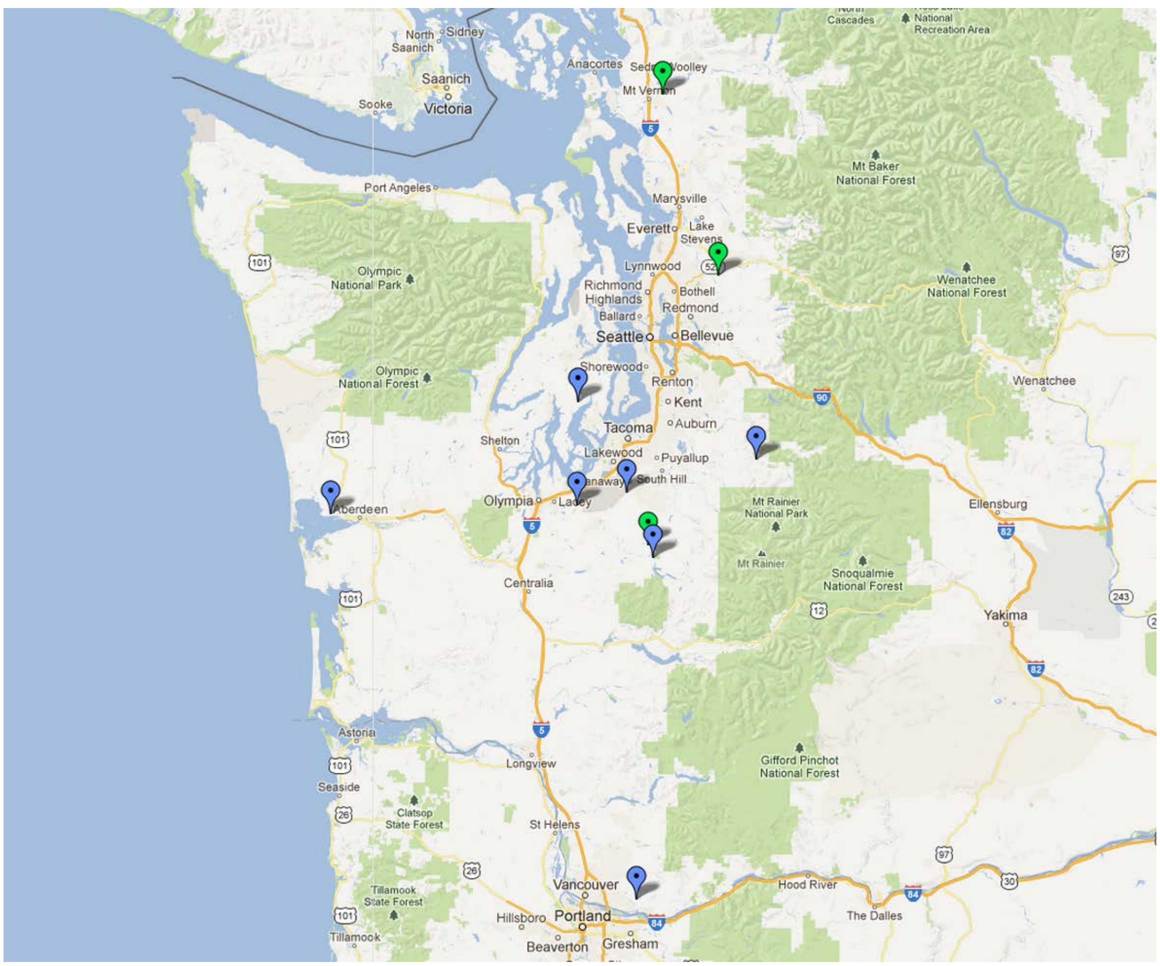


Figure 8. Map. Washington State DOT candidate sites.

Site Visits

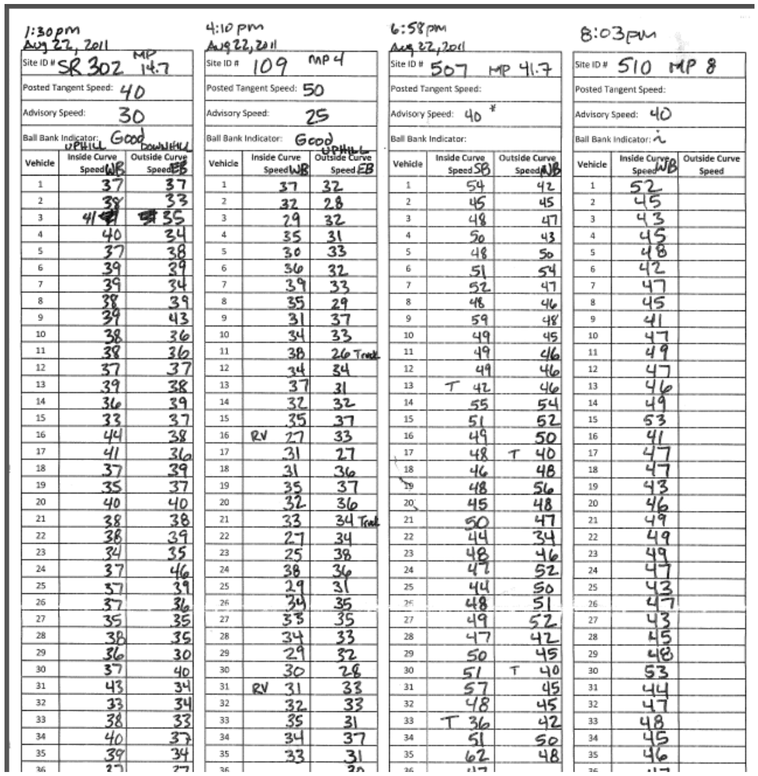
The research team conducted site visits to all candidate locations. These field observations identified roadway characteristics including curve layout, operational conditions, presence of speed and advisory signs, and relevant roadway conditions (see the example photo in figure 9).

In addition, a speed study was conducted using a radar gun to verify whether a speeding problem exists. (An example of the site visit data collection form is shown in figure 10.) At least 25 speed observations were collected for both directions of traffic unless physically prohibited due to site conditions or topography. Mean speed, by direction, was calculated for each location. When sample size was sufficient, 85th percentile speeds were calculated. A speeding problem was identified if at least one of the following conditions existed:

- Mean speed exceeded the advisory speed limit by 5 mph or more, or, if an advisory speed was not posted, exceeded the posted speed limit by 5 mph or more.
- 85th percentile speed exceeded the advisory speed limit by 5 mph or more, or exceeded the posted speed limit by 5 mph or more, if an advisory speed was not present.

A field report was prepared which included all of the field information collected for each site visited; see the example shown in figure 11.

Figure 9. Photo. Candidate curve site in Washington State.



1:30pm Aug 22, 2011			4:10 pm Aug 22, 2011			6:58pm Aug 22, 2011			8:03pm		
Site ID # SR 302 MP 14.7			Site ID # 109 MP 4			Site ID # 507 MP 41.7			Site ID # 510 MP 8		
Posted Tangent Speed: 40			Posted Tangent Speed: 50			Posted Tangent Speed:			Posted Tangent Speed:		
Advisory Speed: 30			Advisory Speed: 25			Advisory Speed: 40 *			Advisory Speed: 40		
Ball Bank Indicator: Good			Ball Bank Indicator: Good			Ball Bank Indicator:			Ball Bank Indicator: ?		
Vehicle	Inside Curve Speed WB (UPHILL)	Outside Curve Speed EB (DOWNHILL)	Vehicle	Inside Curve Speed WB	Outside Curve Speed EB (UPHILL)	Vehicle	Inside Curve Speed SB	Outside Curve Speed NB	Vehicle	Inside Curve Speed WB	Outside Curve Speed
1	37	37	1	37	32	1	54	42	1	52	
2	38	33	2	32	28	2	45	45	2	45	
3	41	35	3	29	32	3	48	47	3	43	
4	40	34	4	35	31	4	50	43	4	45	
5	37	38	5	30	33	5	48	50	5	48	
6	39	39	6	36	32	6	51	54	6	42	
7	39	34	7	39	33	7	52	47	7	47	
8	38	39	8	35	29	8	48	46	8	45	
9	39	43	9	31	37	9	59	48	9	41	
10	38	36	10	34	33	10	49	45	10	47	
11	38	36	11	38	26 Truck	11	49	46	11	49	
12	37	37	12	34	34	12	49	46	12	47	
13	39	38	13	37	31	13	T 42	46	13	46	
14	36	39	14	32	32	14	55	54	14	49	
15	33	37	15	35	37	15	51	52	15	53	
16	44	38	16	RV 27	33	16	49	50	16	41	
17	41	36	17	31	27	17	48	T 40	17	47	
18	37	39	18	31	36	18	46	48	18	47	
19	35	37	19	35	37	19	48	56	19	43	
20	40	40	20	32	36	20	45	48	20	46	
21	38	38	21	33	34 Truck	21	50	47	21	49	
22	38	39	22	27	34	22	44	34	22	49	
23	34	35	23	25	38	23	48	46	23	49	
24	37	46	24	38	36	24	47	52	24	47	
25	37	39	25	29	31	25	44	50	25	43	
26	37	36	26	34	35	26	48	51	26	47	
27	35	35	27	33	35	27	49	52	27	43	
28	38	35	28	34	33	28	47	42	28	45	
29	36	30	29	29	32	29	50	45	29	48	
30	37	40	30	30	28	30	51	T 40	30	53	
31	43	34	31	RV 31	33	31	57	45	31	44	
32	33	34	32	32	33	32	48	45	32	47	
33	38	33	33	35	31	33	T 36	42	33	48	
34	40	37	34	34	37	34	51	50	34	45	
35	39	34	35	33	31	35	62	48	35	46	

Figure 10. Chart. Example site visit speed data collection form.

SITE: Hwy 32

DIRECTION	TANGENT SPEED	ADVISORY SPEED	ACTUAL SPEED AVERAGE	BALL BANK
NB	55	none	58.26	4-5-6

No lighting, but the solar access is good. Shoulders are 3' ACC and 7' gravel. Passing is allowed and chevrons for SB only. The road changes from 4 lanes to 2 lanes before this location.

CRASH DATA: 6 crashes

Figure 11. Photo. Example field report from initial visit.

Selection of Final Sites

Following the site visits, the research team selected the final test curve locations for installation of the TAPCO SDCWS, as shown in table 2 and figure 12.

Table 2. Final test sites by State.

State	Number of Test Sites
Iowa	1
Missouri	1
Texas	4
Washington	3
Wisconsin	3

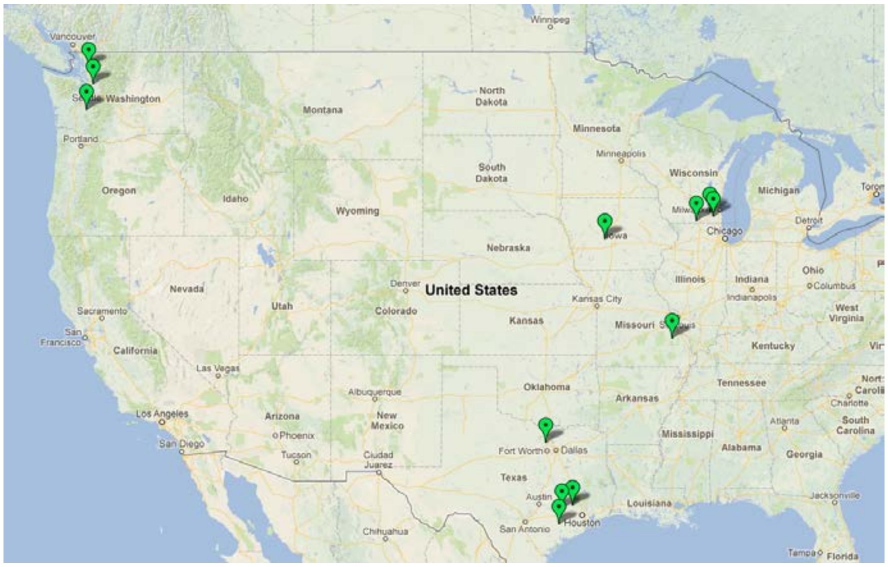


Figure 12. Map. Final test site locations.

Selection of Study Direction

Since only one SDCWS was installed per curve location, it was necessary to determine in which direction of travel the system would be installed (e.g., eastbound versus westbound). If one direction had a higher percentage of speed-related and/or single-vehicle run-off-road crashes than the other direction, the SDCWS was placed for this direction. It should be noted that direction information was not available for all crashes. If no predominant crash direction was noted, the SDCWS was assigned to whichever direction of travel had the highest speeds based on the initial speed study.

Final Site Information by State

Table 3 provides a summary of curve site characteristics for each final test site location. Appendix A includes a summary of the baseline data for each test location.

Table 3. Curve characteristics.

Study Direction	Crashes (#)	Years (#)	Crashes/ Year	ADT	Roadway Geometry					Posted Speed of Tangent Sections	Curve Advisory Speed	Chevrons (#)	Chevron Size (in.)	Access Points In/ Near Curve?
					Lanes (#)	Lane Width (ft)	Road Surface	Shoulder Width (ft)	Shoulder Surface					
EB	8	5	1.6	1,435	2	12	Asphalt	4	Gravel	55	45	7	30x36	Yes
NB	31	5	6.2	1,000	2	11	Asphalt	4	Asphalt	55	40	6	18x24	No
WB	7	3	2.3	3,583	2	12	Asphalt	2	Mix	55	30	9	18x24	Yes
SB	9	3	3.0	3,494	2	12	Asphalt	3	Mix	55	25	5	18x24	No
SB	7	3	2.3	2,369	2	12	Asphalt	3	Asphalt	55	50	5	18x24	Yes
SB	19	5	3.8	1,408	2	11	Asphalt	3	Asphalt	50	20	3	24x30	Yes
SB	6	5	1.2	5,800	2	10	Asphalt	2	Asphalt	50	40	3	18x24	Yes
SB	5	5	1.0	11,000	2	11	Asphalt	5	Asphalt	55	40	6	18x24	No
EB	10	7	1.4	5,000	2	11	Treated Surface	1	Treated Surface	55	40	5	18x24	Yes
NB	8	7	1.1	4,400	2	11	Treated Surface	4	Treated Surface	55	40	13	18x24	No
NB	16	7	2.3	2,500	2	11	Treated Surface	2	Treated Surface	60	35	6	18x24	Yes
WB	9	7	1.3	560	2	11	Asphalt	2	Asphalt	60	35	6	18x24	Yes

INSTALLATION

Once the test sites were established, the research team provided the chevron quantity and sign curve warning sign details to the manufacturer. All installations were completed by the SDCWS manufacturer with support from each State DOT. Table 4 provides a summary of installation dates by location. The manufacturer calibrated the sign and radar operational settings specific to each location. Figure 13 shows several photos from a typical installation.

Table 4. Installation dates.

State	Installation Date
Iowa	September 2012
Missouri	June 2012
Texas	July 2012
Washington	August 2012
Wisconsin	June 2012

Figure 13. Photos. Installation of the SDCWS.

Technology Description

TAPCO's SDCWS utilizes Day-Viz™ LED enhanced solar powered signs and BlinkerBeam™ wireless controllers along with ultra-low power radar to detect and flash a series of chevron signs along with the advance warning sign in a horizontal curve. This system both warns and guides drivers through any upcoming horizontal curves.

The SDCWS is meant to replace existing W1-8 and advance warning signage or be used in the design of a new curve as a low-cost warning system. Chapter 2C of the Manual on Uniform Traffic Control Devices (MUTCD) and engineering judgment should be applied when determining appropriate sign layouts and locations.

Using the length and speed of the curve, the user can set each of the W1-8 chevron signs to flash in a specific sequence or time interval. Each curve design will have different sign placement and geometry for consideration when determining the appropriate flash sequence.

Typically, each sign will flash at least once per second according to MUTCD guidelines, with a minimum flash “ON” time of 100 milliseconds. When the quantity of chevrons exceeds nine, chevrons are commonly divided into two separate sequentially flashing systems in which the first and fifth sign will start flashing at the same time, followed by the second and sixth, and so on. This gives the effect of the system guiding or pulling the driver through the curve and highlights the geometry while still meeting the MUTCD guidelines.

The speed of the sequence and flash duration are determined based on the quantity of signs and speed of the curve. For example, when the speed of the curve is 45 mph and the curve distance from the start of the advance warning sign to the last chevron is 1,000 ft, the flash duration can be set to 15 seconds (1,000 ft ÷ 66 ft/sec = 15 seconds). This time will vary based on existing sign locations, driver speed, and other factors noticed during installation.

The radar can detect up to 300 ft in advance of the curve sign and will commonly be set to flash at or just below the advisory speed of the curve. Once this speed threshold is exceeded, the radar will trigger the flash of the advance warning sign and sequential chevron signs using TAPCO’s 900-Mhz BlinkerBeam™ wireless network. This wireless network is constantly communicating with each sign and providing a synchronization pulse throughout the network. This synchronization pulse is what each sign controller will use to keep the proper flash time and sequence.

During setup, the user can program when the sign LEDs should turn on (called “Beacon Start”) and the duration they should stay on (called “Beacon Stop”). The Beacon Stop will become the duty cycle, which is typically no less than 100 milliseconds. This allows many options for configuring the flash sequence and speed of the flash for each horizontal curve. The system in its entirety can be seen in figure 14.

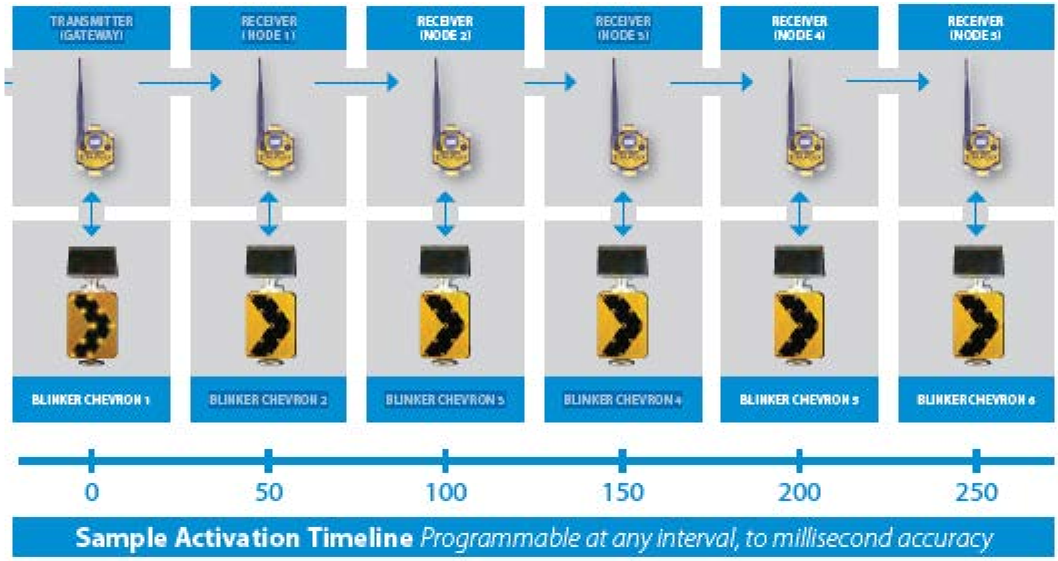


Figure 14. Photo. SDCWS activation sequence.

METHODOLOGY FOR SPEED DATA COLLECTION

The collection of traffic speed and volume data was integral to this project because these data provide the before-and-after contrast necessary to assess the effectiveness of the SDCWS.

Equipment

Pneumatic road tubes and counters were used to collect speed and volume data. The advantage of the road tubes is that they are reasonably accurate, can collect individual vehicle speeds (allowing for spot-checking of the data), are low-cost, and are nondestructive to the existing roadway surface. The counters used were Trax I automatic traffic recorders manufactured by JAMAR Technologies, Inc. The units can collect individual vehicle speeds, headways, vehicle class, and volume.

For each data collection period, the counters were set up to record time, vehicle speed, and vehicle class for individual vehicles. Other metrics such as volume, headway, average speed, etc., can be calculated from these data. Since time on the counter can drift the counters, clocks were checked and reset each time they were used.

Data Collection Periods

Speed and volume data were collected at each test location using the pneumatic road tubes. Data collected about 1 month before installation are referred to as "before" data. Data collected about 1 month after installation are referred to as "1 month after" data. In all States, data will be collected again at about 12 and 18 months after installation (referred to as "1 year" and "18 months" data).

Data Collection Protocol and Quality Assurance

Speed and volume data were collected at three locations per test site. The goal was to understand driver speed selection in advance, at the beginning of the curve, and within the curve. These three locations are described below and shown in figure 15:

- Upstream – Road tubes were placed approximately 500 ft before the advanced curve warning sign (just in advance of being detected by the radar within the advance curve warning sign).
- PC – These tubes were placed at the point of curvature or beginning point of the curve.
- CC – Tubes placed within the center of the curve.

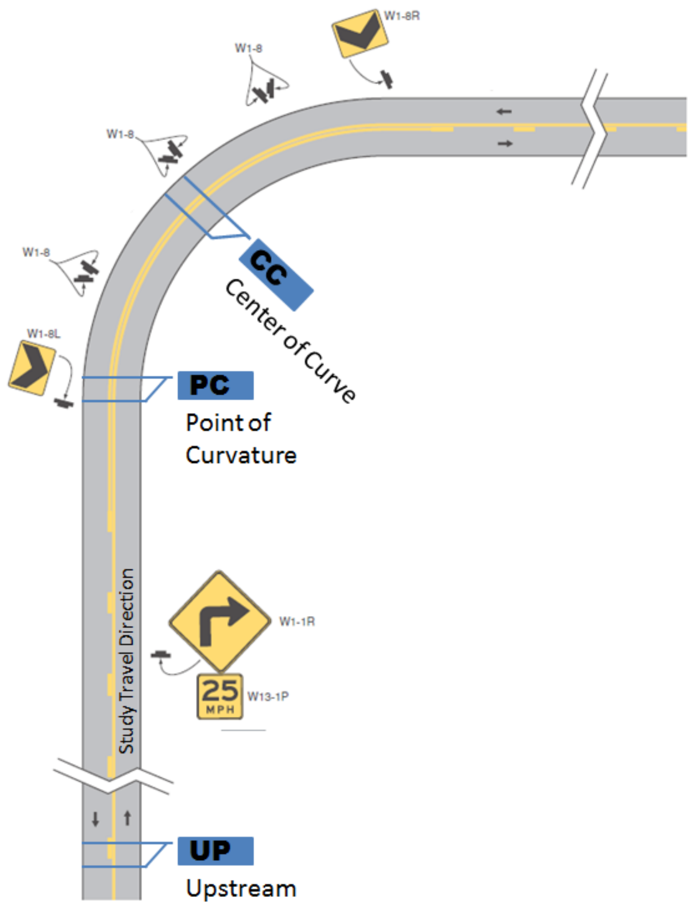


Figure 15. Diagram. Typical traffic counter placement.

In most cases, data were collected for at least 1 day (24 hours) during the week (Monday through Friday). During data collection, the equipment was spot checked to determine whether any problems had occurred. Common problems included the pneumatic tubes getting pulled up from the pavement, the tubes being damaged in some way, or the counters malfunctioning.

Data were checked in the field during data collection to spot problems early, and the full data sets were checked when data collection was complete. Data were checked for the following situations that, based on the team's experience, indicate problems with the counters:

- Large number of low speeds (≤5 mph).
- Large number of high speeds (90 mph and higher) (this usually indicates a problem with road tube layout).
- Large number of vehicles with vehicle classification = 14 (class = 14 are vehicles that the counter cannot identify).

SPEED ANALYSIS

This chapter describes the speed metrics used to assess the effectiveness of the SDCWS. Since data were collected at three locations per curve, results for individual sites are summarized.

Speed Metrics

The change in speed from the before period was compared to each after period. A negative result indicates that speeds were reduced from the before period to the after period. A positive value indicates that speed increased from the before period to the after period. Mean and 85th percentile speeds are shown using a trend line. This is shown for graphical purposes only and should not be interpreted to indicate that speeds can be interpolated between data collection periods.

The change in mean and 85th percentile speed from the before period speed to specific after period speed are shown in miles per hour (mph). The percentage change in the fraction of vehicles exceeding the posted or advisory speed is also presented. A number of speed metrics were calculated for the direction of travel towards the signs. They include average speed, standard deviation (SD) of speed, 50th percentile speed, 85th percentile speed, and number of vehicles traveling 5, 10, 15, or 20 mph over the posted or advisory speed limit. For simplicity in setting up the pneumatic road tubes, the traffic counters were set up to record both directions of traffic on the two-way roadway. Results were reduced by lane and are only presented for traffic traveling in the direction of the SDCWS.

Results to Date

This interim report does not provide a commentary on the results to date. Tables 5 and 6 provide a summary of speed statistics across all sites at both PC and CC. The table shows the changes from before to 1 month after, with a negative sign showing a reduction in speed or percentage. Appendix contains the full data set collected before installation and 1 month after installation, in both tabular and graphic formats. The schedule of the data collection for each State is provided in table 7. This shows both data that have been collected and what will be collected in the future.

Table 5. Summary of results at point of curvature after 1 month.

State		IA	MO	TX				WA			WI		
Road		Hwy 144	Hwy 221	FM 109	FM 407	FM 530	FM 1488	SR 7	SR 9	SR 203	Hwy 20	Hwy 67	Hwy 213
Posted Speed		55	55	60	55	60	55	50	55	55	55	55	55
Curve Advisory Speed		45	40	35	40	-0.9	40	20	40	None	30	25	50
Change in mean speed (mph)		-1.5	-1.5	-0.8	-1.8	-2	-2.4	-2.8	-1.4	-2	-1.8	-1.6	-0.7
Change in 85th percentile speed(mph)		-1	-1	-1	-2	-2.6	-3	-3	-1	-2	-2	-1	0
Change in fraction of vehicles exceeding posted or advisory speed by	5 mph	-19.7%	-6.4%	-2.2%	-6.7%	-20.3%	-8.5%	-7.3%	-30.4%	-2.1%	-9.1%	0.0%	-9.5%
	10 mph	-33.3%	-17.1%	-8.8%	-20.9%	-36.4%	-27.1%	-30.0%	-50.0%	-14.5%	-19.0%	-3.1%	-25.0%
	15 mph	0.0%	-32.0%	-23.3%	-41.9%	-63.6%	-53.6%	-51.4%	-100.0%	-46.5%	-40.7%	-8.0%	0.0%
	20 mph	0.0%	-50.0%	0.0%	0.0%	0.0%	0.0%	-77.8%	0.0%	-62.5%	-57.1%	-21.5%	0.0%

Table 6. Summary of results at center of curve after 1 month.

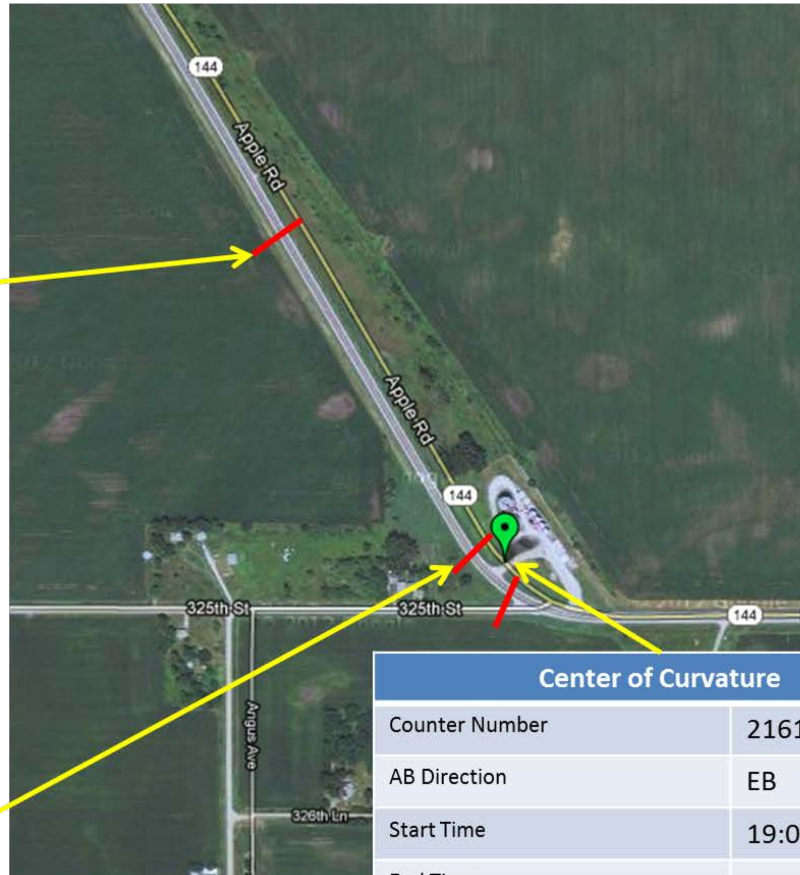
State		IA	MO	TX				WA			WI		
Road		Hwy 144	Hwy 221	FM 109	FM 407	FM 530	FM 1488	SR 7	SR 9	SR 203	Hwy 20	Hwy 67	Hwy 213
Posted Speed		55	55	60	55	60	55	50	55	55	55	55	55
Curve Advisory Speed		45	40	35	40	35	40	20	40	None	30	25	50
Change in mean speed (mph)		-2.1	0.3	-1.4	-1.1	-2	-0.1	-1.4	-0.9	-0.1	-1.8	-1.8	-1
Change in 85th percentile speed (mph)		-2	0	-2	-2	-2.6	0	-1	-1	0	-2	-2	-1
Change in fraction of vehicles exceeding posted or advisory speed by	5 mph	-38.1%	0.0%	-5.7%	-8.2%	-20.3%	-4.8%	-19.0%	-26.3%	0.0%	-18.2%	-2.1%	-11.9%
	10 mph	-58.3%	10.5%	-27.7%	-29.7%	-36.4%	2.5%	-45.0%	-33.3%	-2.8%	-45.5%	-11.6%	-20.0%
	15 mph	0.0%	28.6%	-51.4%	-60.0%	-63.6%	0.0%	0.0%	0.0%	-4.0%	-66.7%	-28.3%	50.0%
	20 mph	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	-100.0%	-46.7%	0.0%

Table 7. Schedule of activities, all sites.

Activity Description	Schedule (Week)	Status
Before data collection		
Washington	7/17/2012	**Complete**
Wisconsin	5/21 2012	
Missouri	6/13 2012	
Texas	6/25 and 7/9 2012	
Iowa	8/29 2013	
Installation		
Washington	8/1/2012	**Complete**
Wisconsin	6/11 2012	
Missouri	6/25 2012	
Texas	7/16/2012	
Iowa	9/10 2012	
1-month after data collection		
Washington	9/12/2012	**Complete**
Wisconsin	7/9 2012	
Missouri	8/1 2012	
Texas	9/3, 9/10,/9/24 2012	
Iowa	10/10 2012	
12-month after data collection		
Washington	August 2013	
Wisconsin	June 2013	
Missouri	July 2013	
Texas	June/July 2013	
Iowa	September 2013	
18-month after data collection		
Washington	February 2014	
Wisconsin	December 2013	
Missouri	January 2014	
Texas	December 2013/January 2014	
Iowa	March 2014	
Before Crash data collection		
Washington	April 2013	
Wisconsin	May 2013	
Missouri	February 2013	
Texas	TBD	
Iowa	February 2013	
After Crash data collection		
Washington	April 2014	
Wisconsin	May 2014	
Missouri	September 2013	
Texas	TBD	
Iowa	February 2014	
First Year Evaluation	12/31/2013	
Final Report	8/31/2014	

Hwy 144(IA)-Eastbound Before

Upstream	
Counter Number	20335
AB Direction	EB
Start Time	19:09:38
End Time	19:58:28
Duration Stopwatch	7:31:30
	32:20:15



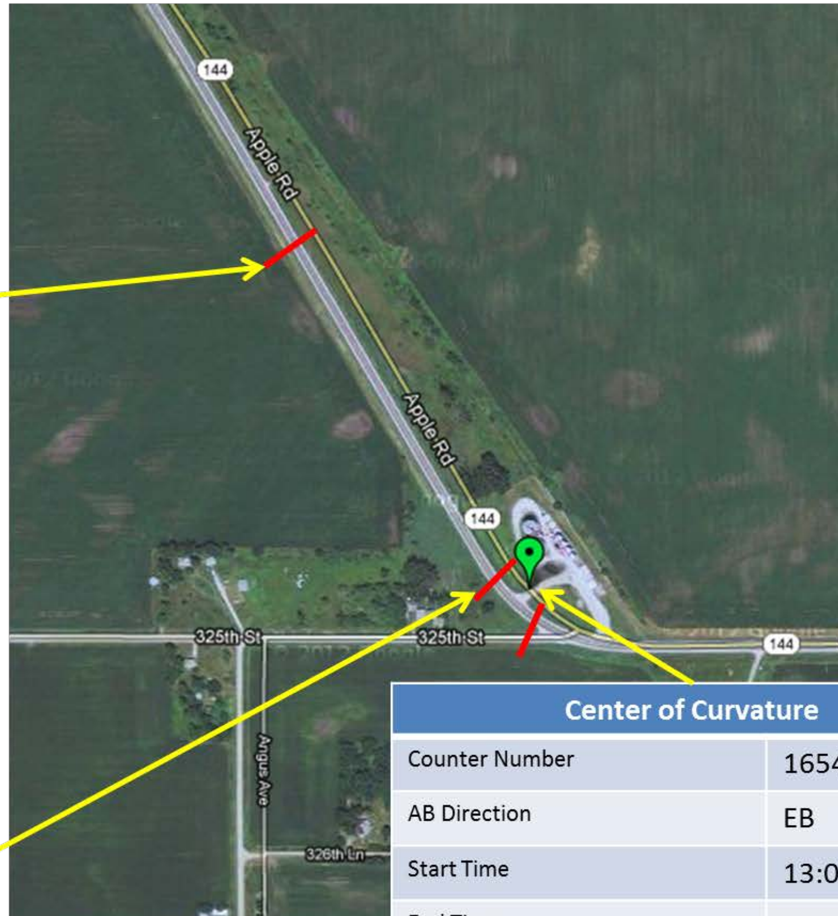
Point of Curvature	
Counter Number	21608
AB Direction	EB
Start Time	19:09:38
End Time	20:05:22
Duration Stopwatch	7:31:30
	32:27:10

Center of Curvature	
Counter Number	21610
AB Direction	EB
Start Time	19:09:38
End Time	20:02:43
Duration Stopwatch	7:31:30
	32:24:30

Figure 16. Photo. Iowa Highway 144 before data collection.

Hwy 144(IA)-Eastbound
1 Month After

Upstream	
Counter Number	20330
AB Direction	EB
Start Time	13:06:50
End Time	9:02:50
Duration Stopwatch	0:00:00
	115:55:35



Point of Curvature	
Counter Number	21610
AB Direction	EB
Start Time	13:06:50
End Time	9:21:57
Duration Stopwatch	0:00:00
	116:14:40

Center of Curvature	
Counter Number	16542
AB Direction	EB
Start Time	13:06:50
End Time	9:29:05
Duration Stopwatch	0:00:00
	116:22:10

Figure 17. Photo. Iowa Highway 144 1 month after data collection.

Hwy 144(IA)-Eastbound

Figure 18. Photo. Iowa Highway 144 site layout.

Iowa 144
Date: 8/29-8/30/2012
Period: Before

	location (gps at center of curve)
2-12’ lanes	# lanes and width
Left	curve direction (left or right)
Gravel 4’	shoulder type and width
45	posted speed of curve in each direction
55	tangent speed in each direction
55	advisory speed in each direction
See below	grade (average of 3 readings and list if positive or negative)
See below	super elevation
See Layout	location and type of signing before and in the
Asphalt	pavement type and condition
None	presence and location of street lighting

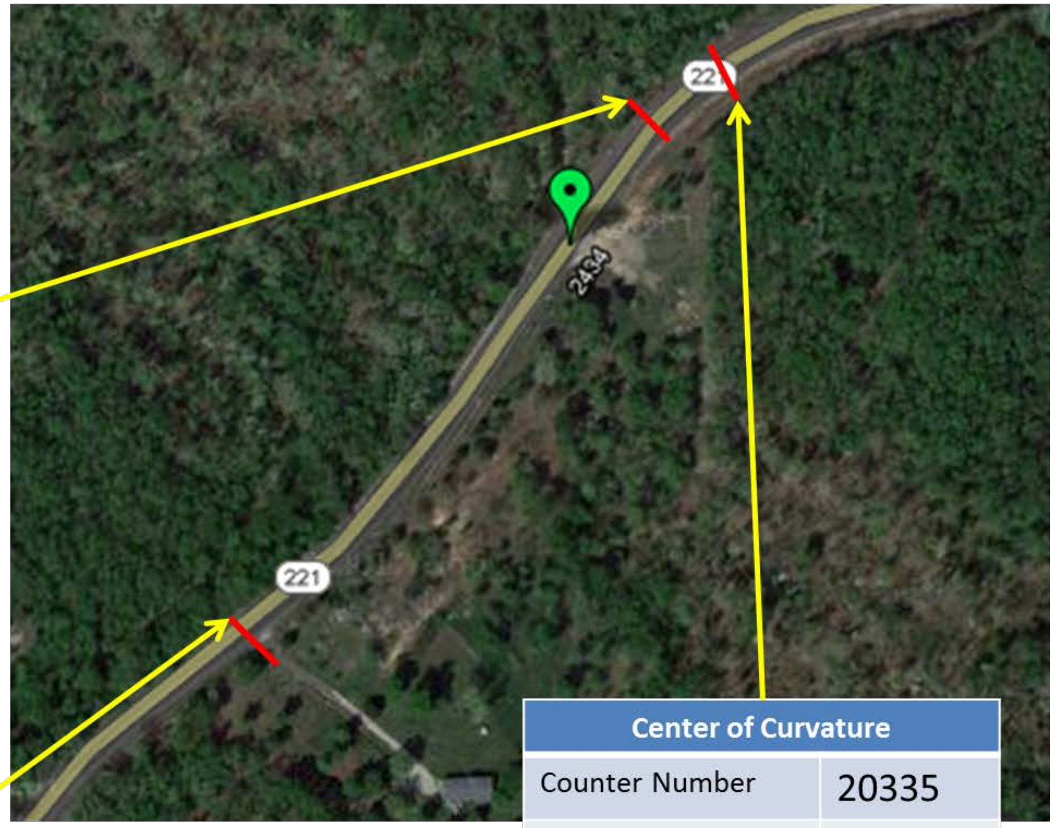
	Begin S-N				Center W-E				End W-E			
Grade	EB	Center	WB	Average	EB	Center	WB	Average	EB	Center	WB	Average
	-.4	-.1	-.2	-.23	-0	-.9	-.4	-.43	-.6	-.5	-.8	-.63

	Begin W-E				Center S-N				End S-N			
Super Elevation	EB	Center	WB	Average	EB	Center	WB	Average	EB	Center	WB	Average
	-5.3	-3.7	-4.9	-4.63	-8.5	-7.1	-7.4	-7.67	-1.2	+1	-1.4	-.53

Figure 19. Chart. Iowa Highway 144 site information.

Hwy 221(MO)-Northbound Before

Point of Curvature	
Counter Number	20333
AB Direction	NB
Start Time	16:41:50
End Time	19:18:36
Duration Stopwatch	26:36:40



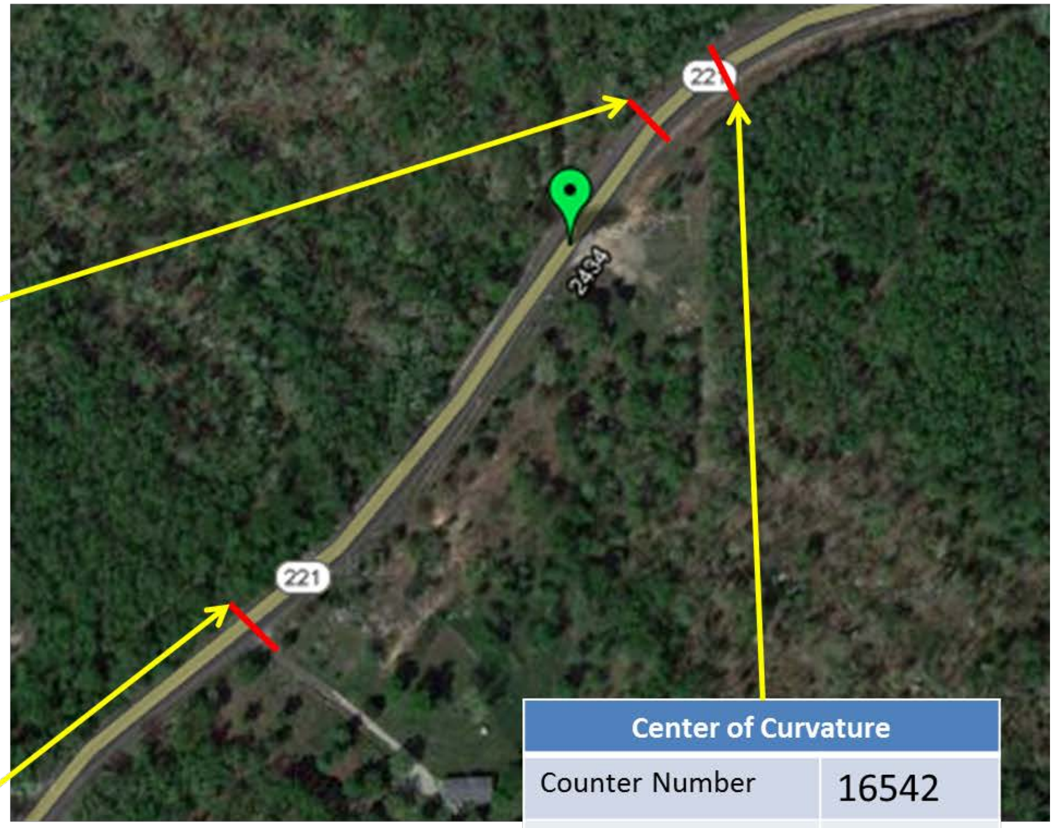
Upstream	
Counter Number	22078
AB Direction	NB
Start Time	16:41:50
End Time	19:14:47
Duration Stopwatch	26:32:50

Center of Curvature	
Counter Number	20335
AB Direction	NB
Start Time	16:41:50
End Time	19:25:10
Duration Stopwatch	26:43:15

Figure 20. Photo. Missouri Highway 221 before data collection.

Hwy 221(MO)-Northbound
1 Month After

Point of Curvature	
Counter Number	21610
AB Direction	NB
Start Time	7:51:02
End Time	9:04:16
Duration Stopwatch	25:12:10



Upstream	
Counter Number	20330
AB Direction	NB
Start Time	7:51:02
End Time	8:57:56
Duration Stopwatch	25:06:50

Center of Curvature	
Counter Number	16542
AB Direction	NB
Start Time	7:51:02
End Time	9:07:51
Duration Stopwatch	25:16:50

Figure 21. Photo. Missouri Highway 221 1 month after data collection.

Hwy 221(MO)-Northbound

6 Chevrons

Figure 22. Photo. Missouri Highway 221 site layout.

Missouri 221
Date: 6/13-6/1/2012
Period: Before

N42°31.432’ W088°58.944’	location (gps at center of curve)
2 Lanes, 22’ Asphalt	# lanes and width
Right	curve direction (left or right)
4’ Asphalt Right 4’ +3’ Asphalt Left sharp drop	shoulder type and width
55	posted speed of curve in each direction
55	tangent speed in each direction
40	advisory speed in each direction
See Below	grade (average of 3 readings and list if positive or negative)
See Below	super elevation
See Layout	location and type of signing before and in the
Asphalt, Good	pavement type and condition
None	presence and location of street lighting

	Begin S-N				Center S-N				End W-E			
Grade	NB	Center	SB	Average	NB	Center	SB	Average	NB	Center	SB	Average
	-3.6	-3.3	-2.9	-3.27	-4.5	-4.4	-4.7	-4.53	-8.8	-9.1	-9.8	-9.23

	Begin W-E				Center S-N				End S-N			
Super Elevation	NB	Center	SB	Average	NB	Center	SB	Average	NB	Center	SB	Average
	-4.2	-2.6	-1.2	-2.67	-8.6	-8.0	-6.0	-7.53	2.0	-0.7	-1.4	-.03

Figure 23. Chart. Missouri Highway 221 site information.

Washington SR9
Date: 7/17-7/18, 2012
Period: Before

PC	
Counter Number	20333
AB Direction	SB
Start Time	7:59
End Time	8:25

Upstream	
Counter Number	20334
AB Direction	SB
Start Time	7:22
End Time	8:25

Center of Curve	
Counter Number	21608
AB Direction	SB
Start Time	7:41
End Time	8:25

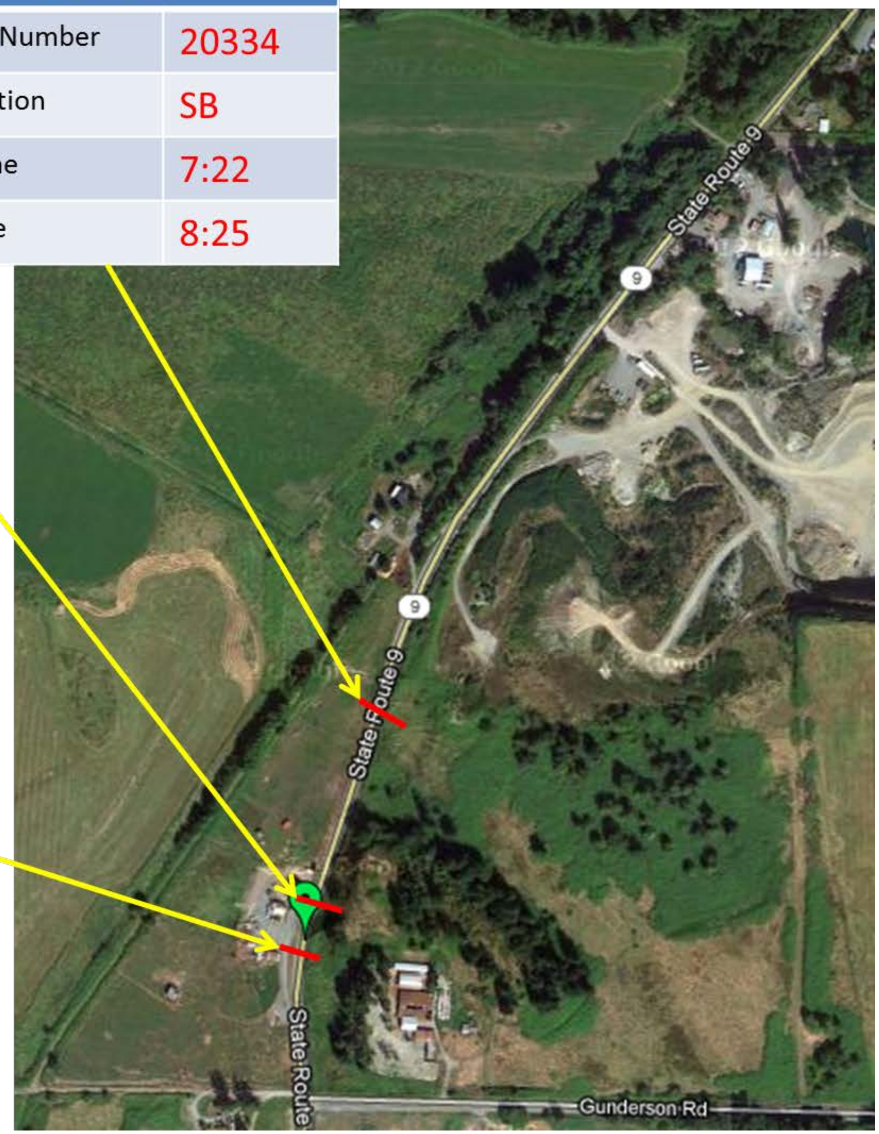


Figure 24. Map. Washington State Route 9 before data collection.

Washington SR9
Date: 9/12-9/13, 2012
Period: 1 Month After

PC	
Counter Number	20333
AB Direction	SB
Start Time	1:57
End Time	3:34

Upstream	
Counter Number	20334
AB Direction	SB
Start Time	1:12
End Time	3:23

Center of Curve	
Counter Number	21608
AB Direction	SB
Start Time	1:35
End Time	3:35

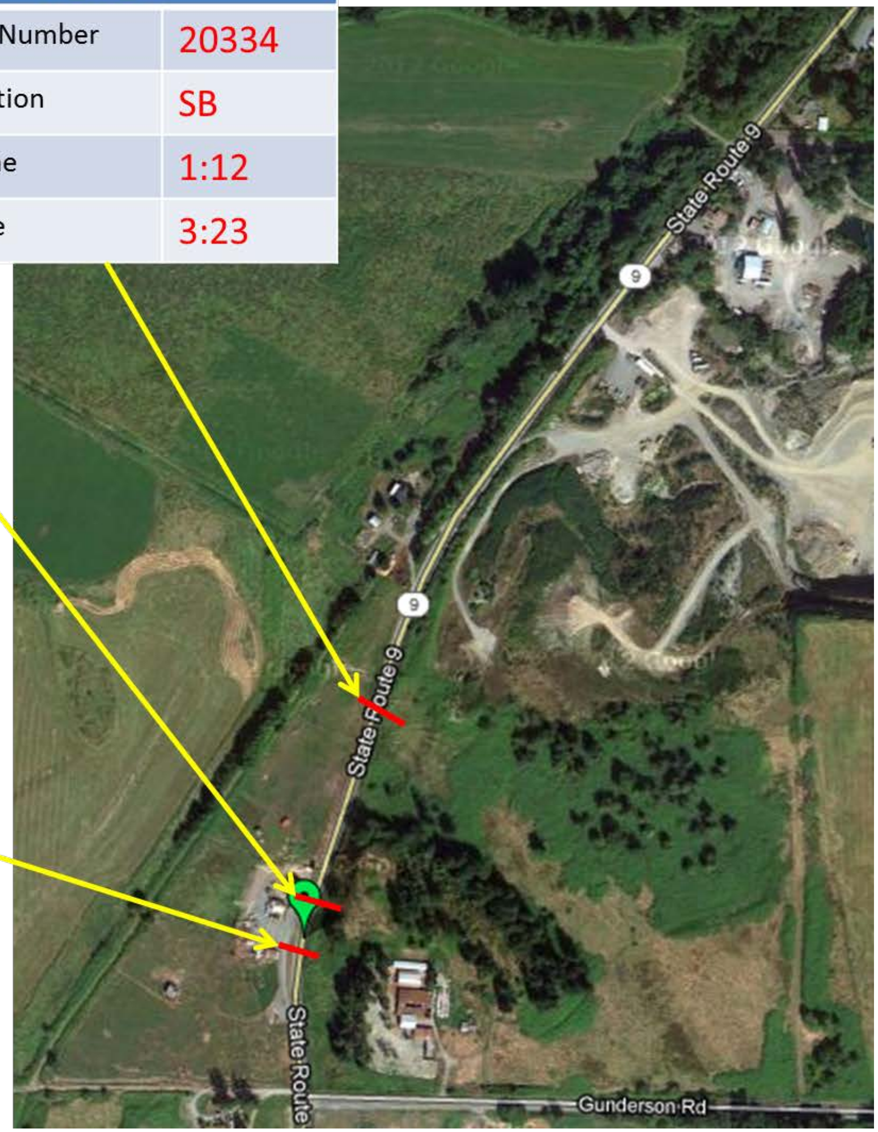


Figure 25. Map. Washington State Route 9 1 month after data collection.

Washington SR 9
Date: 7/17-7/18/2012
Period: Before

	location (gps at center of curve)
2 Lanes, 10’ Each CL Rumble 12” Wide	# lanes and width
Left	curve direction (left or right)
2’ Asphalt Shoulder Both	shoulder type and width
50	posted speed of curve in each direction
50	tangent speed in each direction
40	advisory speed in each direction
See Below	grade (average of 3 readings and list if positive or negative)
See Below	super elevation
See Layout	location and type of signing before and in the
Asphalt	pavement type and condition
None	presence and location of street lighting

Figure 26. Chart. Washington State Route 9 site information.

Washington SR203

Date: 7/17-7/18, 2012

Period: Before

PC	
Counter Number	21610
AB Direction	SB
Start Time	5:08
End Time	6:45

Upstream	
Counter Number	20330
AB Direction	SB
Start Time	5:53
End Time	6:30

Center of Curve	
Counter Number	16542
AB Direction	SB
Start Time	5:32
End Time	6:56

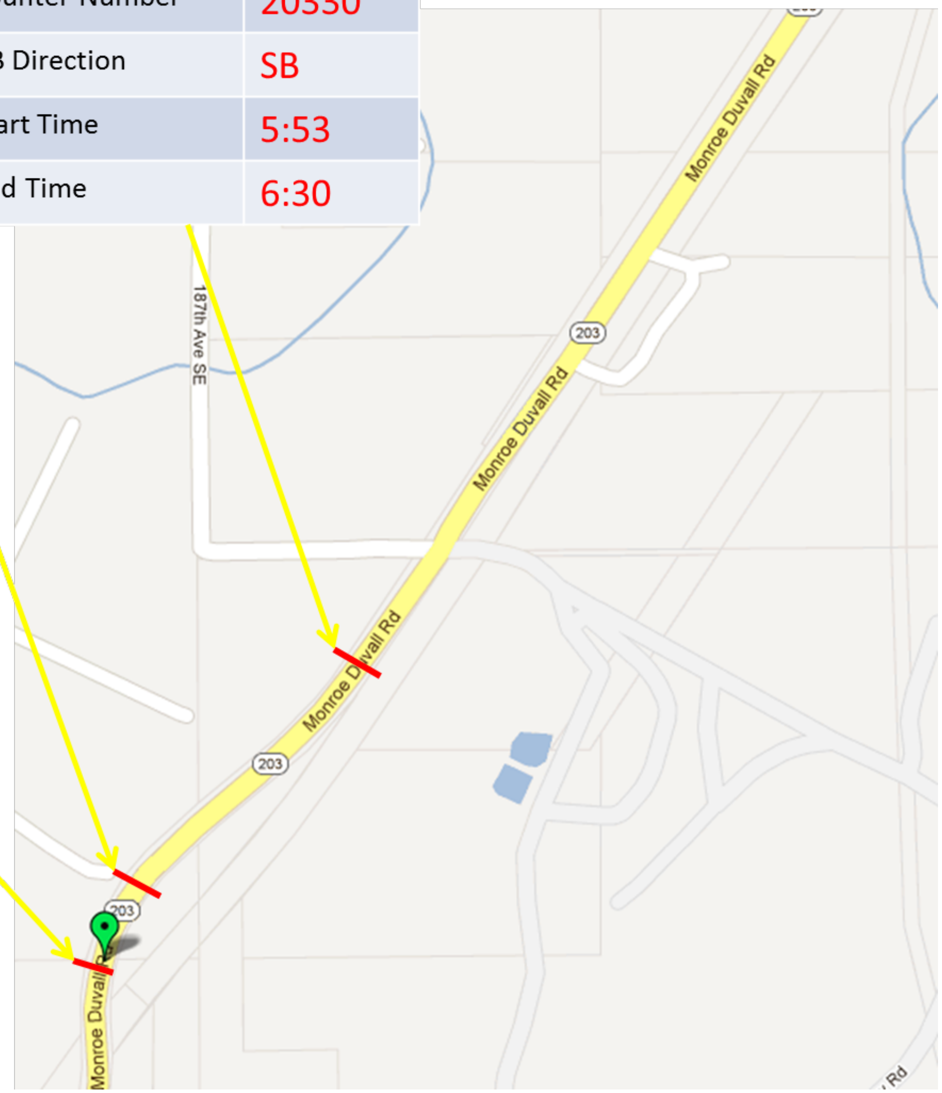


Figure 27. Map. Washington State Route 203 before data collection.

Washington SR203
Date: 9/12-9/13, 2012
Period: 1 Month After

PC	
Counter Number	21610
AB Direction	SB
Start Time	11:23
End Time	1:21

Upstream	
Counter Number	20330
AB Direction	SB
Start Time	10:57
End Time	12:54

Center of Curve	
Counter Number	16542
AB Direction	SB
Start Time	11:40
End Time	1:36

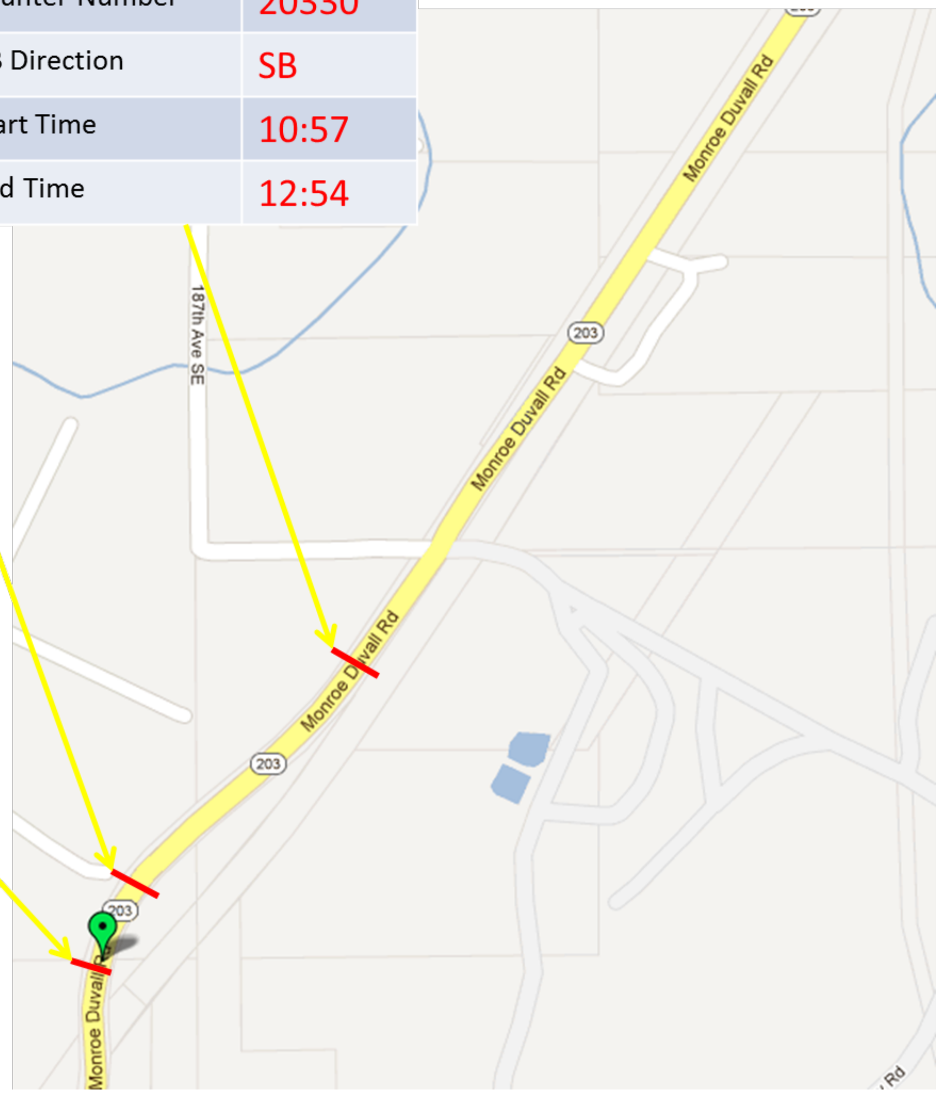


Figure 28. Map. Washington State Route 203 1 month after data collection.

Washington SR 203
Date: 7/17-7/18/2012
Period: Before

	location (gps at center of curve)
2 lanes with 12” CL Rumble, 11’ NB Lane;10.5’ SB Lane	# lanes and width
Left	curve direction (left or right)
NB-4.5’ Asphalt Shld SB-8’ Asphalt w/ 12” Rumble	shoulder type and width
55	posted speed of curve in each direction
55	tangent speed in each direction
None	advisory speed in each direction
See Below	grade (avg. of 3 readings and list if positive or negative)
See Below	super elevation
See Layout	location and type of signing before and in the
Asphalt	pavement type and condition
None	presence and location of street lighting

Figure 29. Chart. Washington State Route 203 site information.

Washington SR7
Date: 7/17-7/18, 2012
Period: Before

Upstream	
Counter Number	16540
AB Direction	SB
Start Time	2:35
End Time	4:20

Synced at 1:30PM

PC	
Counter Number	21569
AB Direction	SB
Start Time	2:13
End Time	3:30

Center of Curve	
Counter Number	22078
AB Direction	SB
Start Time	1:55
End Time	3:15

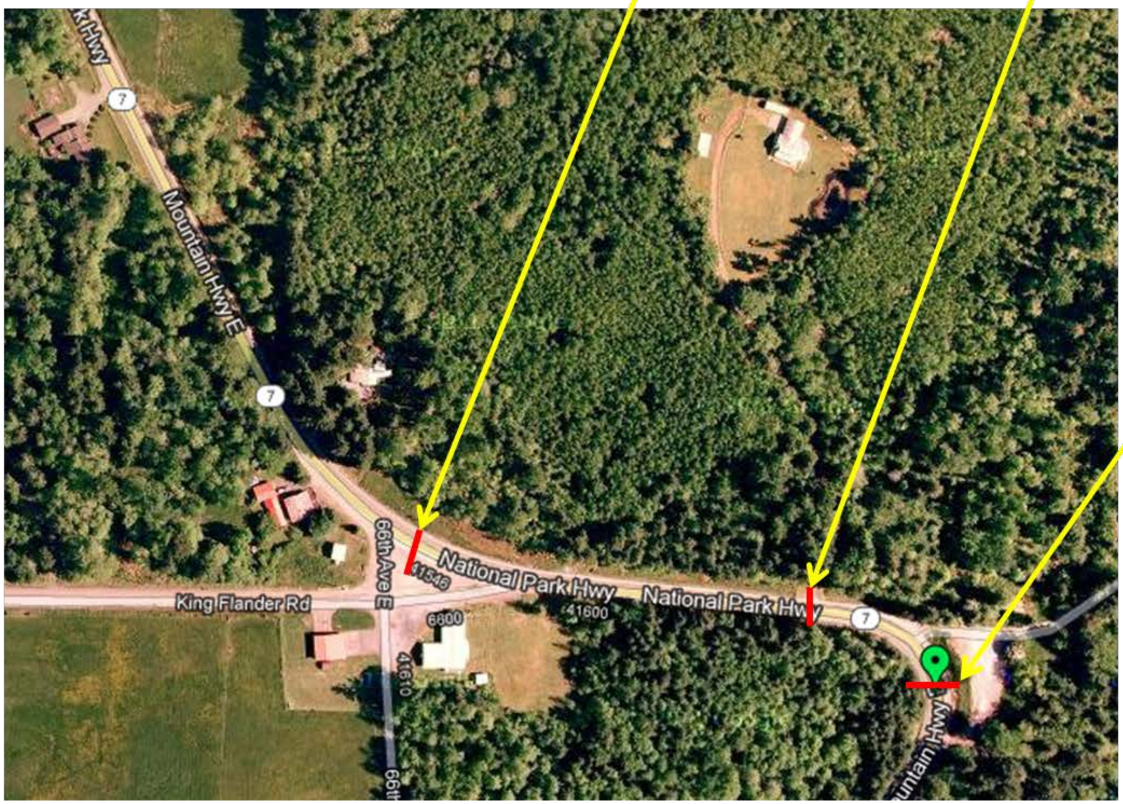


Figure 30. Map. Washington State Route 7 before data collection.

Washington SR7
Date: 9/12-9/13, 2012
Period: 1 Month After

Upstream	
Counter Number	16540
AB Direction	SB
Start Time	7:34AM
End Time	7:41PM

PC	
Counter Number	21569
AB Direction	SB
Start Time	7:50AM
End Time	7:36PM

Center of Curve	
Counter Number	22078
AB Direction	SB
Start Time	8:10AM
End Time	7:26PM

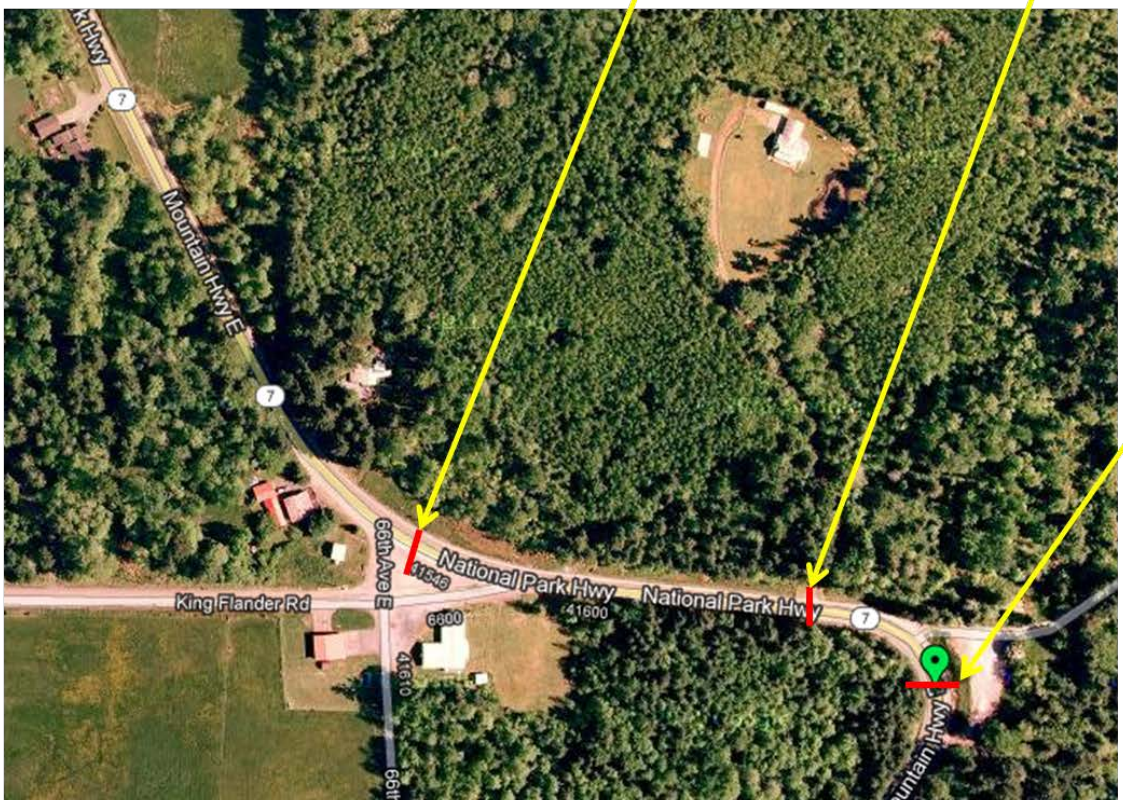


Figure 31. Photo. Washington State Route 7 1 month after data collection.

Washington SR 7
Date: 7/17-7/18/2012
Period: Before

	location (gps at center of curve)
2 Lane with 12" Rumble NB 11' Lane; SB 10' Lane	# lanes and width
Right	curve direction (left or right)
Paved	shoulder type and width
50	posted speed of curve in each direction
50	tangent speed in each direction
20	advisory speed in each direction
See Below	grade (average of 3 readings and list if positive or negative)
See Below	super elevation
See Layout	location and type of signing before and in the
Asphalt, Good	pavement type and condition
None	presence and location of street lighting

Figure 32. Chart. Washington State Route 7 site information.

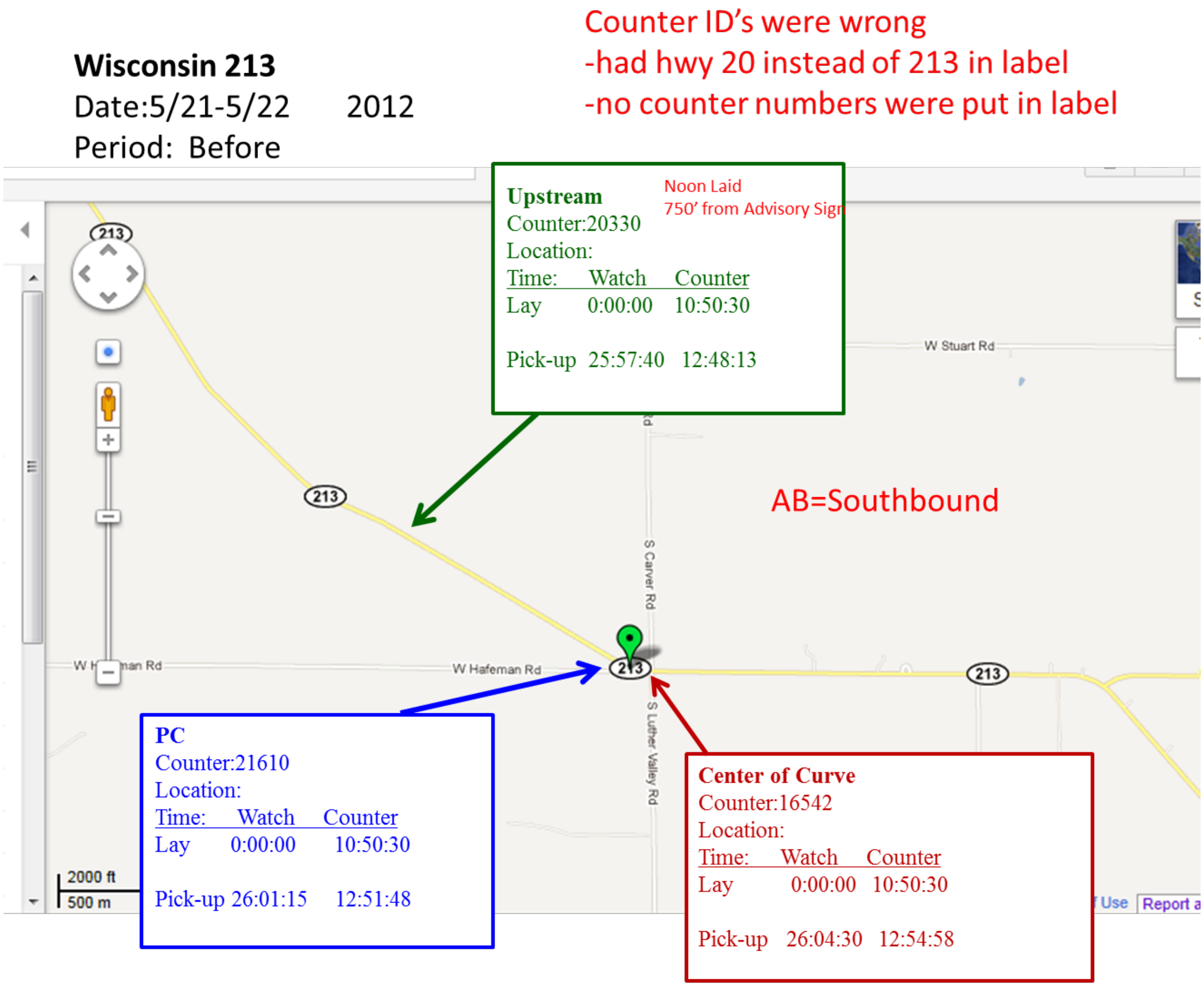


Figure 33. Map. Wisconsin Highway 213 before data collection.

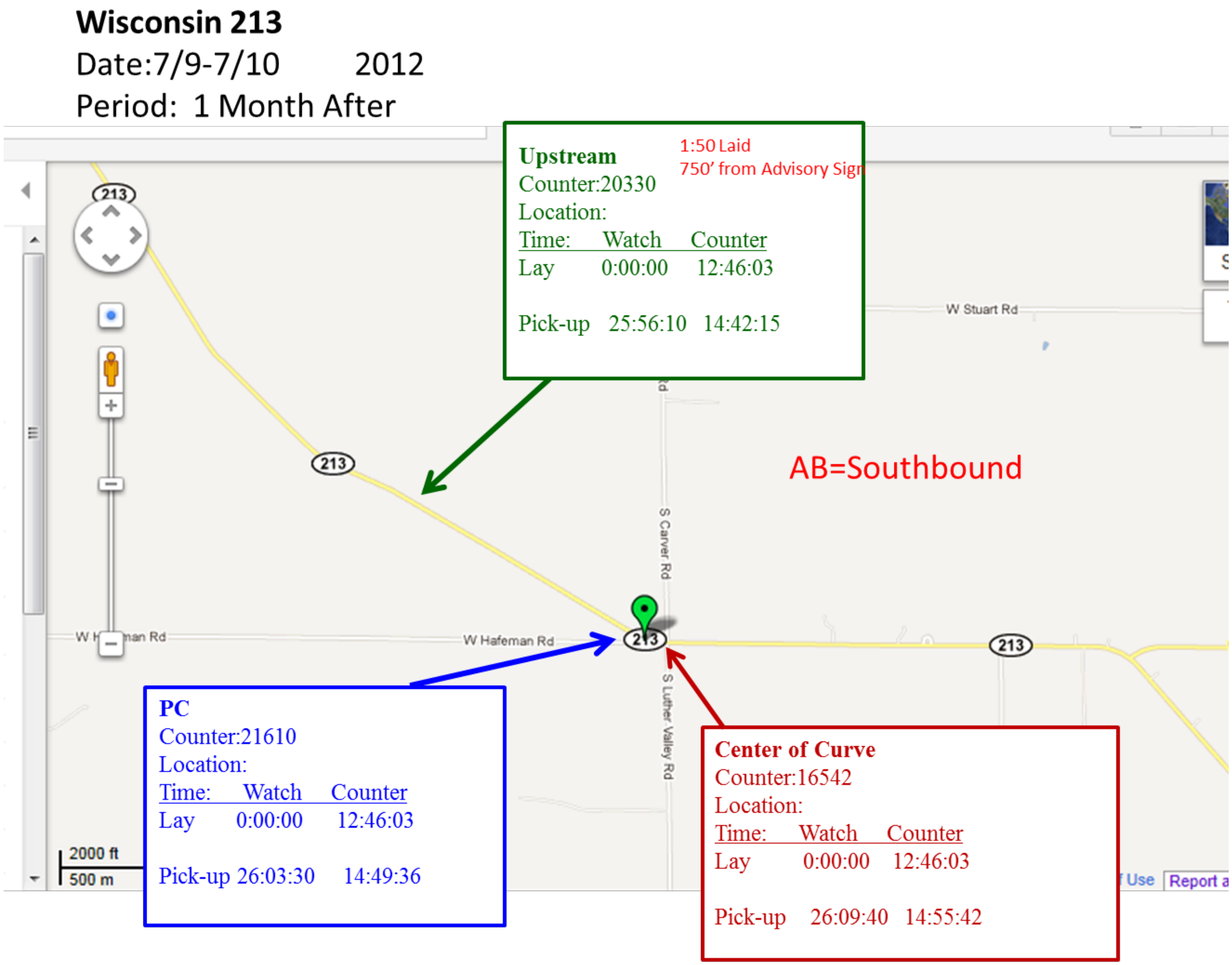


Figure 34. Map. Wisconsin Highway 213 1 month after data collection.

Wisconsin 213
Date:5/21-5/22 2012
Period: Before

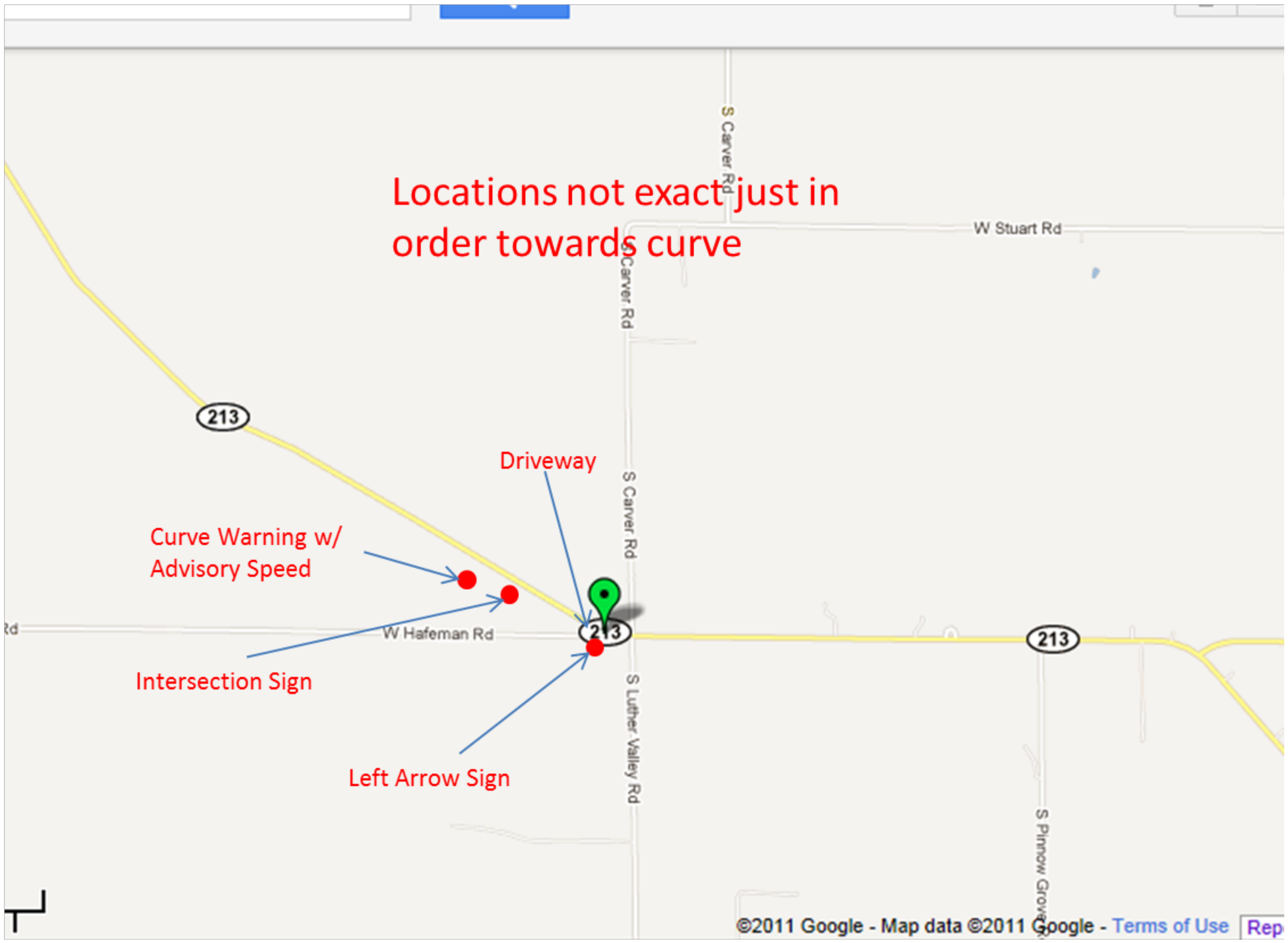


Figure 35. Map. Wisconsin Highway 213 site layout.

Wisconsin 213
Date: 5/21-5/22/2012
Period: Before

N42°35.977’ W089°12.570’	location (gps at center of curve)
2 Lanes, 24’	# lanes and width
Left	curve direction (left or right)
3’ Asphalt with varying gravel edge	shoulder type and width
55	posted speed of curve in each direction
55	tangent speed in each direction
50	advisory speed in each direction
Below	grade (average of 3 readings and list if positive or negative)
Below	super elevation
Previous Slide (5 Chevrons)	location and type of signing before and in the
Asphalt, Good	pavement type and condition
None	presence and location of street lighting

	Begin W-E				Center W-E				End W-E			
Grade	SB	Center	NB	Average	SB	Center	NB	Average	SB	Center	NB	Average
	-4.9	-4.9	-4.8	-4.87	-5.6	-5.4	-5.7	-5.57	-3.8	-3.2	-3.1	-3.37

	Begin S-N				Center S-N				End S-N			
Super Elevation	SB	Center	NB	Average	SB	Center	NB	Average	SB	Center	NB	Average
	-3.8	-3.5	-4.7	-4.00	-6.5	-7.1	-8.6	-7.40	-4.6	-4.8	-5.4	-4.93

Figure 36. Chart. Wisconsin Highway 213 site information.

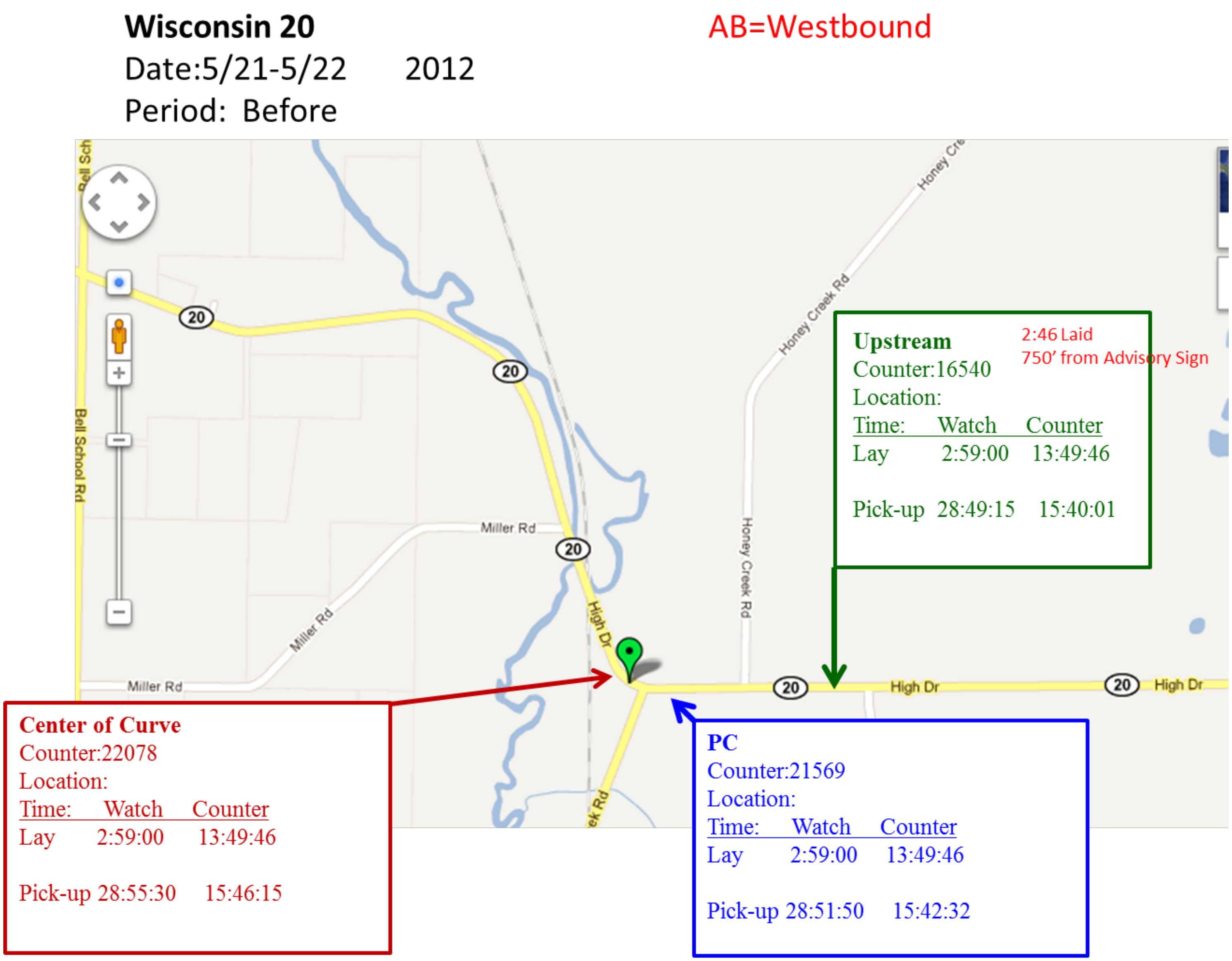


Figure 37. Map. Wisconsin Highway 20 before data collection.

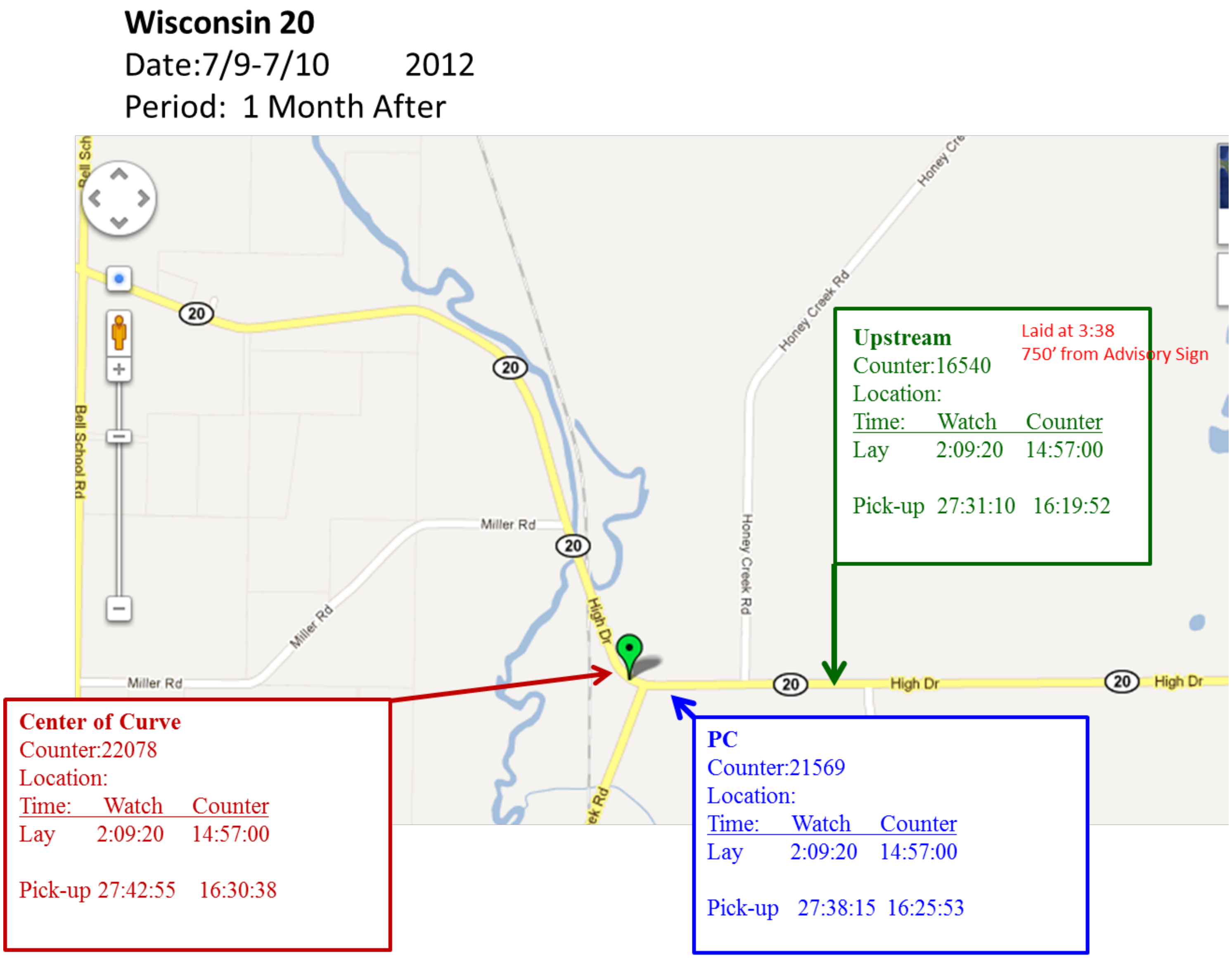


Figure 38. Map. Wisconsin Highway 20 1 month after data collection.

Figure 39. Map. Wisconsin Highway 20 site layout.

Wisconsin 20
Date: 5/21-5/22/2012
Period: Before

N42° 46.212’ W088° 18.078’	location (gps at center of curve)
2 Lanes, 25’	# lanes and width
Right	curve direction (left or right)
South (2’ Asphalt, 6’ gravel) North(14’ Asphalt w/Drainage	shoulder type and width
55	posted speed of curve in each direction
55	tangent speed in each direction
30	advisory speed in each direction
See Below	grade (average of 3 readings and list if positive or negative)
See Below	super elevation
See Layout (9 Chevrons)	location and type of signing before and in the curve
Asphalt, Good	pavement type and condition
None	presence and location of street lighting

	Begin W-E				Center W-E				End S-N			
Grade	SB	Center	NB	Average	SB	Center	NB	Average	SB	Center	NB	Average
	3	3	2.5	2.83	7.3	7	7.2	7.17	-5.9	-6.4	-6.5	-6.27

	Begin S-N				Center S-N				End W-E			
Super Elevation	SB	Center	NB	Average	SB	Center	NB	Average	SB	Center	NB	Average
	-4	-5.3	-3	-4.10	-7.7	-8.3	-8.2	-8.07	-3.4	-5.6	-4	-4.33

Figure 40. Chart. Wisconsin Highway 20 site information.

Figure 41. Map. Wisconsin Highway 67 before data collection.

Wisconsin 67
Date:7/9-7/10 2012
Period: 1 Month After

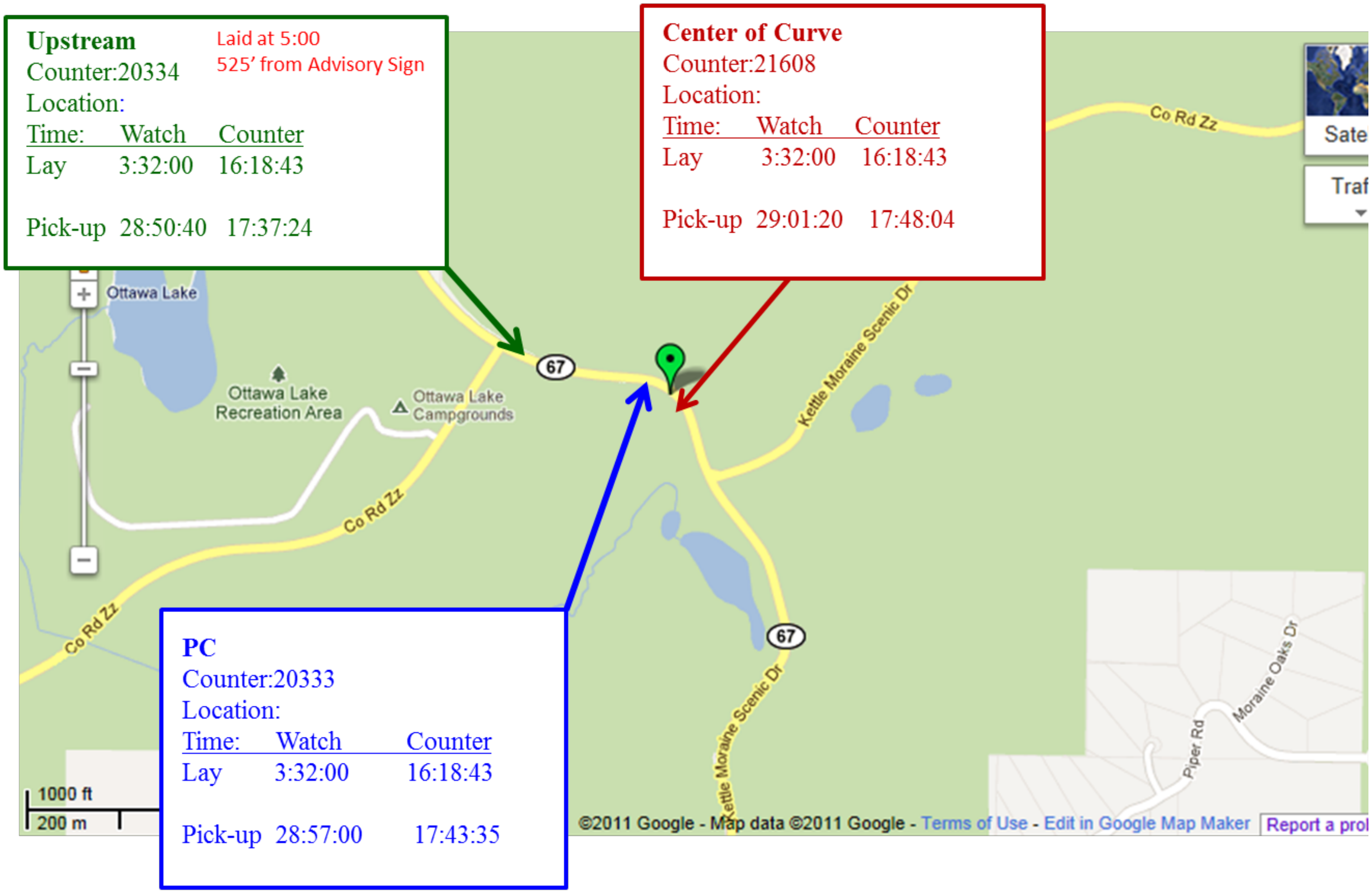


Figure 42. Map. Wisconsin Highway 67 1 month after data collection.

Figure 43. Map. Wisconsin Highway 67 site layout.

Wisconsin 67
Date: 5/21-5/22/2012
Period: Before

N42° 56.244' W088° 28.056'	location (gps at center of curve)
2 Lanes, 24'	# lanes and width
Right	curve direction (left or right)
South (3.5' asphalt w/4' Gravel then guardrail through curve) North (1.5' asphalt w/ 3' gravel)	shoulder type and width
55	posted speed of curve in each direction
55	tangent speed in each direction
25	advisory speed in each direction
See Below	grade (average of 3 readings and list if positive or negative)
See Below	super elevation
See Layout(5 Chevrons)	location and type of signing before and in the curve
Asphalt, good	pavement type and condition
None	presence and location of street lighting

	Begin W-E				Center W-E				End S-N			
Grade	SB	Center	NB	Average	SB	Center	NB	Average	SB	Center	NB	Average
	-1.6	-1.7	-1.9	-1.73	-0.1	-0.12	-0.2	-0.14	0.7	0.6	1	0.77
	Begin S-N				**Center S-N**				**End W-E**			
Super Elevation	SB	Center	NB	Average	SB	Center	NB	Average	SB	Center	NB	Average
	2	1.1	-0.4	0.90	5.8	5.2	5.1	5.37	3.6	3.2	3.1	3.30

Figure 44. Chart. Wisconsin Highway 67 site information.

APPENDIX B. SITE DATA TABLES AND FIGURES

In this appendix are the data tables and figures for each site. Each curve has three tables and two figures representing the data collected during the “before” and “1 month after” periods. The first two tables are the speed statistics collected at the PC and CC. The statistics compare the before data to 1 month after, with a negative change representing a reduction. The fraction of vehicles exceeding the speed limit change shows a percentage change in the vehicles exceeding the speed limit between the data collection periods. Also in those tables are speed statistics using the tracking methodology described in the literature review. The third table contains the statistics collected from the tracking methodology and shows the speed reductions that occurred from upstream to the respective point in the curve.

The figures are graphical representations of the data shown in the tables. One figure shows the vehicles mean and 85th percentile speeds at the data collection points, while the other figure shows the change in vehicles exceeding the speed limit at the data collection points.

Iowa Highway 144

Table 8. Results for Iowa - Hwy 144 at PC.

	Before	1 Month	Change
ADT	1435	1408	-27
Sample	717	708	
Upstream Mean Speed	60.0	58.9	-1.1
Mean Speed	50.7	49.2	-1.5
Standard Deviation	5.2	5.8	
85th Percentile Speed	56	55	-1
fraction of vehicles exceeding advisory speed			
Percentage of Vehicles 5+ Over Limit	0.61	0.49	-19.7%
Percentage of Vehicles 10+ Over Limit	0.24	0.16	-33.3%
Percentage of Vehicles 15+ Over Limit	0.04	0.04	0.0%
Percentage of Vehicles 20+ Over Limit	0.00	0.01	0.0%
Tracking Data			
Sample	705	700	
Upstream Mean Speed	60.0	59.1	-0.9
Mean Speed	50.7	49.3	-1.4
Standard Deviation	5.2	5.5	
85th Percentile Speed	56	55	-1

Table 9. Results for Iowa - Hwy 144 at CC.

	Before	1 Month	Change
ADT	1468	1428	-40
Sample	718	713	
Upstream Mean Speed	60.0	58.9	-1.1
Mean Speed	48	45.9	-2.1
Standard Deviation	6.2	6.3	
85th Percentile Speed	53	51	-2
fraction of vehicles exceeding advisory speed			
Percentage of Vehicles 5+ Over Limit	0.42	0.26	-38.1%
Percentage of Vehicles 10+ Over Limit	0.12	0.05	-58.3%
Percentage of Vehicles 15+ Over Limit	0.01	0.01	0.0%
Percentage of Vehicles 20+ Over Limit	0.00	0.00	0.0%
Tracking Data			
Sample	705	700	
Upstream Mean Speed	60.0	59.1	-0.9
Mean Speed	48.3	46.0	-2.3
Standard Deviation	5.6	6	
85th Percentile Speed	53	51	-2

Table 10. Speed Reduction for Iowa - Hwy 144.

	Before	1 Month	Change
Mean Speed Reduction Upstream to PC	9	9.7	0.5
Mean Speed Reduction Upstream to CC	11.7	13.0	1.3
Mean Speed Reduction PC to CC	2.5	3.3	0.8
85th Percentile Speed Reduction Upstream to PC	14	15	1
85th Percentile Speed Reduction Upstream to CC	17	18	1
85th Percentile Speed Reduction PC to CC	5	5	0

Iowa (Hwy 144)

Speed Limit: 55 mph
Curve Advisory Speed: 45 mph
Installed: September 2012

Impact on Vehicle Speeds

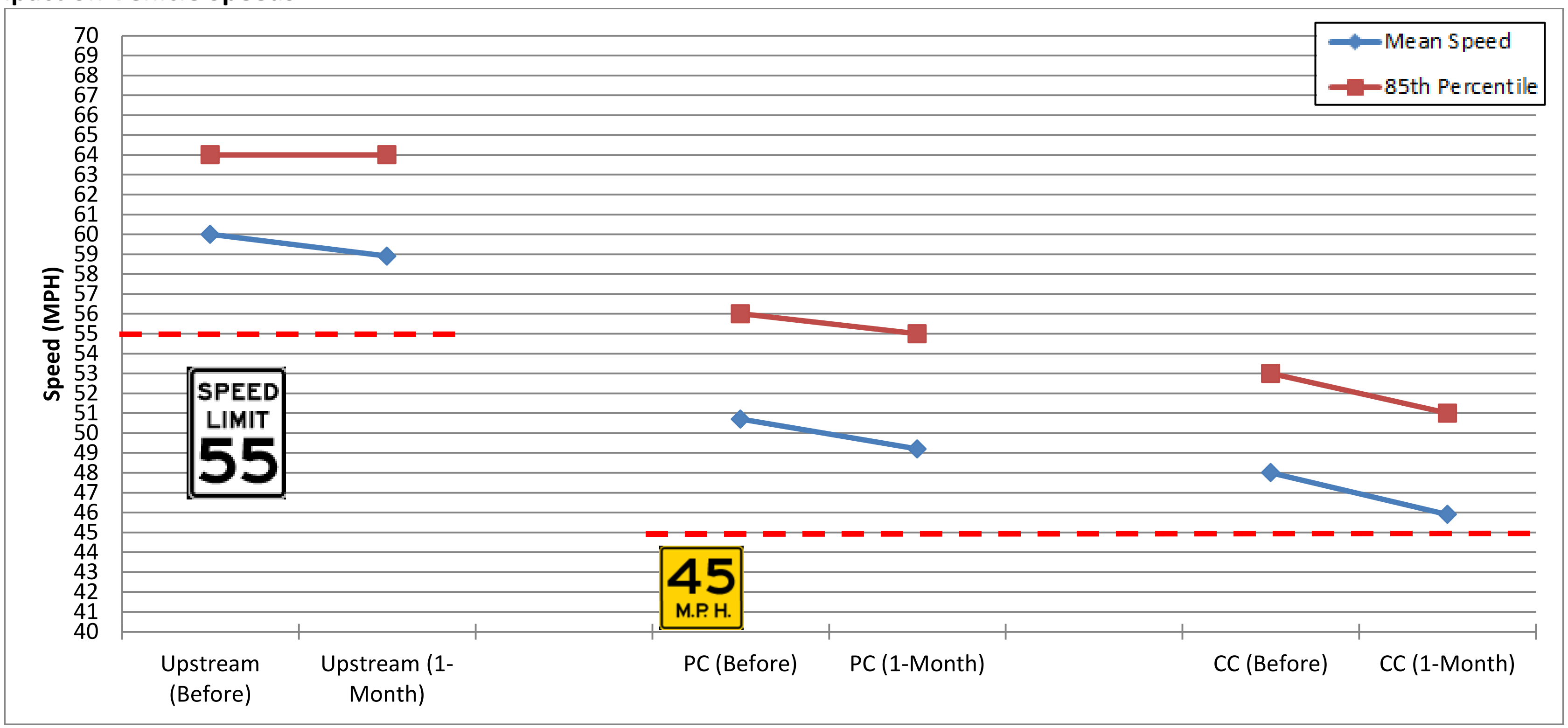


Figure 45. Graph. Impact on vehicle speed - Iowa Hwy 144.

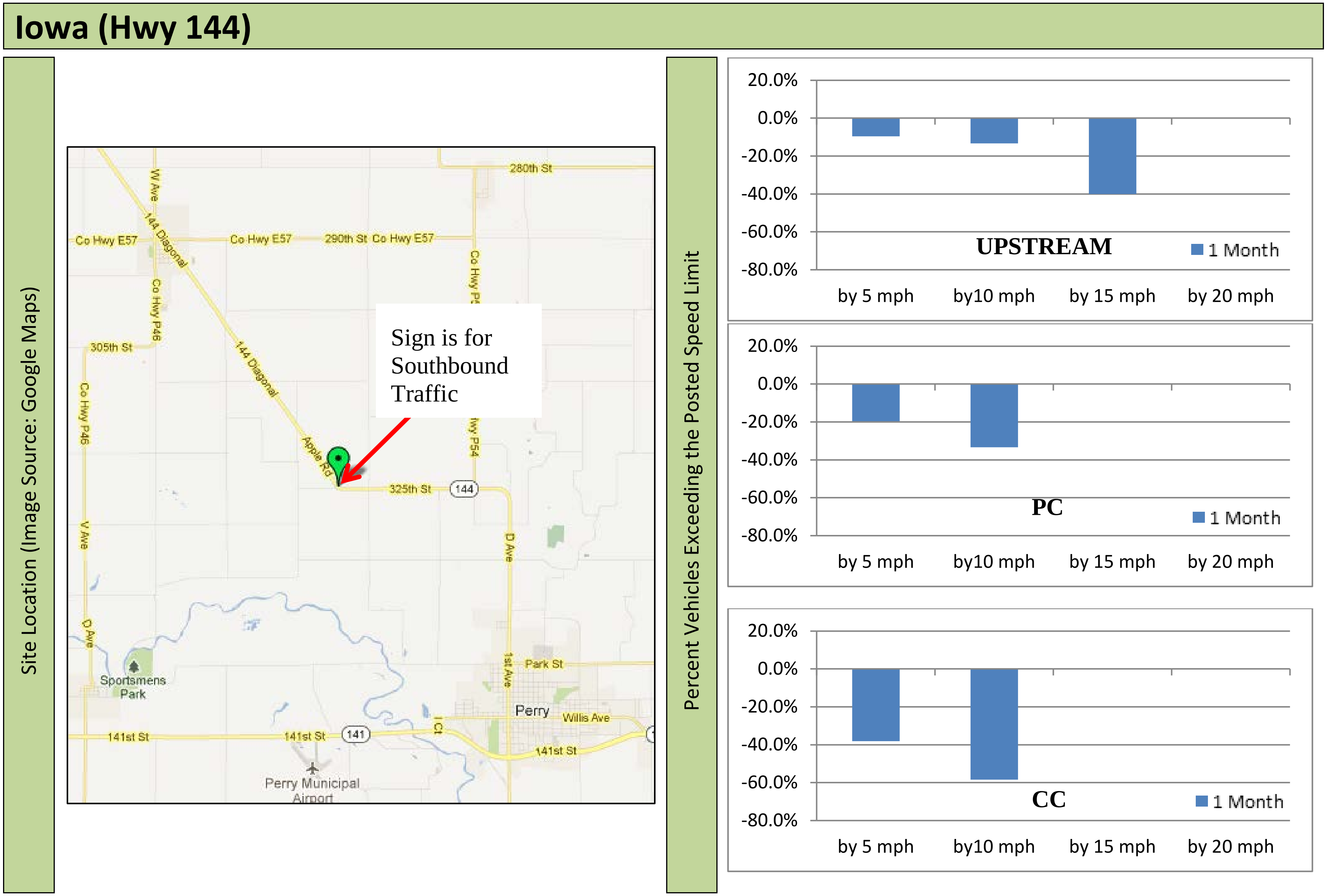


Figure 46. Map and graphs. Location and change in percentile vehicle speed - Iowa Hwy 144.

Missouri Highway 221

Table 11. Results for Missouri - Hwy 221 at PC.

	Before	1 Month	Change
ADT	5277	5158	-119
Sample	2566	2523	
Upstream Mean Speed	52.2	52.8	0.6
Mean Speed	51.7	50.2	-1.5
Standard Deviation	4.7	4.8	
85th Percentile Speed	56	55	-1
fraction of vehicles exceeding advisory speed			
Percentage of Vehicles 5+ Over Limit	0.94	0.88	-6.4%
Percentage of Vehicles 10+ Over Limit	0.70	0.58	-17.1%
Percentage of Vehicles 15+ Over Limit	0.25	0.17	-32.0%
Percentage of Vehicles 20+ Over Limit	0.04	0.02	-50.0%
Tracking Data			
Sample	2501	2459	
Upstream Mean Speed	52.2	52.8	0.6
Mean Speed	51.7	50.2	-1.5
Standard Deviation	4.7	4.8	
85th Percentile Speed	57	55	-2

Table 12. Results for Missouri - Hwy 221 at CC.

	Before	1 Month	Change
ADT	5274	5169	-105
Sample	2559	2522	
Upstream Mean Speed	52.2	52.8	0.6
Mean Speed	48.3	48.6	0.3
Standard Deviation	4.4	4.6	
85th Percentile Speed	53	53	0
fraction of vehicles exceeding advisory speed			
Percentage of Vehicles 5+ Over Limit	0.82	0.82	0.0%
Percentage of Vehicles 10+ Over Limit	0.38	0.42	10.5%
Percentage of Vehicles 15+ Over Limit	0.07	0.09	28.6%
Percentage of Vehicles 20+ Over Limit	0.01	0.01	0.0%
Tracking Data			
Sample	2501	2459	
Upstream Mean Speed	52.2	52.8	0.6
Mean Speed	48.3	48.6	0.3
Standard Deviation	4.4	4.6	
85th Percentile Speed	53	53	0

Table 13. Speed reduction for Missouri - Hwy 221.

	Before	1 Month	Change
Mean Speed Reduction Upstream to PC	0.6	2.6	2
Mean Speed Reduction Upstream to CC	3.9	4.3	0.4
Mean Speed Reduction PC to CC	3.4	1.7	-1.7
85th Percentile Speed Reduction Upstream to PC	3	6	3
85th Percentile Speed Reduction Upstream to CC	7	8	1
85th Percentile Speed Reduction PC to CC	5	3	-2

Missouri (Hwy 221)

Speed Limit: 55 mph
Curve Advisory Speed: 40 mph
Installed: July 2012

Impact on Vehicle Speeds

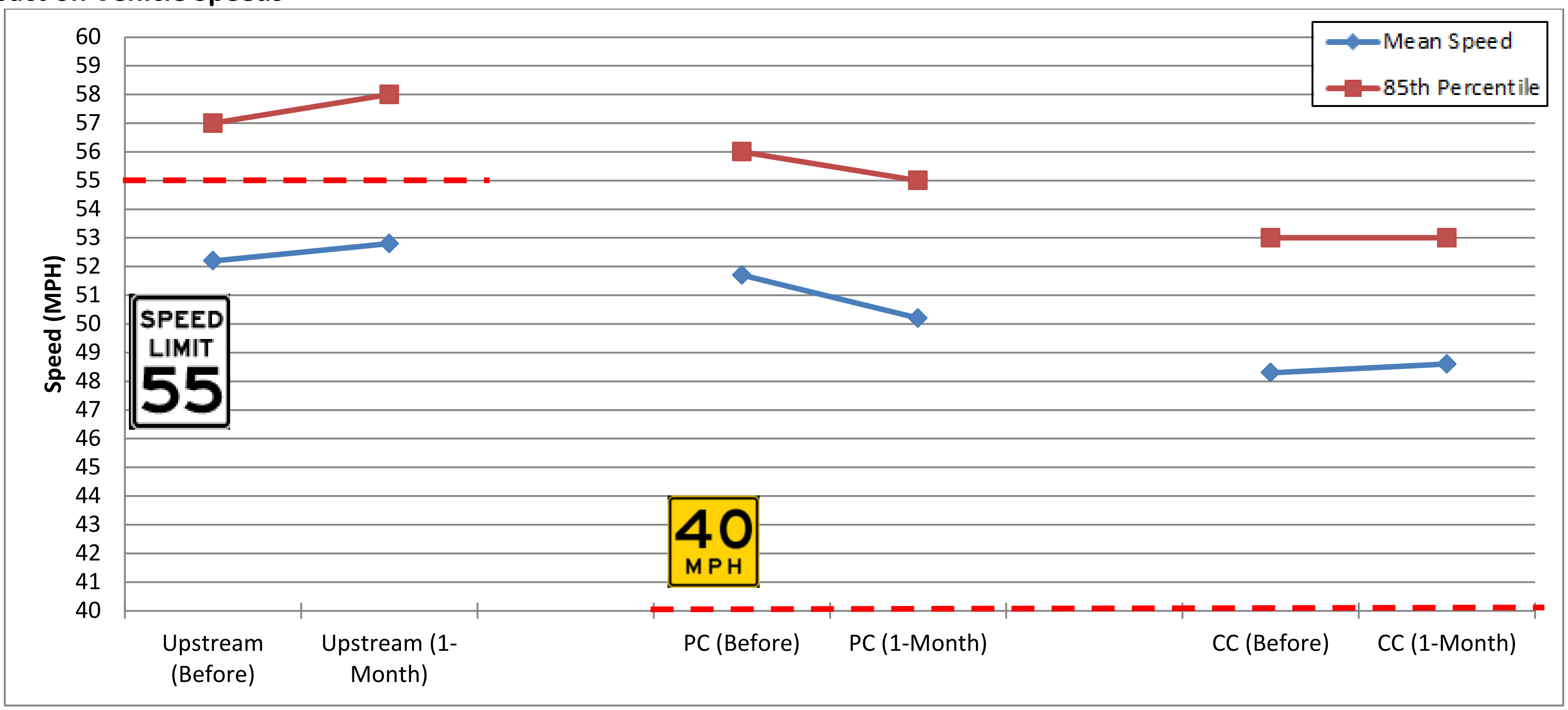
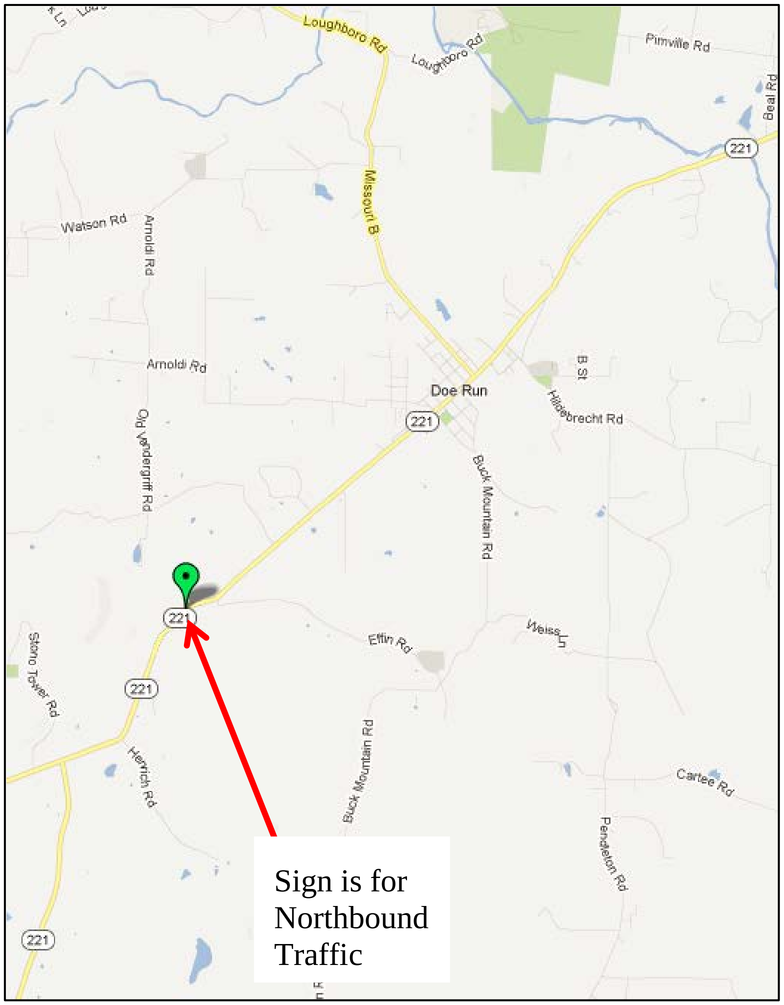


Figure 47. Graph. Impact on vehicle speed - Missouri Hwy 221.

Missouri (Hwy 221)

Site Location (Image Source: Google Maps)



Percent Vehicles Exceeding the Posted Speed Limit

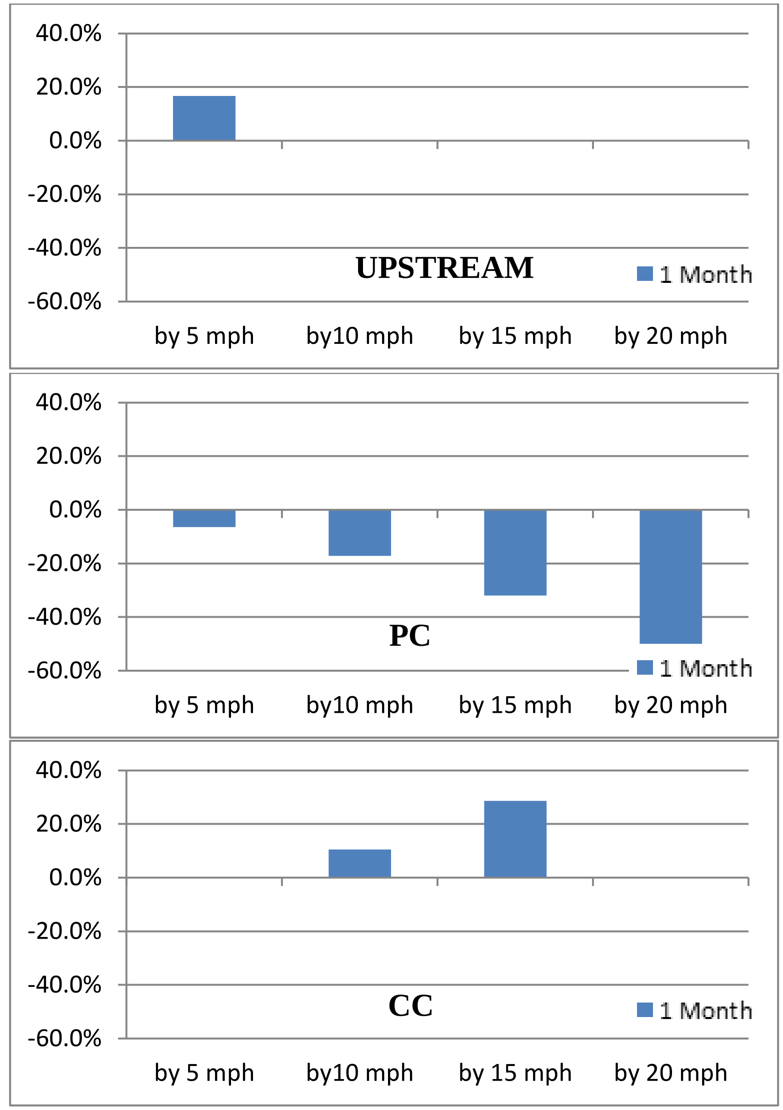


Figure 48. Map and graphs. Location and change in percentile vehicle speed - Missouri Hwy 221.

Washington SR 7

Table 14. Results for Washington - SR 7 at PC.

	Before	1 Month	Change
ADT	1408	1413	5
Sample	763	766	
Upstream Mean Speed	42.5	40.5	-2.0
Mean Speed	33.1	30.3	-2.8
Standard Deviation	4.7	4.6	
85th Percentile Speed	33	30	-3
fraction of vehicles exceeding advisory speed			
Percentage of Vehicles 5+ Over Limit	0.96	0.89	-7.3%
Percentage of Vehicles 10+ Over Limit	0.80	0.56	-30.0%
Percentage of Vehicles 15+ Over Limit	0.37	0.18	-51.4%
Percentage of Vehicles 20+ Over Limit	0.09	0.02	-77.8%
Sample	716	733	
Tracking Data			
Upstream Mean Speed	42.6	40.8	-1.8
Mean Speed	33.3	30.5	-2.8
Standard Deviation	4.6	4.4	
85th Percentile Speed	38	35	-3

Table 15. Results for Washington - SR 7 at CC.

	Before	1 Month	Change
ADT	1420	1444	24
Sample	750	770	
Upstream Mean Speed	42.5	40.5	-2.0
Mean Speed	27.2	25.8	-1.4
Standard Deviation	2.9	3.3	
85th Percentile Speed	30	29	-1
fraction of vehicles exceeding advisory speed			
Percentage of Vehicles 5+ Over Limit	0.84	0.68	-19.0%
Percentage of Vehicles 10+ Over Limit	0.20	0.11	-45.0%
Percentage of Vehicles 15+ Over Limit	0.01	0.01	0.0%
Percentage of Vehicles 20+ Over Limit	0.00	0.00	0.0%
Tracking Data			
Sample	716	733	
Upstream Mean Speed	42.6	40.8	-1.8
Mean Speed	27.2	26.0	-1.2
Standard Deviation	2.8	3.1	
85th Percentile Speed	30	29	-1

Table 16. Speed reduction for Washington - SR 7.

	Before	1 Month	Change
Mean Speed Reduction Upstream to PC	9.3	10.3	1
Mean Speed Reduction Upstream to CC	15.4	14.8	-0.6
Mean Speed Reduction PC to CC	6.1	4.5	-1.6
85th Percentile Speed Reduction Upstream to PC	14	15.2	1.2
85th Percentile Speed Reduction Upstream to CC	20	21	1
85th Percentile Speed Reduction PC to CC	9	7	-2

Washington (SR 7)

Speed Limit: 50 mph
Curve Advisory Speed: 20 mph
Installed: August 2012

Impact on Vehicle Speeds

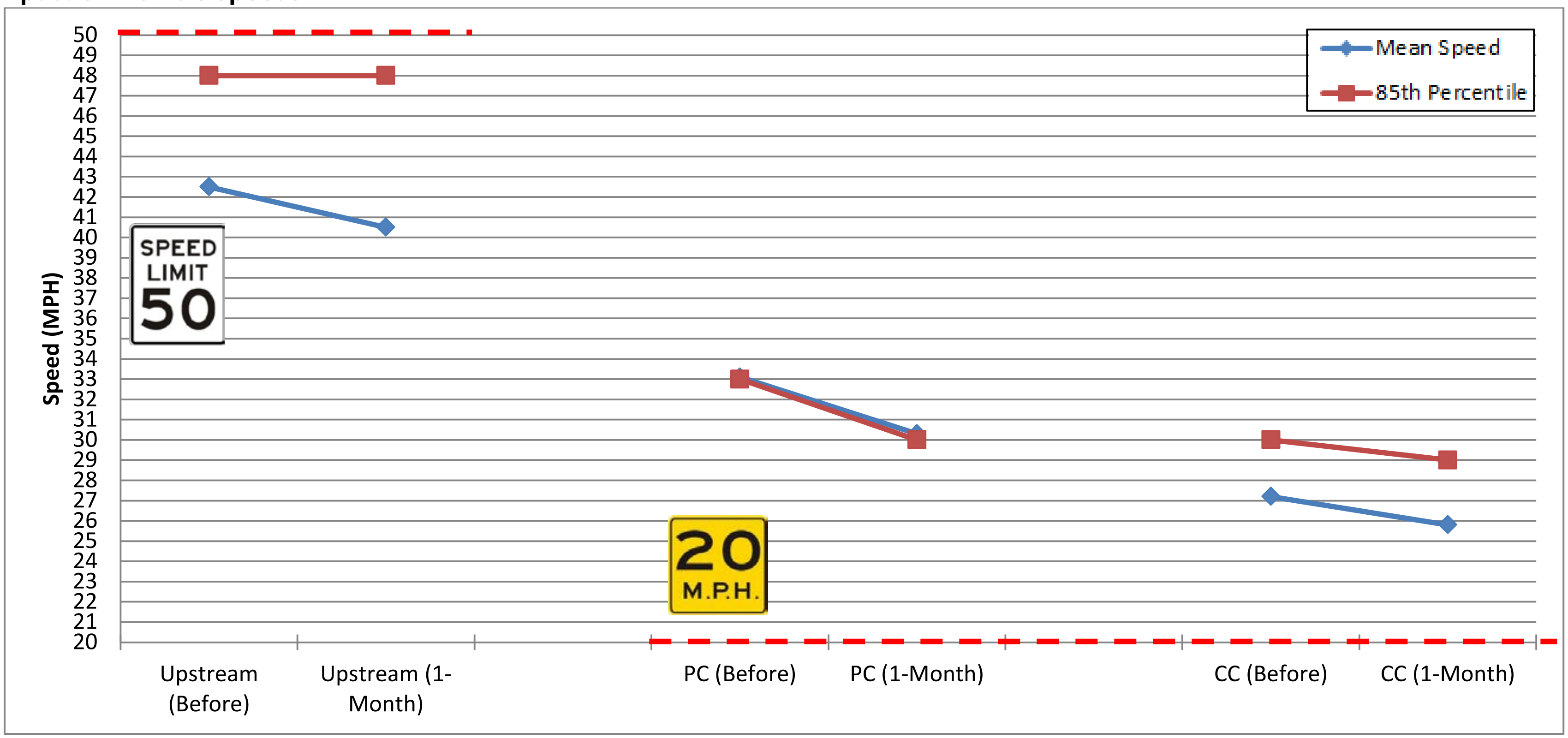
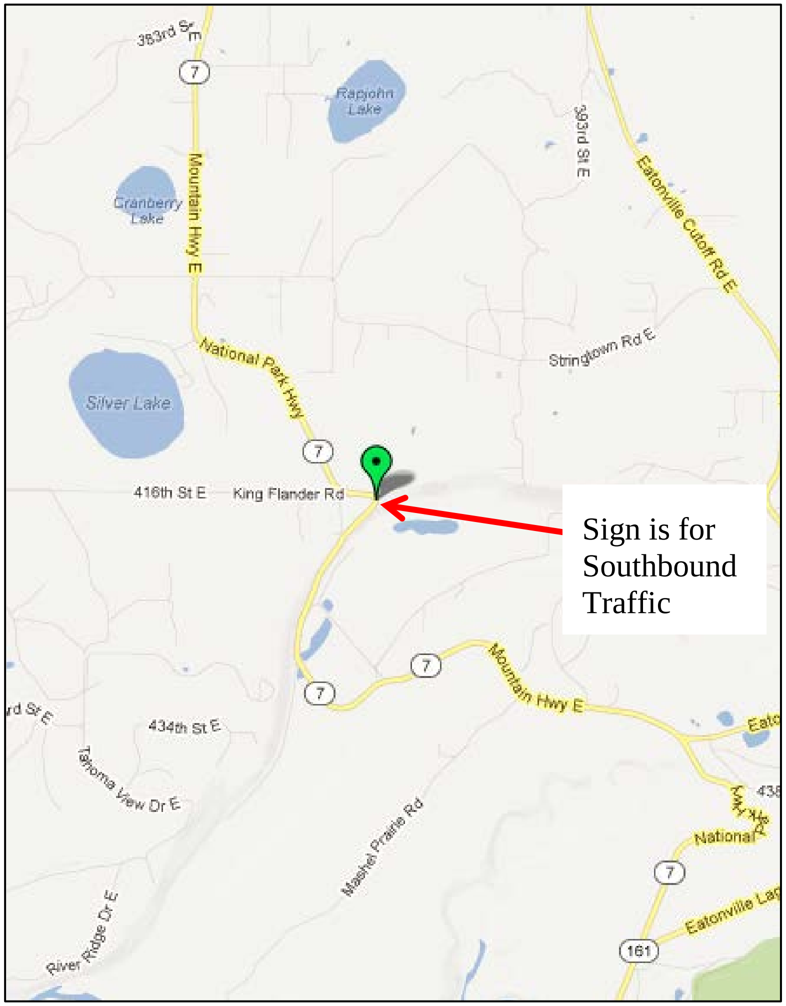


Figure 49. Graph. Impact on vehicle speed - Washington SR 7.

Washington (SR 7)

Site Location (Image Source: Google Maps)



Percent Vehicles Exceeding the Posted Speed Limit

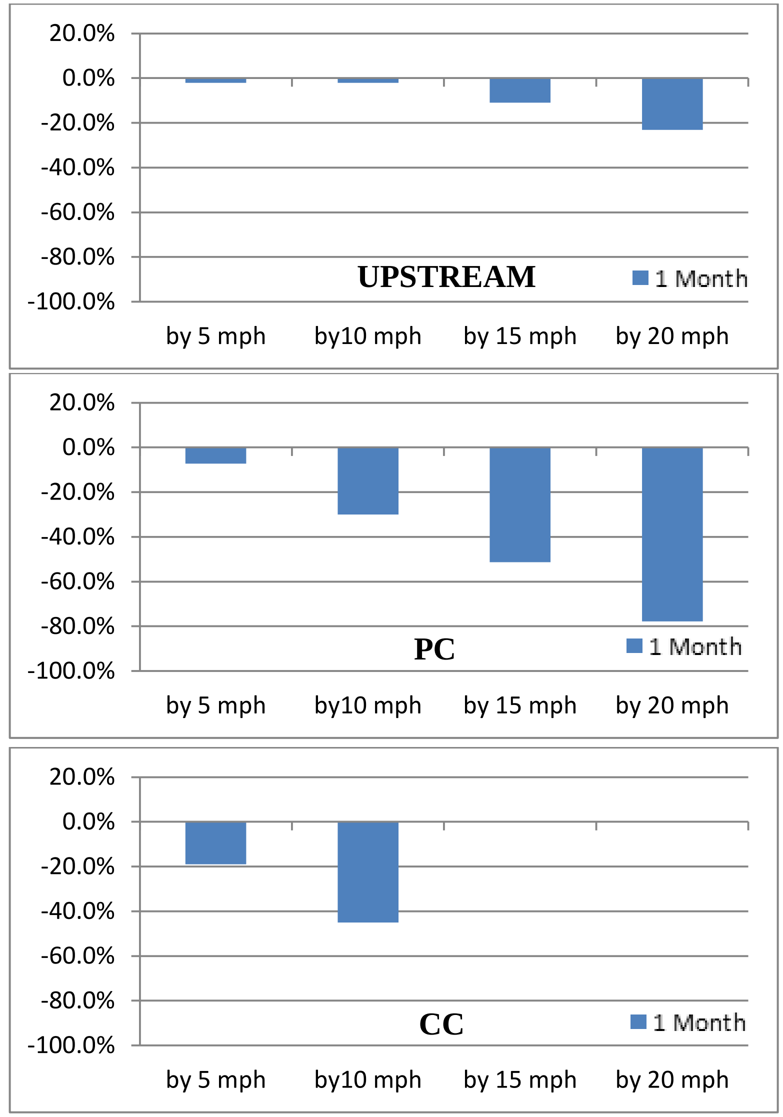


Figure 50. Map and graphs. Location and change in percentile vehicle speed - Washington SR 7.

Washington SR 9

Table 17. Results for Washington - SR 9 at PC.

	Before	1 Month	Change
ADT	5533	6212	679
Sample	2702	3062	
Upstream Mean Speed	46.9	48.7	1.8
Mean Speed	41	39.6	-1.4
Standard Deviation	5.0	5.0	
85th Percentile Speed	46	45.0	-1
fraction of vehicles exceeding advisory speed			
Percentage of Vehicles 5+ Over Limit	0.23	0.16	-30.4%
Percentage of Vehicles 10+ Over Limit	0.04	0.02	-50.0%
Percentage of Vehicles 15+ Over Limit	0.01	0.00	-100.0%
Percentage of Vehicles 20+ Over Limit	0.00	0.00	0.0%
Tracking Data			
Sample	2598	2957	
Upstream Mean Speed	47.1	48.8	1.7
Mean Speed	41.1	39.7	-1.4
Standard Deviation	4.9	4.9	
85th Percentile Speed	46	44	-2

Table 18. Results for Washington - SR 9 at CC.

	Before	1 Month	Change
ADT	5523	6227	704
Sample	2688	3081	
Upstream Mean Speed	46.9	48.7	1.8
Mean Speed	40.2	39.3	-0.9
Standard Deviation	5.0	5.0	
85th Percentile Speed	45	44	-1
fraction of vehicles exceeding advisory speed			
Percentage of Vehicles 5+ Over Limit	0.19	0.14	-26.3%
Percentage of Vehicles 10+ Over Limit	0.03	0.02	-33.3%
Percentage of Vehicles 15+ Over Limit	0.00	0.00	0.0%
Percentage of Vehicles 20+ Over Limit	0.00	0.00	0.0%
Tracking Data			
Sample	2598	2957	
Upstream Mean Speed	47.1	48.8	1.7
Mean Speed	40.3	39.3	-1
Standard Deviation	5.0	4.9	
85th Percentile Speed	45	44	-1

Table 19. Speed reduction for Washington - SR 9.

	Before	1 Month	Change
Mean Speed Reduction Upstream to PC	6.0	9.1	3.1
Mean Speed Reduction Upstream to CC	6.8	9.5	2.7
Mean Speed Reduction PC to CC	0.8	0.4	-0.4
85th Percentile Speed Reduction Upstream to PC	9	13	4
85th Percentile Speed Reduction Upstream to CC	10	13	3
85th Percentile Speed Reduction PC to CC	2	1	-1

Washington (SR 9)

Speed Limit: 55 mph
Curve Advisory Speed: 40 mph
Installed: August 2012

Impact on Vehicle Speeds

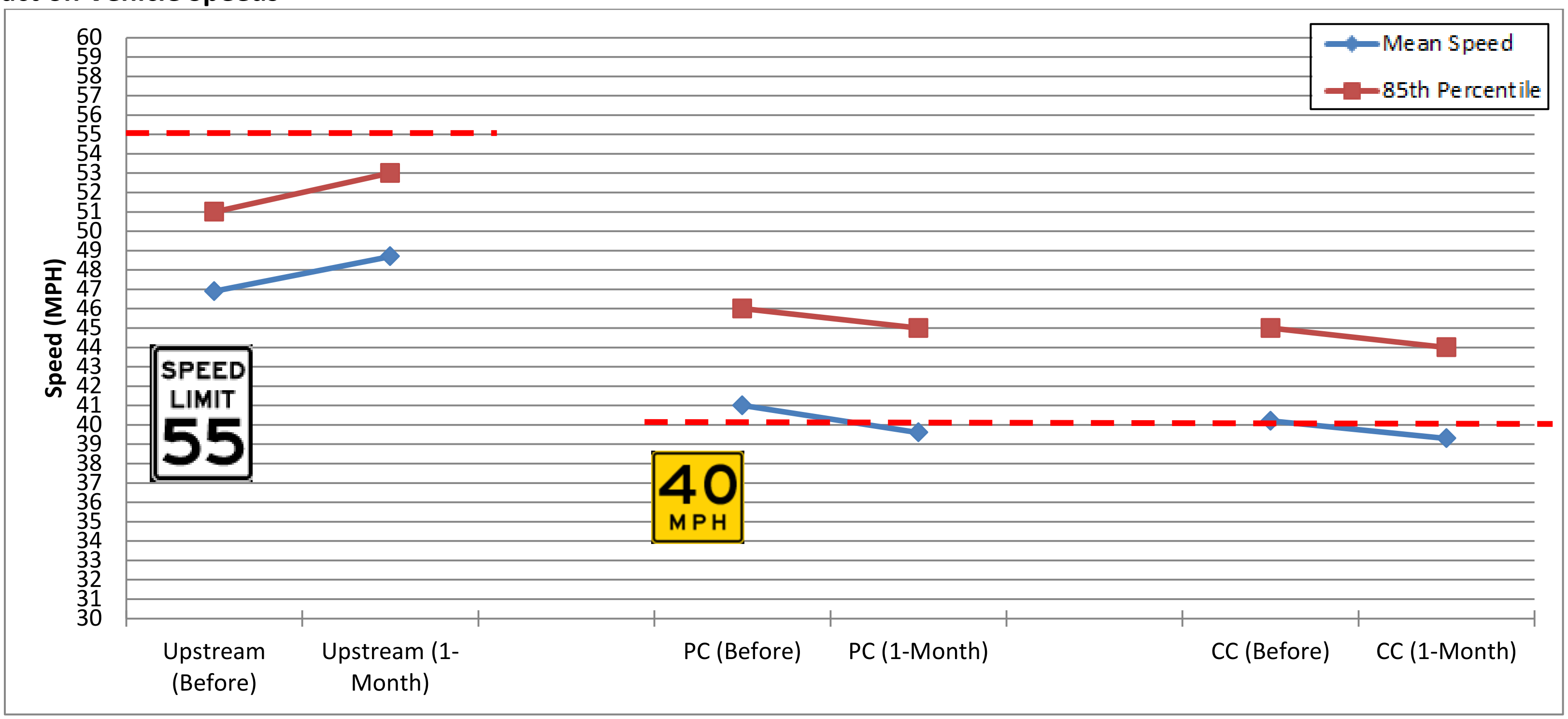


Figure 51. Graph. Impact on vehicle speed - Washington SR 9.

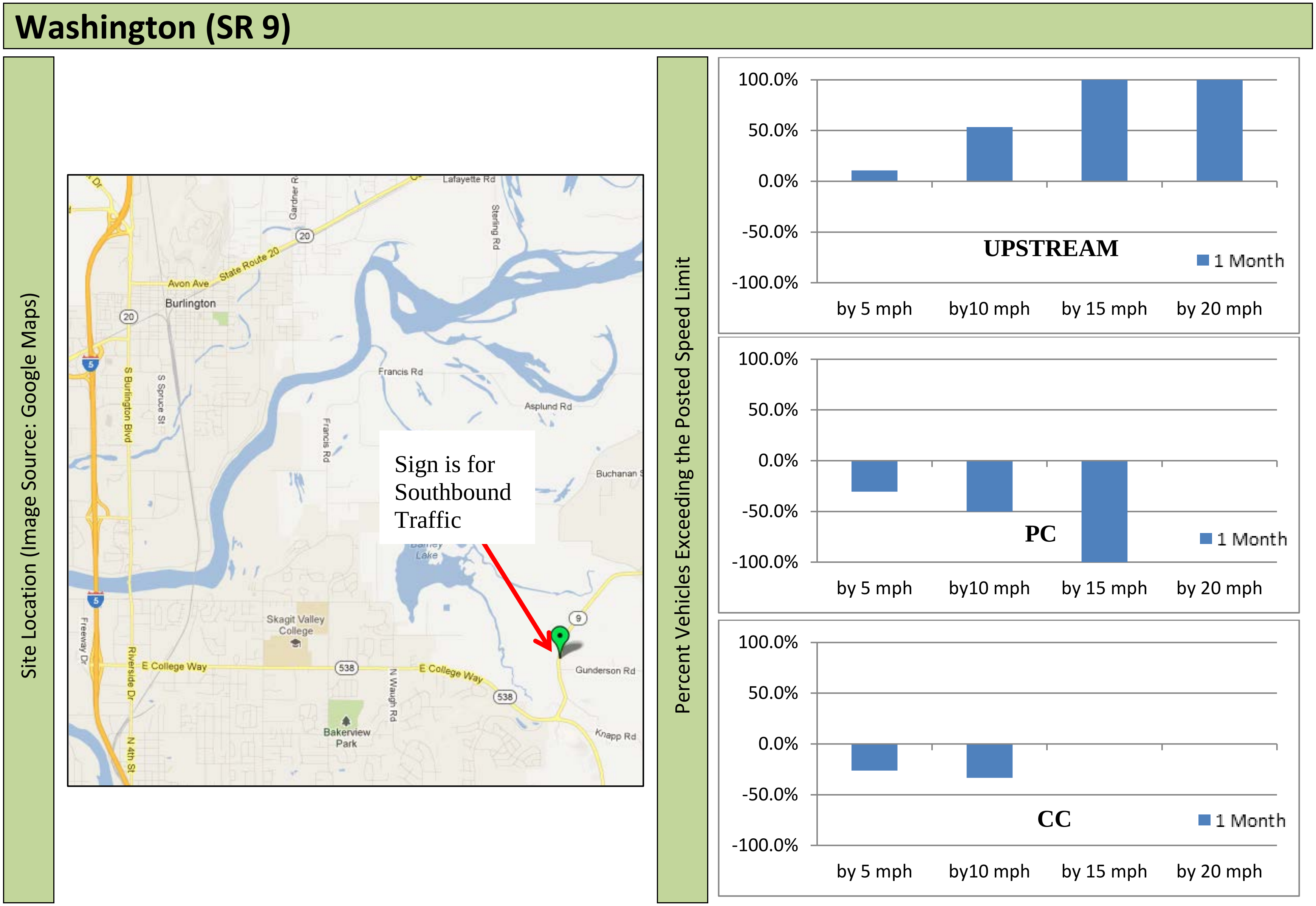


Figure 52. Map and graphs. Location and change in percentile vehicle speed - Washington SR 9.

Washington SR 203

Table 20. Results for Washington - SR 203 at PC.

	Before	1 Month	Change
ADT	10088	10761	673
Sample	4901	5190	
Upstream Mean Speed	53.8	54.2	0.4
Mean Speed	53.5	51.5	-2.0
Standard Deviation	5.0	4.5	
85th Percentile Speed	58	56	-2
fraction of vehicles exceeding advisory speed			
Percentage of Vehicles 5+ Over Limit	0.96	0.94	-2.1%
Percentage of Vehicles 10+ Over Limit	0.83	0.71	-14.5%
Percentage of Vehicles 15+ Over Limit	0.43	0.23	-46.5%
Percentage of Vehicles 20+ Over Limit	0.08	0.03	-62.5%
Tracking Data			
Sample	4637	4902	
Upstream Mean Speed	54.1	54.4	0.3
Mean Speed	53.6	51.6	-2
Standard Deviation	4.7	4.5	
85th Percentile Speed	58	56	-2

Table 21. Results for Washington - SR 203 at CC.

	Before	1 Month	Change
ADT	10120	10756	636
Sample	4921	5148	
Upstream Mean Speed	53.8	54.2	0.4
Mean Speed	51.6	51.5	-0.1
Standard Deviation	4.6	4.6	
85th Percentile Speed	56	56	0
fraction of vehicles exceeding advisory speed			
Percentage of Vehicles 5+ Over Limit	0.94	0.94	0.0%
Percentage of Vehicles 10+ Over Limit	0.72	0.70	-2.8%
Percentage of Vehicles 15+ Over Limit	0.25	0.24	-4.0%
Percentage of Vehicles 20+ Over Limit	0.03	0.03	0.0%
Tracking Data			
Sample	4637	4902	
Upstream Mean Speed	54.1	54.4	0.3
Mean Speed	51.8	51.6	-0.2
Standard Deviation	4.5	4.6	
85th Percentile Speed	56	56	0

Table 22. Speed reduction for Washington - SR 203.

	Before	1 Month	Change
Mean Speed Reduction Upstream to PC	0.5	2.8	2.3
Mean Speed Reduction Upstream to CC	2.4	2.8	0.4
Mean Speed Reduction PC to CC	1.8	0	-1.8
85th Percentile Speed Reduction Upstream to PC	3	6	3
85th Percentile Speed Reduction Upstream to CC	6	7	1
85th Percentile Speed Reduction PC to CC	3	2	-1

Washington (SR 203)

Speed Limit: 55 mph
Curve Advisory Speed: None
Installed: August 2012

Impact on Vehicle Speeds

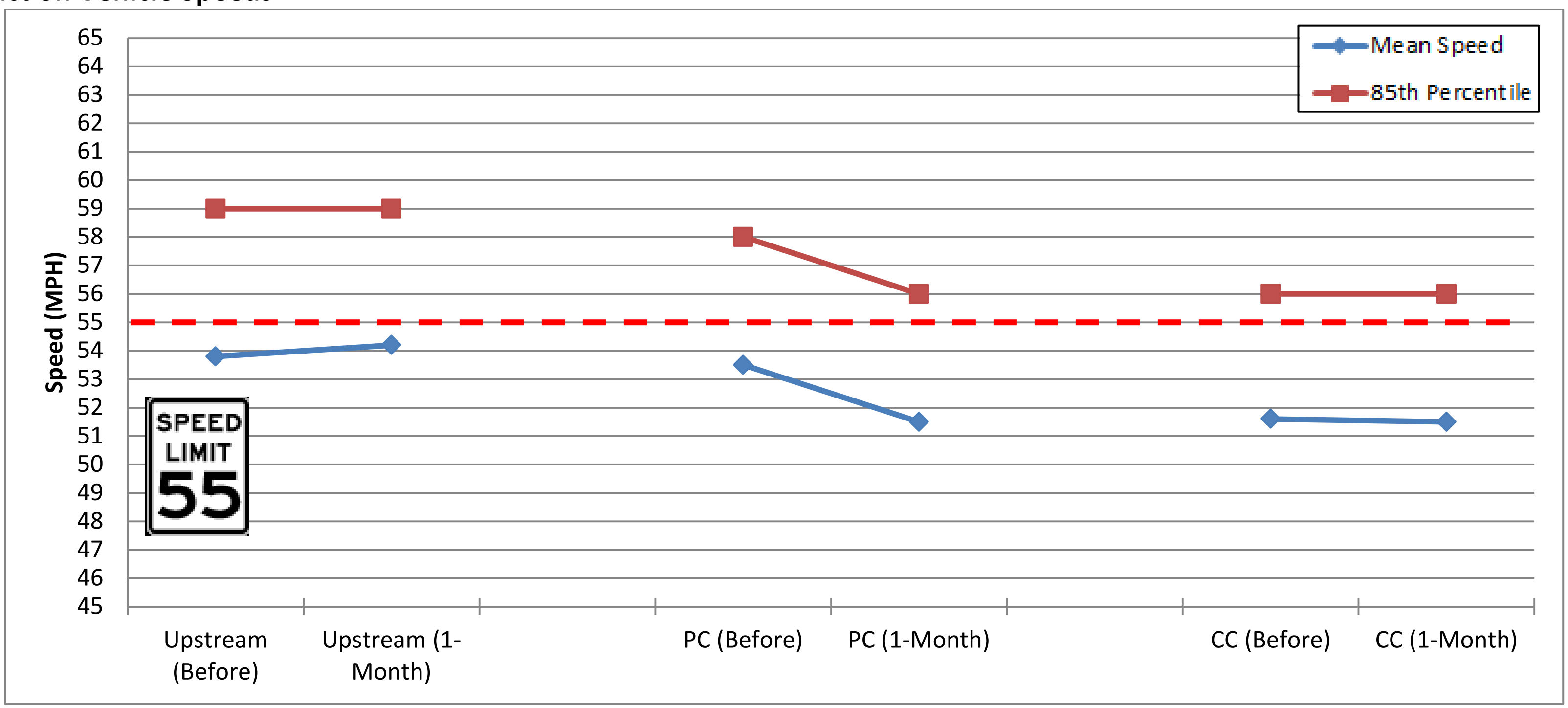


Figure 53. Graph. Impact on vehicle speed - Washington SR 203.

Washington (SR 203)

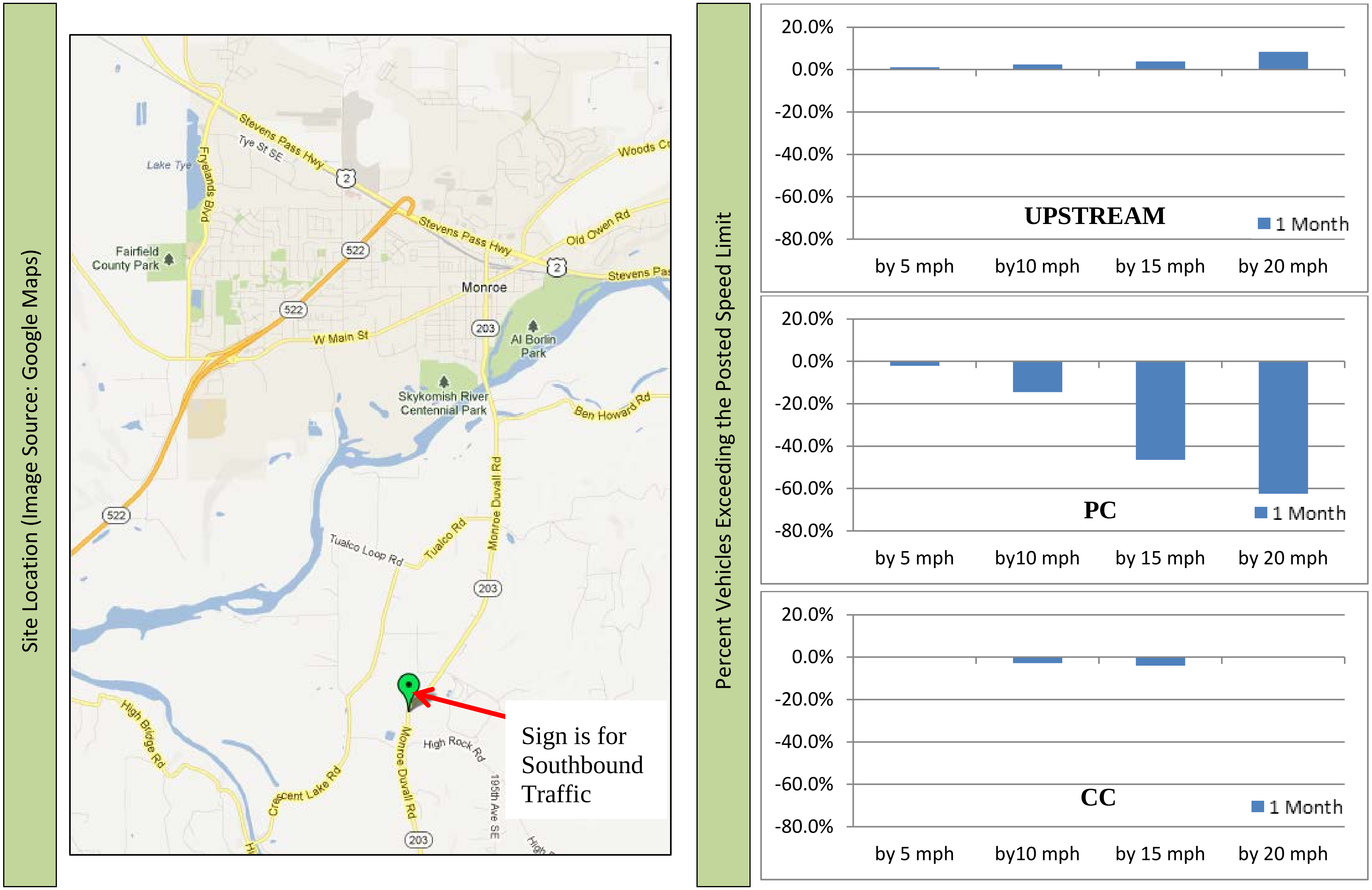


Figure 54. Map and graphs. Location and change in percentile vehicle speed - Washington SR 203.

Wisconsin Highway 20

Table 23. Results for Wisconsin - Hwy 20 at PC.

	Before	1 Month	Change
ADT	3583	3250	-333
Sample	1692	1556	
Upstream Mean Speed	53.7	55.2	1.5
Mean Speed	39.6	37.8	-1.8
Standard Deviation	7.6	7.1	
85th Percentile Speed	47	45	-2
fraction of vehicles exceeding advisory speed			
Percentage of Vehicles 5+ Over Limit	0.77	0.70	-9.1%
Percentage of Vehicles 10+ Over Limit	0.58	0.47	-19.0%
Percentage of Vehicles 15+ Over Limit	0.27	0.16	-40.7%
Percentage of Vehicles 20+ Over Limit	0.07	0.03	-57.1%
Tracking Data			
Sample	1318	1251	
Upstream Mean Speed	54.1	55.7	1.6
Mean Speed	42.1	40.1	-2
Standard Deviation	5.7	5.4	
85th Percentile Speed	48	45	-3

Table 24. Results for Wisconsin - Hwy 20 at CC.

	Before	1 Month	Change
ADT	3128	2823	-305
Sample	1456	1350	
Upstream Mean Speed	53.7	55.2	1.5
Mean Speed	37.4	35.6	-1.8
Standard Deviation	4.8	4.6	
85th Percentile Speed	42	40	-2
fraction of vehicles exceeding advisory speed			
Percentage of Vehicles 5+ Over Limit	0.77	0.63	-18.2%
Percentage of Vehicles 10+ Over Limit	0.33	0.18	-45.5%
Percentage of Vehicles 15+ Over Limit	0.06	0.02	-66.7%
Percentage of Vehicles 20+ Over Limit	0.01	0.00	-100.0%
Tracking Data			
Sample	1318	1251	
Upstream Mean Speed	54.1	55.7	1.6
Mean Speed	37.8	36.1	-1.7
Standard Deviation	4.4	4.1	
85th Percentile Speed	42	40	-2

Table 25. Speed reduction for Wisconsin - Hwy 20.

	Before	1 Month	Change
Mean Speed Reduction Upstream to PC	12.0	15.6	3.6
Mean Speed Reduction Upstream to CC	16.2	19.5	3.3
Mean Speed Reduction PC to CC	4.3	4.0	-0.3
85th Percentile Speed Reduction Upstream to PC	18	20	2
85th Percentile Speed Reduction Upstream to CC	23	25	2
85th Percentile Speed Reduction PC to CC	8	7	-1

Wisconsin (Hwy 20)

Speed Limit: 55 mph
Curve Advisory Speed: 30 mph
Installed: June 2012

Impact on Vehicle Speeds

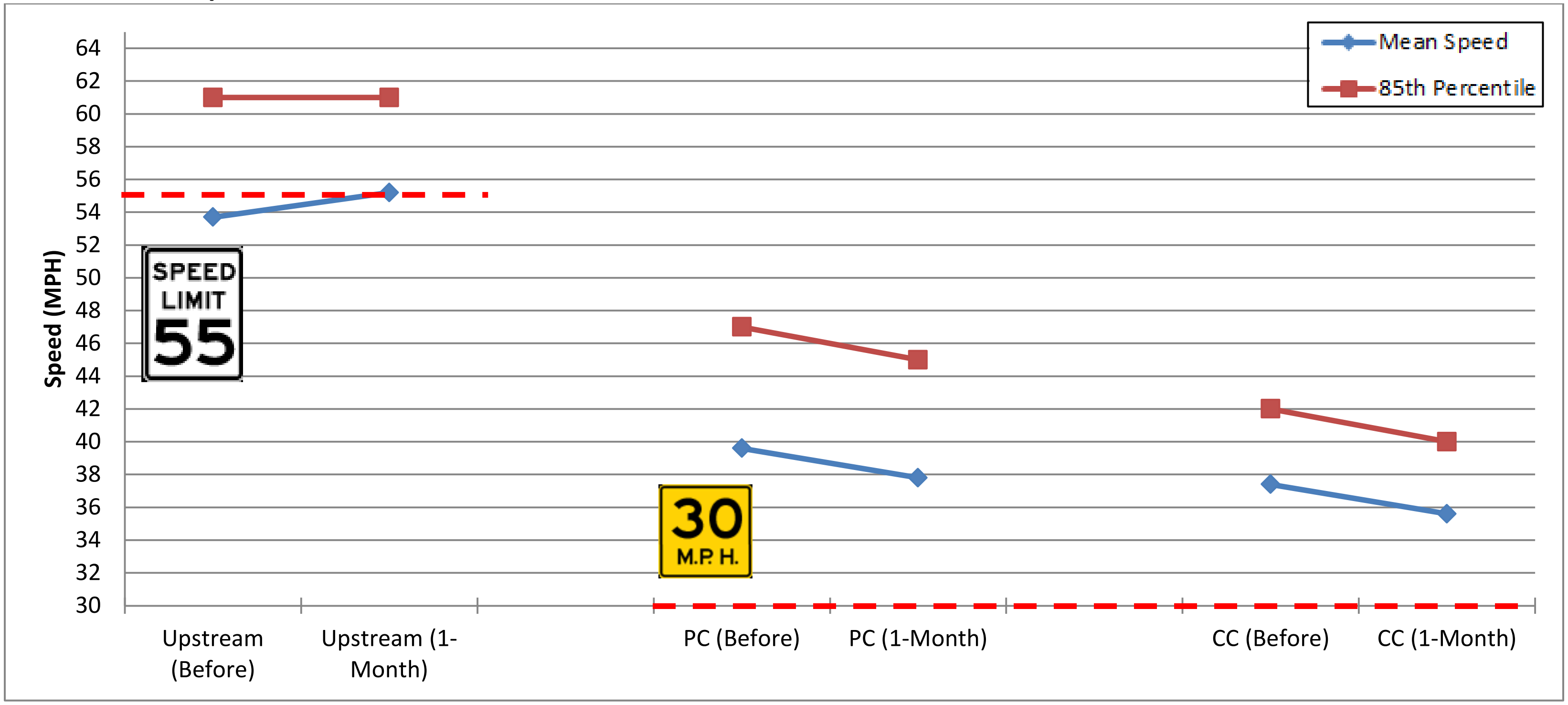
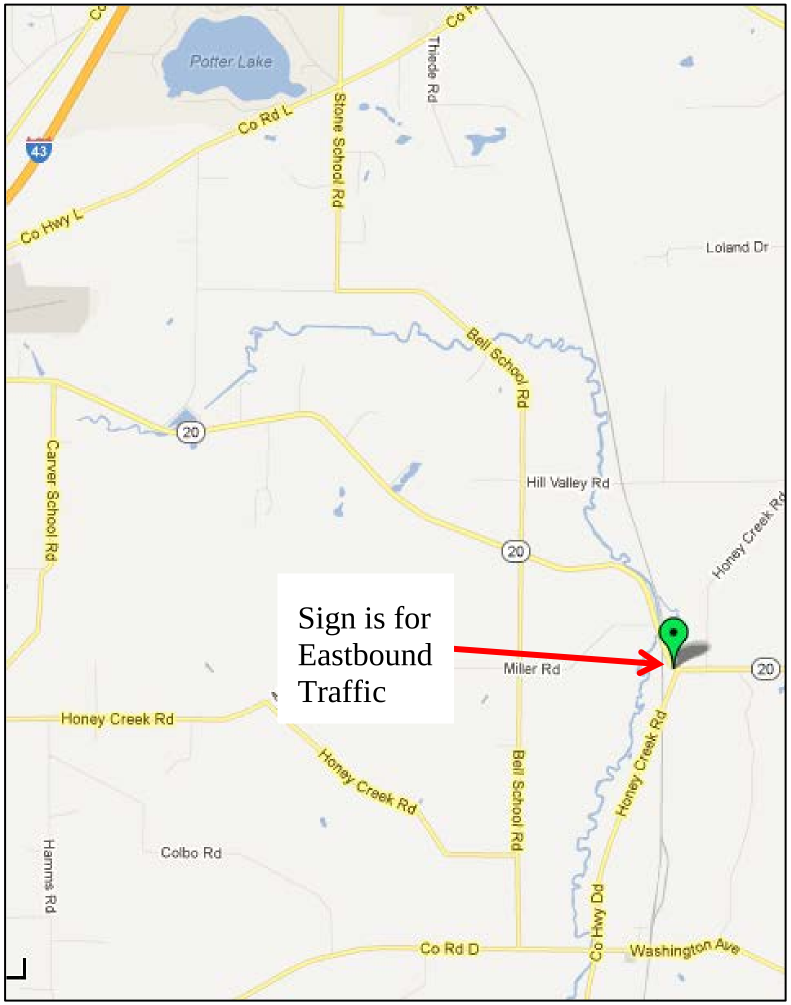


Figure 55. Graph. Impact on vehicle speed - Wisconsin Hwy 20.

Wisconsin (Hwy 20)

Site Location (Image Source: Google Maps)



Percent Vehicles Exceeding the Posted Speed Limit

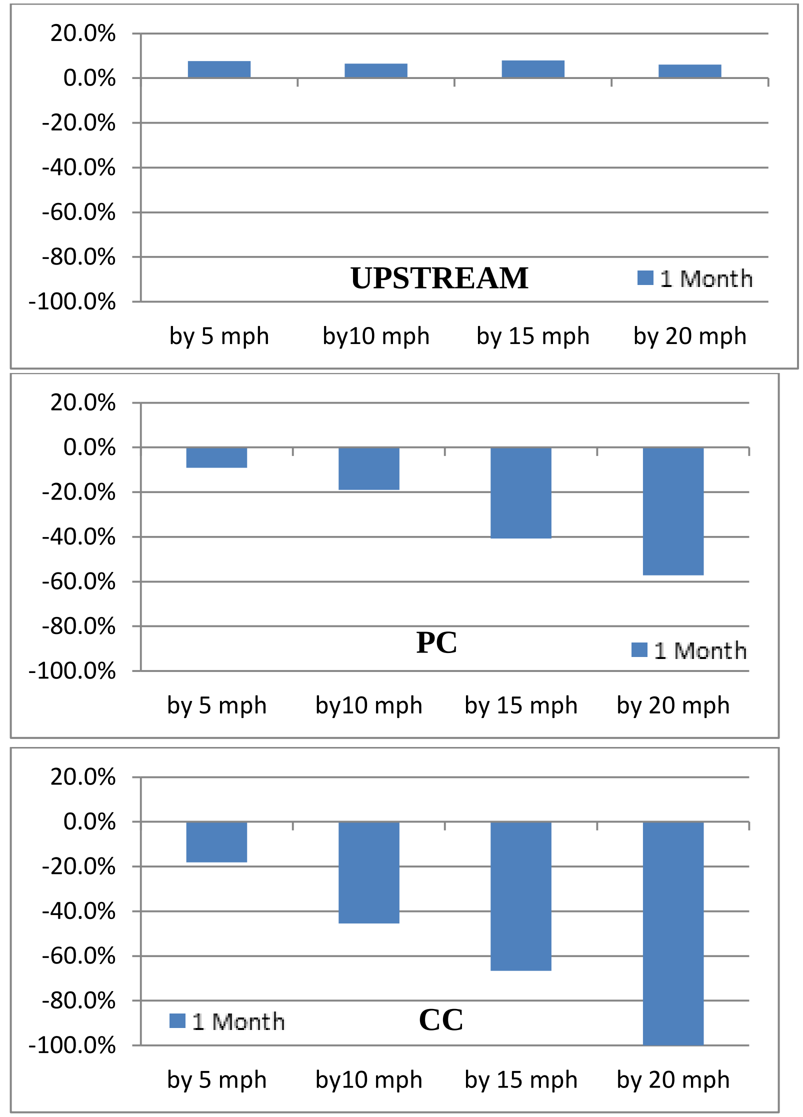


Figure 56. Map and graphs. Location and change in percentile vehicle speed - Wisconsin Hwy 20.

Wisconsin Highway 67

Table 26. Results for Wisconsin - Hwy 67 at PC.

	Before	1 Month	Change
ADT	3494	4018	524
Sample	1726	1992	
Upstream Mean Speed	50.0	48.9	-1.1
Mean Speed	46.1	44.5	-1.6
Standard Deviation	5.9	6	
85th Percentile Speed	52	51	-1
fraction of vehicles exceeding advisory speed			
Percentage of Vehicles 5+ Over Limit	0.99	0.99	0.0%
Percentage of Vehicles 10+ Over Limit	0.97	0.94	-3.1%
Percentage of Vehicles 15+ Over Limit	0.87	0.80	-8.0%
Percentage of Vehicles 20+ Over Limit	0.65	0.51	-21.5%
Tracking Data			
Sample	1668	1931	
Upstream Mean Speed	50.0	48.9	-1.1
Mean Speed	46.1	44.5	-1.6
Standard Deviation	5.8	6.0	
85th Percentile Speed	52	51	-1

Table 27. Results for Wisconsin - Hwy 67 at CC.

	Before	1 Month	Change
ADT	3496	4004	508
Sample	1713	1979	
Upstream Mean Speed	50.0	48.9	-1.1
Mean Speed	39.7	37.9	-1.8
Standard Deviation	5.0	5.0	
85th Percentile Speed	45	43	-2
fraction of vehicles exceeding advisory speed			
Percentage of Vehicles 5+ Over Limit	0.97	0.95	-2.1%
Percentage of Vehicles 10+ Over Limit	0.86	0.76	-11.6%
Percentage of Vehicles 15+ Over Limit	0.53	0.38	-28.3%
Percentage of Vehicles 20+ Over Limit	0.15	0.08	-46.7%
Tracking Data			
Sample	1668	1931	
Upstream Mean Speed	50.0	48.9	-1.1
Mean Speed	39.7	37.9	-1.8
Standard Deviation	5.0	5.0	
85th Percentile Speed	45	43	-2

Table 28. Speed Reduction for Wisconsin - Hwy 67.

	Before	1 Month	Change
Mean Speed Reduction Upstream to PC	3.9	4.40	0.5
Mean Speed Reduction Upstream to CC	10.2	11.0	0.8
Mean Speed Reduction PC to CC	6.4	6.6	0.2
85th Percentile Speed Reduction Upstream to PC	11	13	2
85th Percentile Speed Reduction Upstream to CC	19	20	1
85th Percentile Speed Reduction PC to CC	9	9	0

Wisconsin (Hwy 67)

Speed Limit: 55mph
Curve Advisory Speed: 25 mph
Installed: June 2012

Impact on Vehicle Speeds

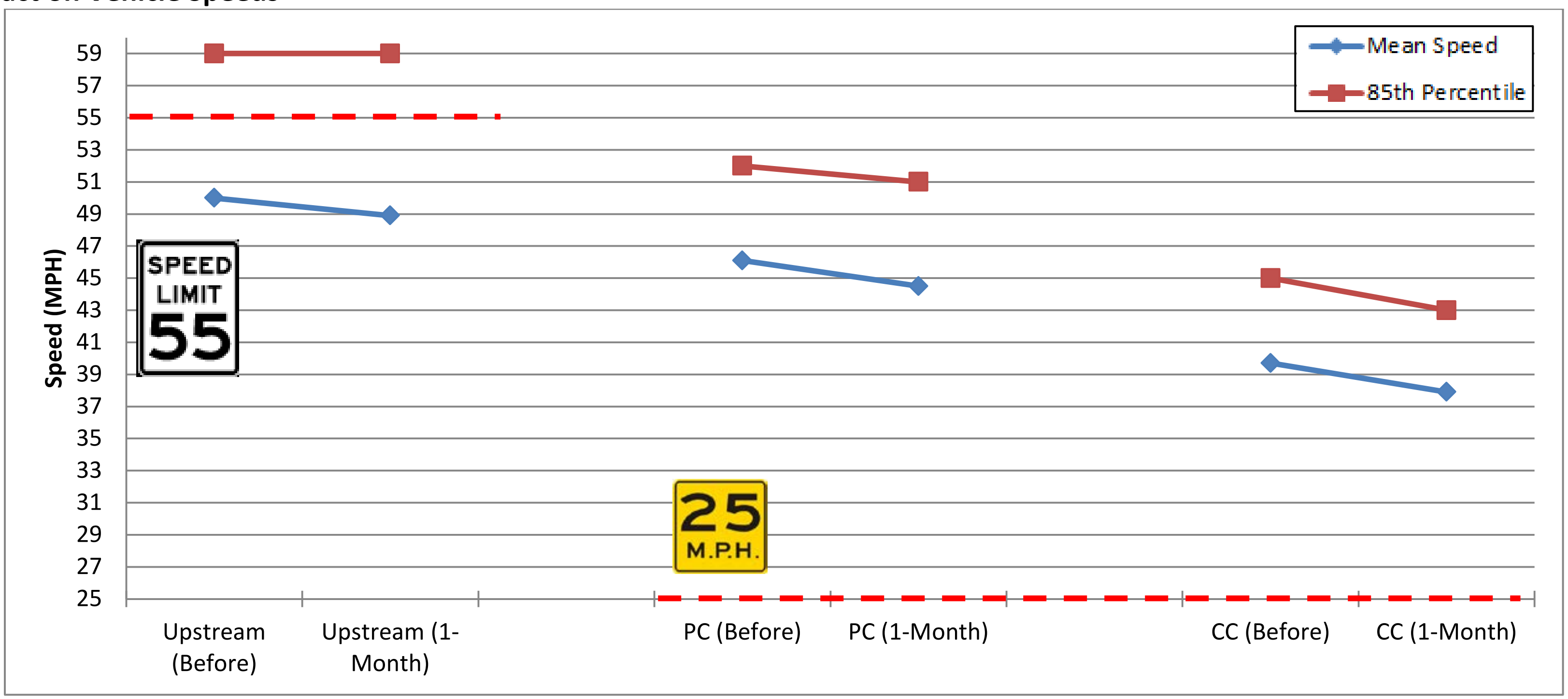


Figure 57. Graph. Impact on vehicle speed - Wisconsin Hwy 67.

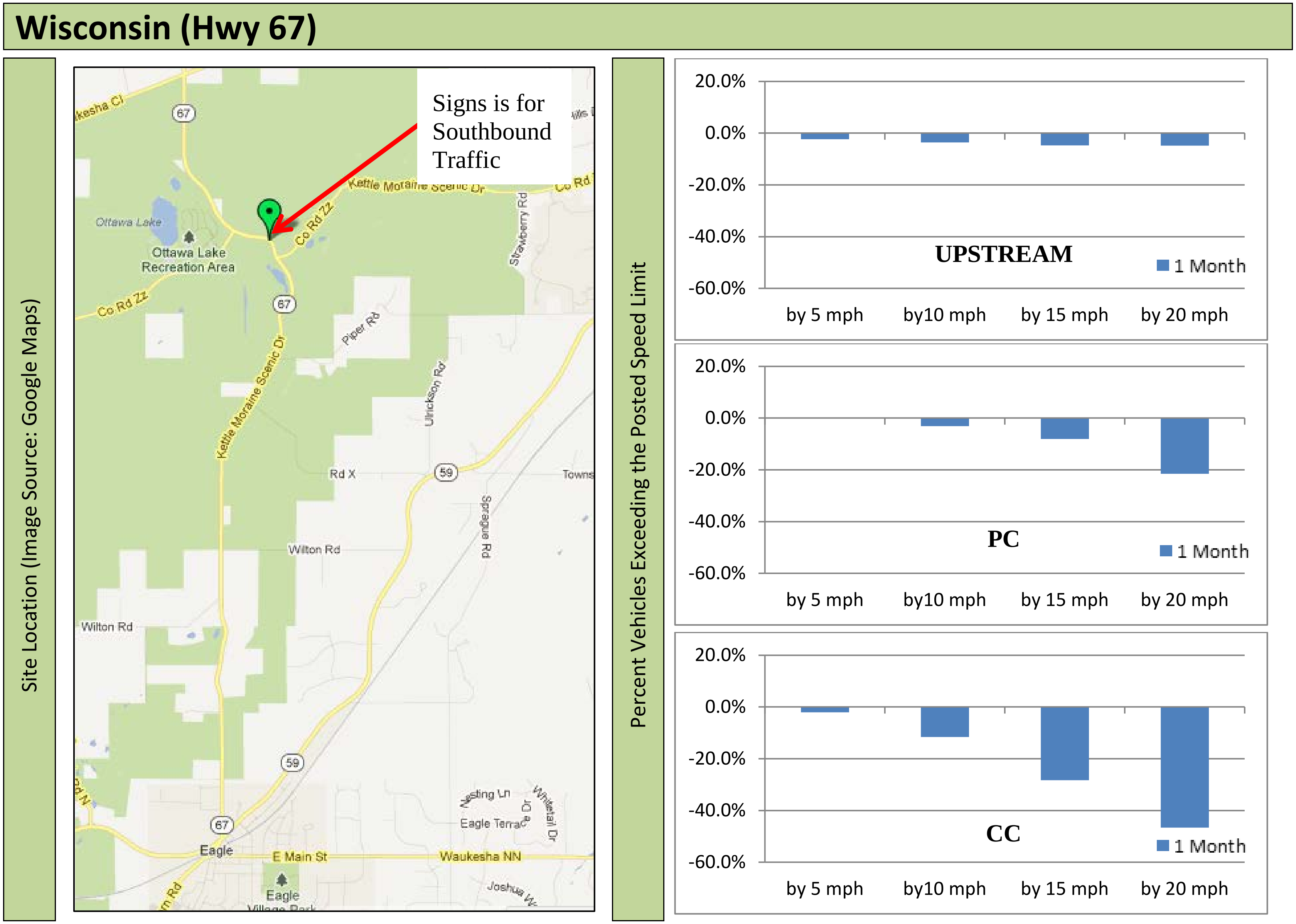


Figure 58. Map and graphs. Location and change in percentile vehicle speed - Wisconsin Hwy 67.

Wisconsin Highway 213

Table 29. Results for Wisconsin - Hwy 213 at PC.

	Before	1 Month	Change
ADT	2369	2249	-120
Sample	1156	1119	
Upstream Mean Speed	58.8	59.8	1.0
Mean Speed	55.3	54.6	-0.7
Standard Deviation	7	6.6	
85th Percentile Speed	61	61	0
fraction of vehicles exceeding advisory speed			
Percentage of Vehicles 5+ Over Limit	0.63	0.57	-9.5%
Percentage of Vehicles 10+ Over Limit	0.28	0.21	-25.0%
Percentage of Vehicles 15+ Over Limit	0.03	0.03	0.0%
Percentage of Vehicles 20+ Over Limit	0.00	0.00	0.0%
Tracking Data			
Sample	1134	1098	
Upstream Mean Speed	58.9	59.9	1
Mean Speed	55.5	54.8	-0.7
Standard Deviation	6.5	6.2	
85th Percentile Speed	61	61	0

Table 30. Results for Wisconsin - Hwy 213 at CC.

	Before	1 Month	Change
ADT	2552	2428	-124
Sample	1220	1193	
Upstream Mean Speed	58.8	59.8	1.0
Mean Speed	53.2	52.2	-1.0
Standard Deviation	9.7	9.8	
85th Percentile Speed	61	60	-1
fraction of vehicles exceeding advisory speed			
Percentage of Vehicles 5+ Over Limit	0.59	0.52	-11.9%
Percentage of Vehicles 10+ Over Limit	0.25	0.20	-20.0%
Percentage of Vehicles 15+ Over Limit	0.02	0.03	50.0%
Percentage of Vehicles 20+ Over Limit	0.00	0.00	0.0%
Tracking Data			
Sample	1134	1098	
Upstream Mean Speed	58.9	59.9	1
Mean Speed	54.7	54.0	-0.7
Standard Deviation	7.7	7.5	
85th Percentile Speed	61	61	0

Table 31. Speed reduction for Wisconsin - Hwy 213.

	Before	1 Month	Change
Mean Speed Reduction Upstream to PC	3.4	5.1	1.7
Mean Speed Reduction Upstream to CC	4.2	5.9	1.7
Mean Speed Reduction PC to CC	0.8	0.8	0
85th Percentile Speed Reduction Upstream to PC	9	10	1
85th Percentile Speed Reduction Upstream to CC	10	11.5	1.5
85th Percentile Speed Reduction PC to CC	2	2	0

Wisconsin (Hwy 213)

Speed Limit: 55 mph
Curve Advisory Speed: 50 mph
Installed: June 2012

Impact on Vehicle Speeds

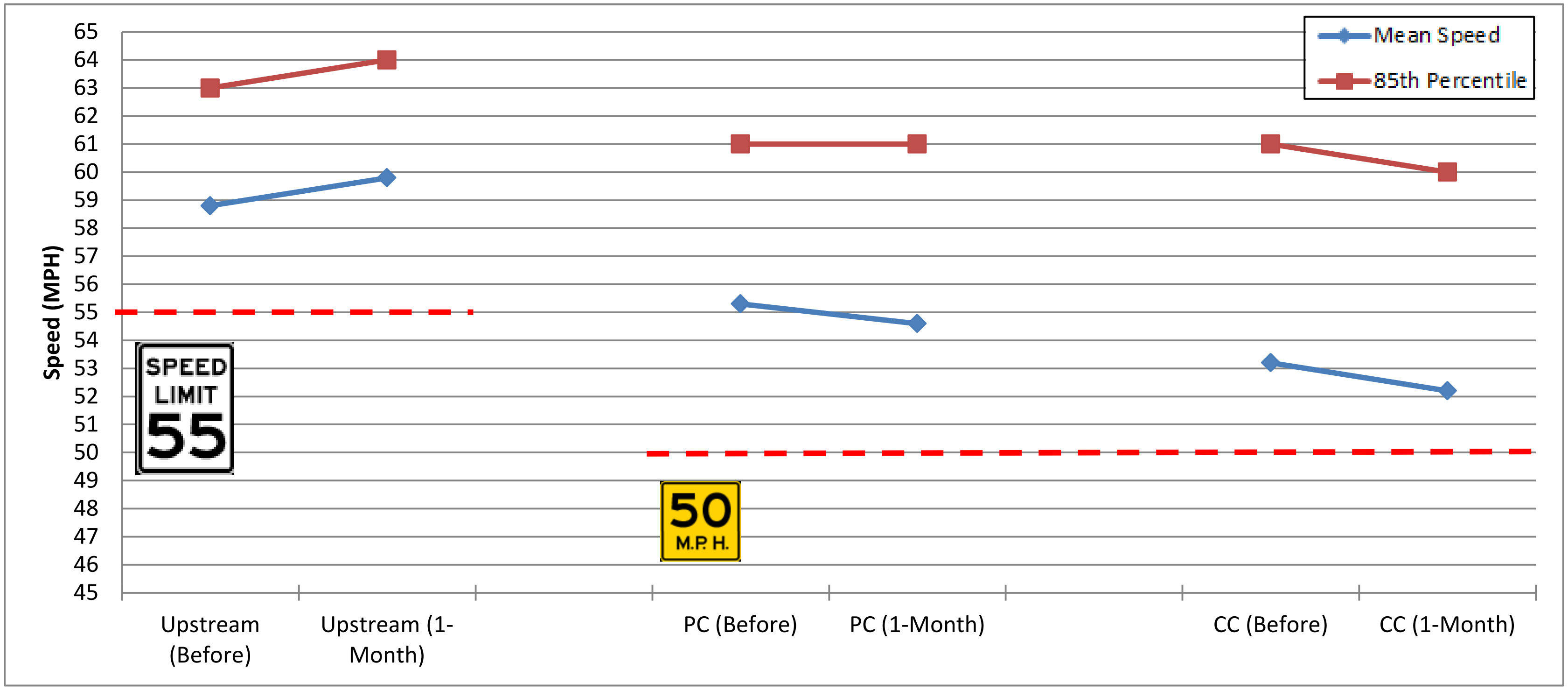


Figure 59. Graph. Impact on vehicle speed - Wisconsin Hwy 213.

Wisconsin (Hwy 213)

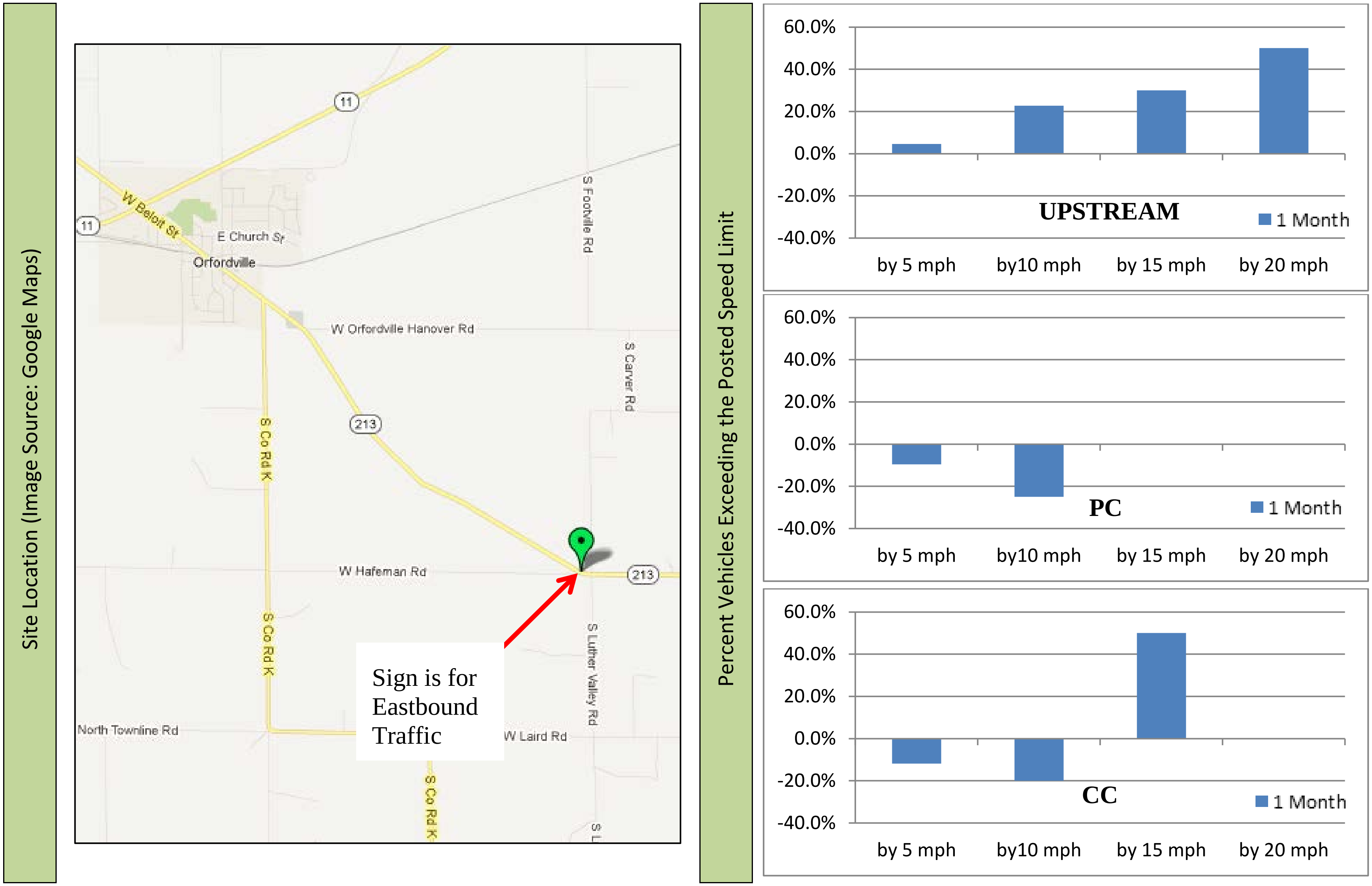


Figure 60. Map and graphs. Location and change in percentile vehicle speed - Wisconsin Hwy 213.

Texas FM 109

Table 32. Results for Texas - FM 109 at PC.

	Before	1 Month	Change
ADT	2187	2031	-156
Sample	1036	954	
Upstream Mean Speed	58.2	59.6	1.4
Mean Speed	46.6	45.8	-0.8
Standard Deviation	5.7	5.4	
85th Percentile Speed	52	51	-1
fraction of vehicles exceeding advisory speed			
Percentage of Vehicles 5+ Over Limit	0.92	0.90	-2.2%
Percentage of Vehicles 10+ Over Limit	0.68	0.62	-8.8%
Percentage of Vehicles 15+ Over Limit	0.30	0.23	-23.3%
Percentage of Vehicles 20+ Over Limit	0.07	0.04	0.0%

Table 33. Results for Texas - FM 109 at CC.

	Before	1 Month	Change
ADT	2129	1991	-138
Sample	1017	938	
Upstream Mean Speed	58.2	59.6	1.4
Mean Speed	45.2	43.8	-1.4
Standard Deviation	5.2	4.7	
85th Percentile Speed	50	48	-2
fraction of vehicles exceeding advisory speed			
Percentage of Vehicles 5+ Over Limit	0.90	0.85	-5.7%
Percentage of Vehicles 10+ Over Limit	0.60	0.43	-27.7%
Percentage of Vehicles 15+ Over Limit	0.18	0.09	-51.4%
Percentage of Vehicles 20+ Over Limit	0.02	0.01	0.0%

Texas (FM 109)

Speed Limit: 60 mph
Curve Advisory Speed: 35 mph
Installed: July 2012
Impact on Vehicle Speeds

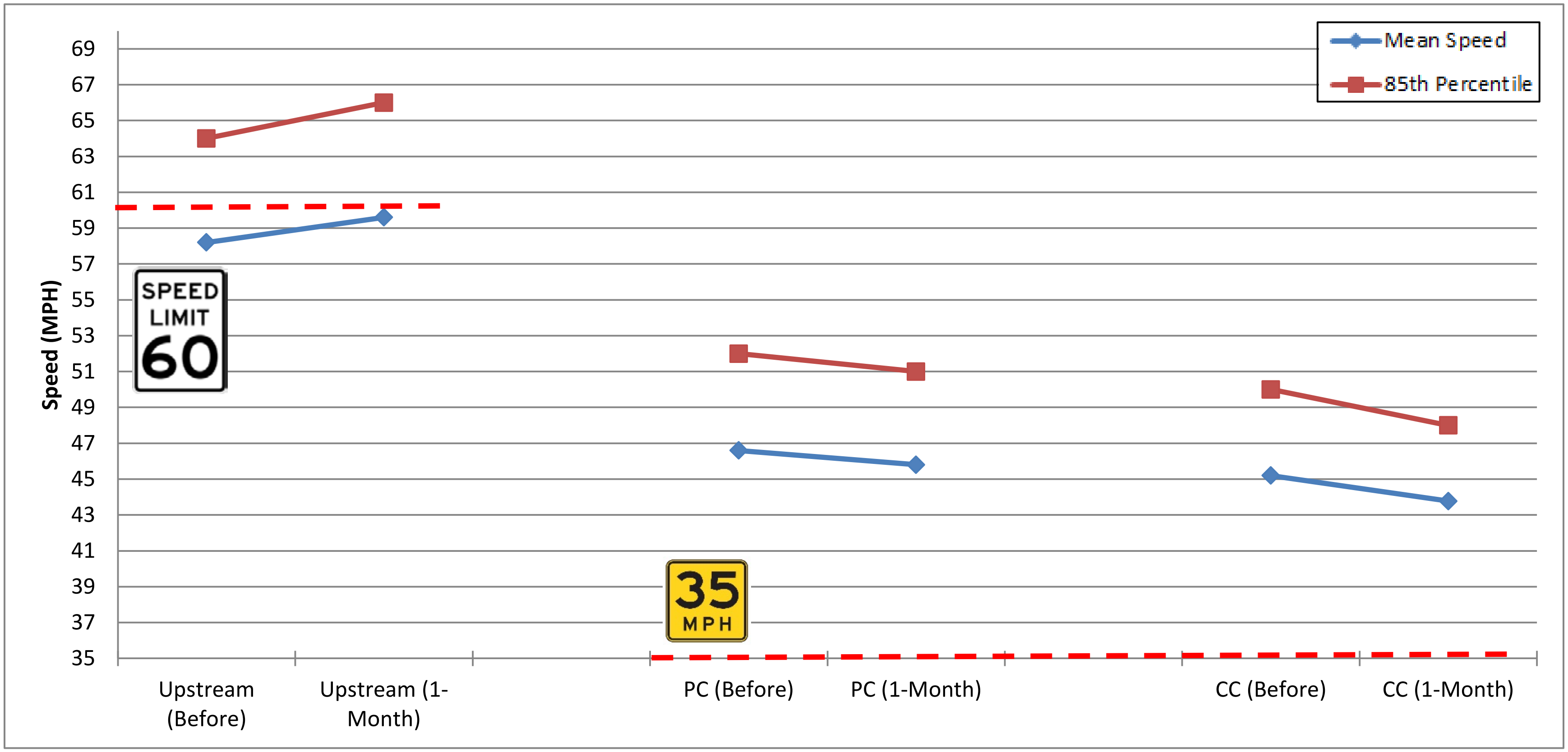
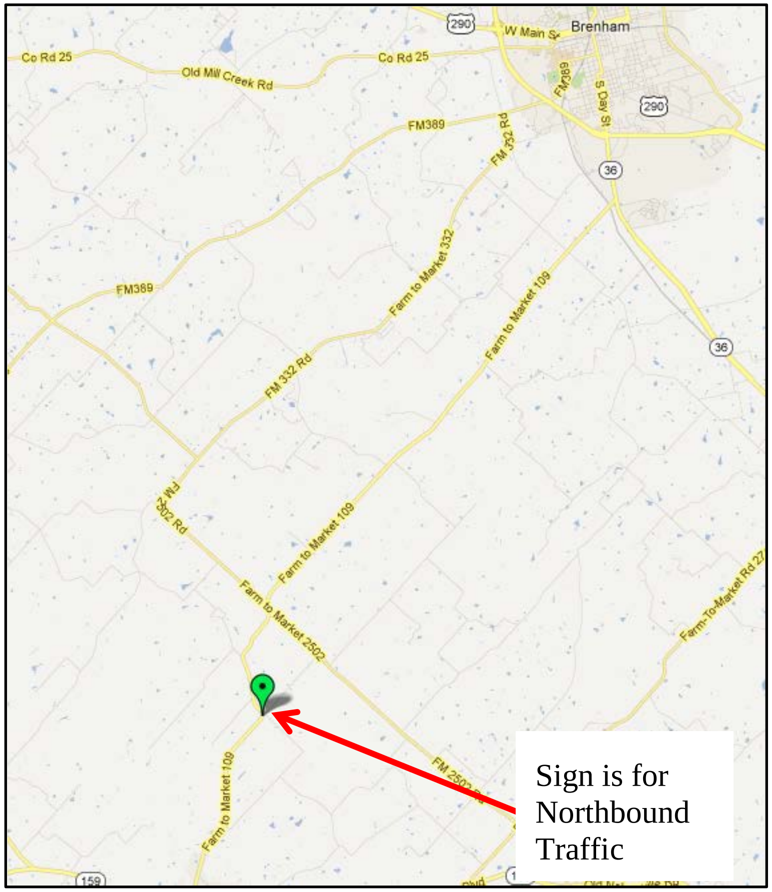


Figure 61. Graph. Impact on vehicle speed - Texas FM 109.

Texas (FM 109)

Site Location (Image Source: Google Maps)



Percent Vehicles Exceeding the Posted Speed Limit

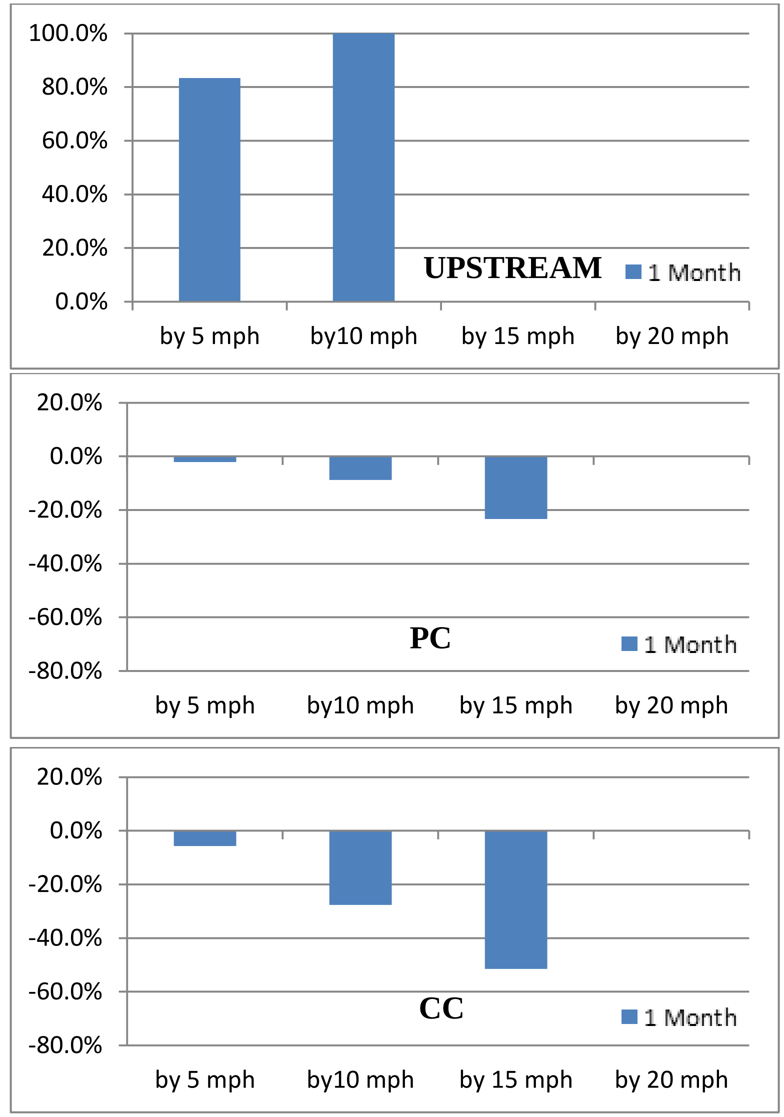


Figure 62. Map and graphs. Location and change in percentile vehicle speed - Texas FM 109.

Texas FM 407

Table 34. Results for Texas - FM 407 at PC.

	Before *	1 Month	Change
ADT	2480	2883	403
Sample	856	1443	
Upstream Mean Speed	61.3	60.1	-1.2
Mean Speed	51.5	49.7	-1.8
Standard Deviation	5.6	5.3	
85th Percentile Speed	57	55	-2
fraction of vehicles exceeding advisory speed			
Percentage of Vehicles 5+ Over Limit	0.89	0.83	-6.7%
Percentage of Vehicles 10+ Over Limit	0.67	0.53	-20.9%
Percentage of Vehicles 15+ Over Limit	0.31	0.18	-41.9%
Percentage of Vehicles 20+ Over Limit	0.06	0.03	0.0%

*Note: Only 18 hours of data collected because of puncture in the tube

Table 35. Results for Texas - FM 407 at CC.

	Before *	1 Month	Change
ADT	2238	2885	647
Sample	579	1446	
Upstream Mean Speed	61.3	60.1	-1.2
Mean Speed	47.3	46.2	-1.1
Standard Deviation	6.3	5.6	
85th Percentile Speed	53	51	-2
fraction of vehicles exceeding advisory speed			
Percentage of Vehicles 5+ Over Limit	0.73	0.67	-8.2%
Percentage of Vehicles 10+ Over Limit	0.37	0.26	-29.7%
Percentage of Vehicles 15+ Over Limit	0.10	0.04	-60.0%
Percentage of Vehicles 20+ Over Limit	0.01	0.01	0.0%

*Note: Only 16 hours of data collected because of puncture in the tube

Texas (FM 407)

Speed Limit: 55 mph
Curve Advisory Speed: 40 mph
Installed: July 2012

Impact on Vehicle Speeds

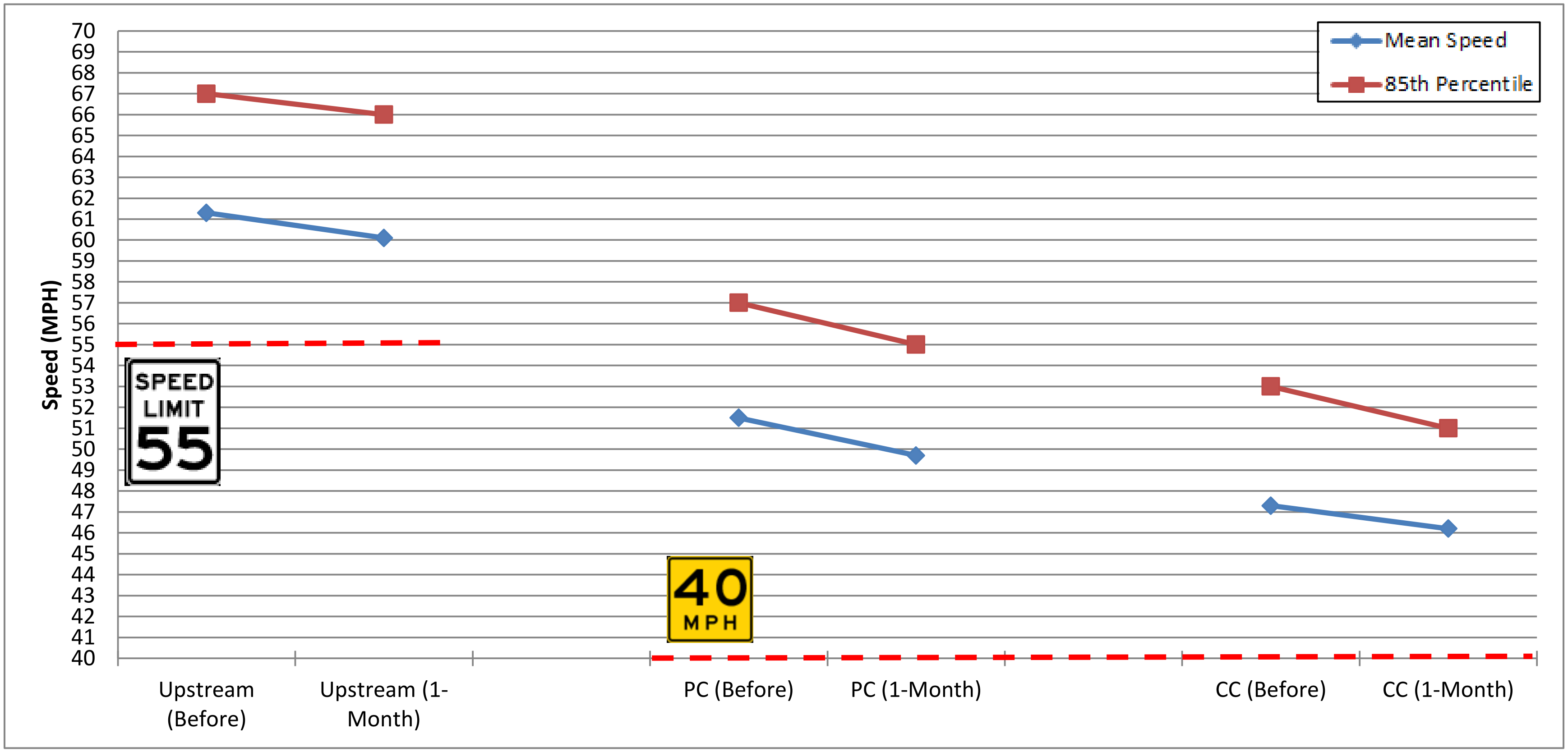


Figure 63. Graph. Impact on vehicle speed - Texas FM 407.

Texas (FM 407)

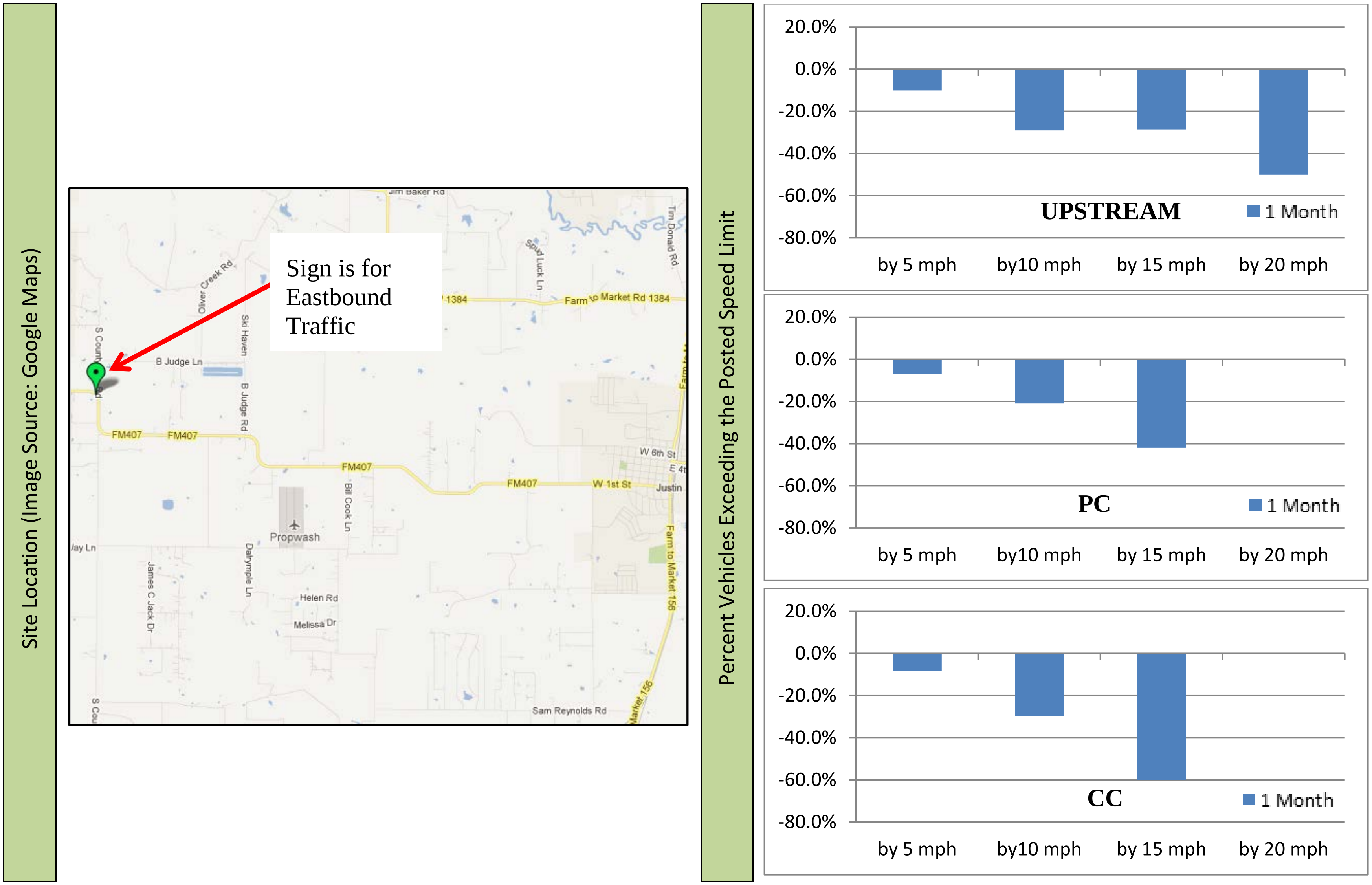


Figure 64. Map and graphs. Location and change in percentile vehicle speed - Texas FM 407.

Texas FM 530

Table 36. Results for Texas - FM 530 at PC.

	Before*	1 Month	Change
ADT	675	418	-257
Sample	71	200	
Upstream Mean Speed	62.1	60.0	-2.1
Mean Speed	47.1	46.2	-0.9
Standard Deviation	9.3	6.3	
85th Percentile Speed	55	53	-2
fraction of vehicles exceeding advisory speed			
Percentage of Vehicles 5+ Over Limit	0.86	0.88	2.3%
Percentage of Vehicles 10+ Over Limit	0.77	0.62	-19.5%
Percentage of Vehicles 15+ Over Limit	0.38	0.33	-13.2%
Percentage of Vehicles 20+ Over Limit	0.20	0.09	0.0%

*Note: The "before" count had many unknown counts, leading to fewer counts for the 24-hour period

Table 37. Results for Texas - FM 530 at CC.

	Before	1 Month	Change
ADT	488	430	-58
Sample	237	204	
Upstream Mean Speed	62.1	60.0	-2.1
Mean Speed	43.2	41.2	-2.0
Standard Deviation	6.1	5.2	
85th Percentile Speed	48.6	46	-2.6
fraction of vehicles exceeding advisory speed			
Percentage of Vehicles 5+ Over Limit	0.79	0.63	-20.3%
Percentage of Vehicles 10+ Over Limit	0.44	0.28	-36.4%
Percentage of Vehicles 15+ Over Limit	0.11	0.04	-63.6%
Percentage of Vehicles 20+ Over Limit	0.02	0.00	0.0%

Texas (FM 530)

Speed Limit: 60 mph
Curve Advisory Speed: 35 mph
Installed: July 2012

Impact on Vehicle Speeds

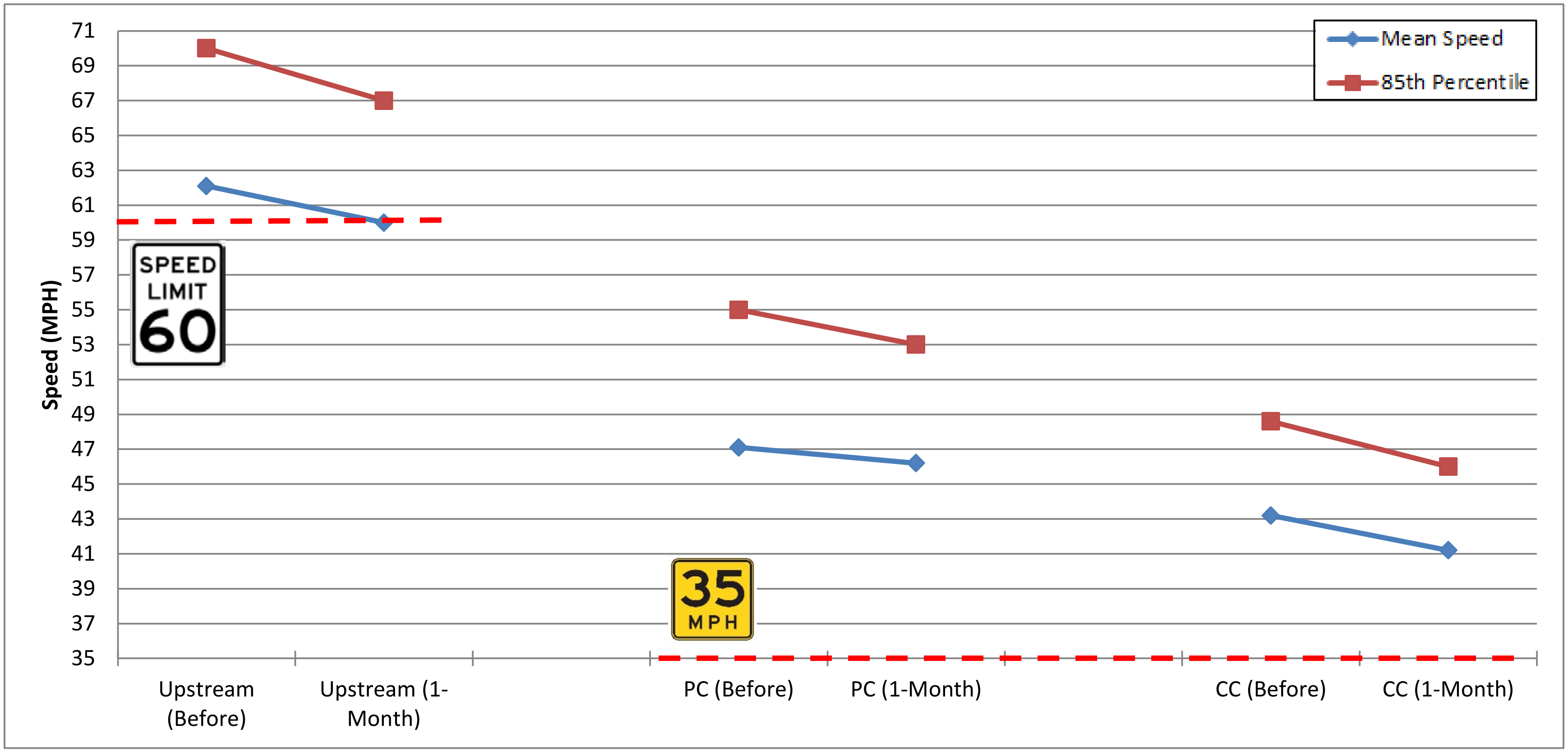


Figure 65. Graph. Impact on vehicle speed - Texas FM 530.

Texas (FM 530)

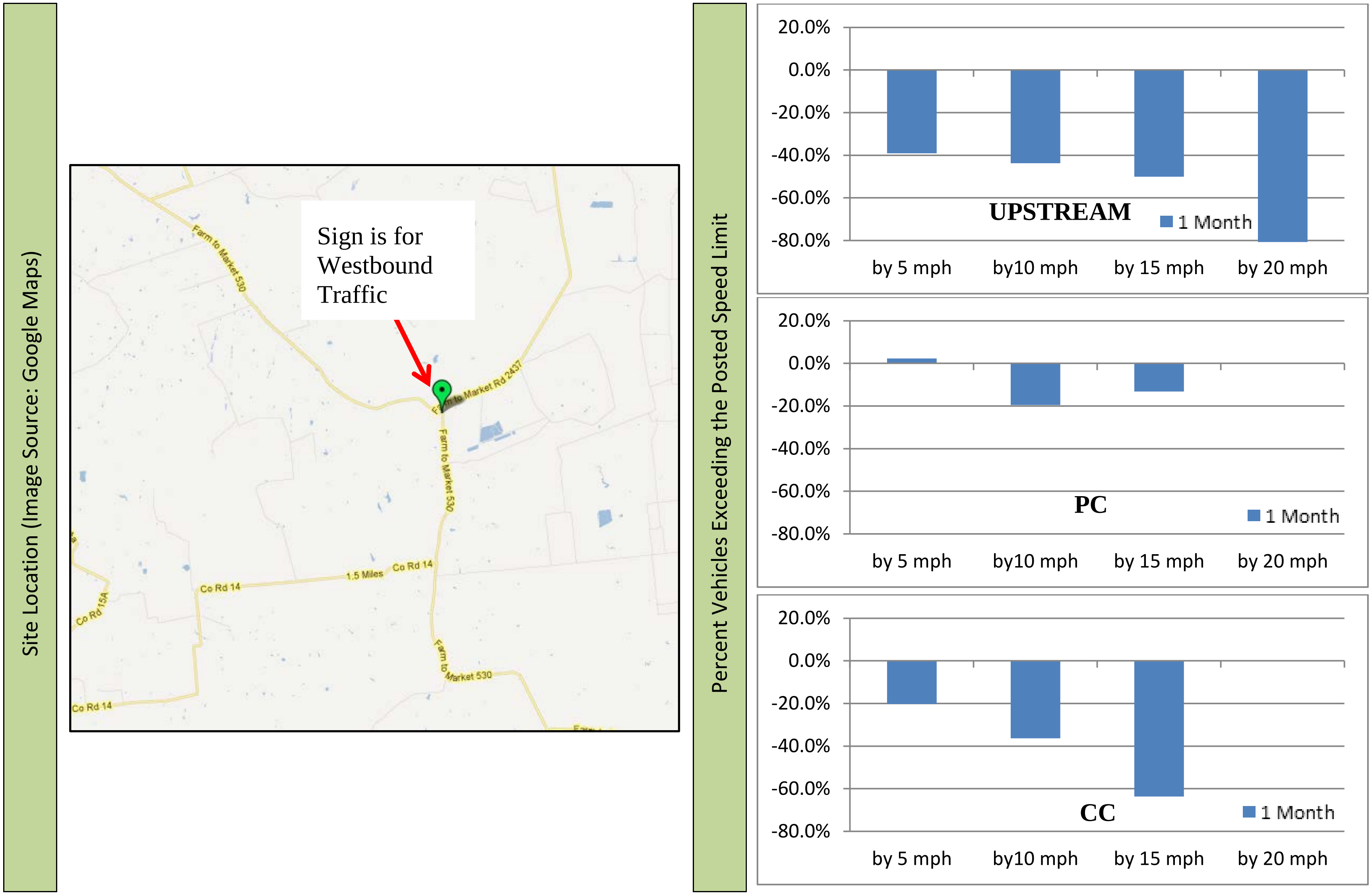


Figure 66. Map and graphs. Location and change in percentile vehicle speed - Texas FM 530.

Texas FM 1148

Table 38. Results for Texas - FM 1148 at PC.

	Before	1 Month	Change
ADT	3549	3742	193
Sample	1746	1832	
Upstream Mean Speed	59.3	58.9	-0.4
Mean Speed	51.9	49.5	-2.4
Standard Deviation	5	4.8	
85th Percentile Speed	57	54	-3
fraction of vehicles exceeding advisory speed			
Percentage of Vehicles 5+ Over Limit	0.94	0.86	-8.5%
Percentage of Vehicles 10+ Over Limit	0.70	0.51	-27.1%
Percentage of Vehicles 15+ Over Limit	0.28	0.13	-53.6%
Percentage of Vehicles 20+ Over Limit	0.06	0.02	0.0%

Table 39. Results for Texas - FM 1148 at CC.

	Before	1 Month	Change
ADT	3538	3708	170
Sample	1748	1831	
Upstream Mean Speed	59.3	58.9	-0.4
Mean Speed	48.5	48.4	-0.1
Standard Deviation	4.5	4.9	
85th Percentile Speed	53	53	0
fraction of vehicles exceeding advisory speed			
Percentage of Vehicles 5+ Over Limit	0.83	0.79	-4.8%
Percentage of Vehicles 10+ Over Limit	0.40	0.41	2.5%
Percentage of Vehicles 15+ Over Limit	0.08	0.08	0.0%
Percentage of Vehicles 20+ Over Limit	0.01	0.01	0.0%

Texas (FM 1148)

Speed Limit: 55 mph
Curve Advisory Speed: 40 mph
Installed: July 2012

Impact on Vehicle Speeds

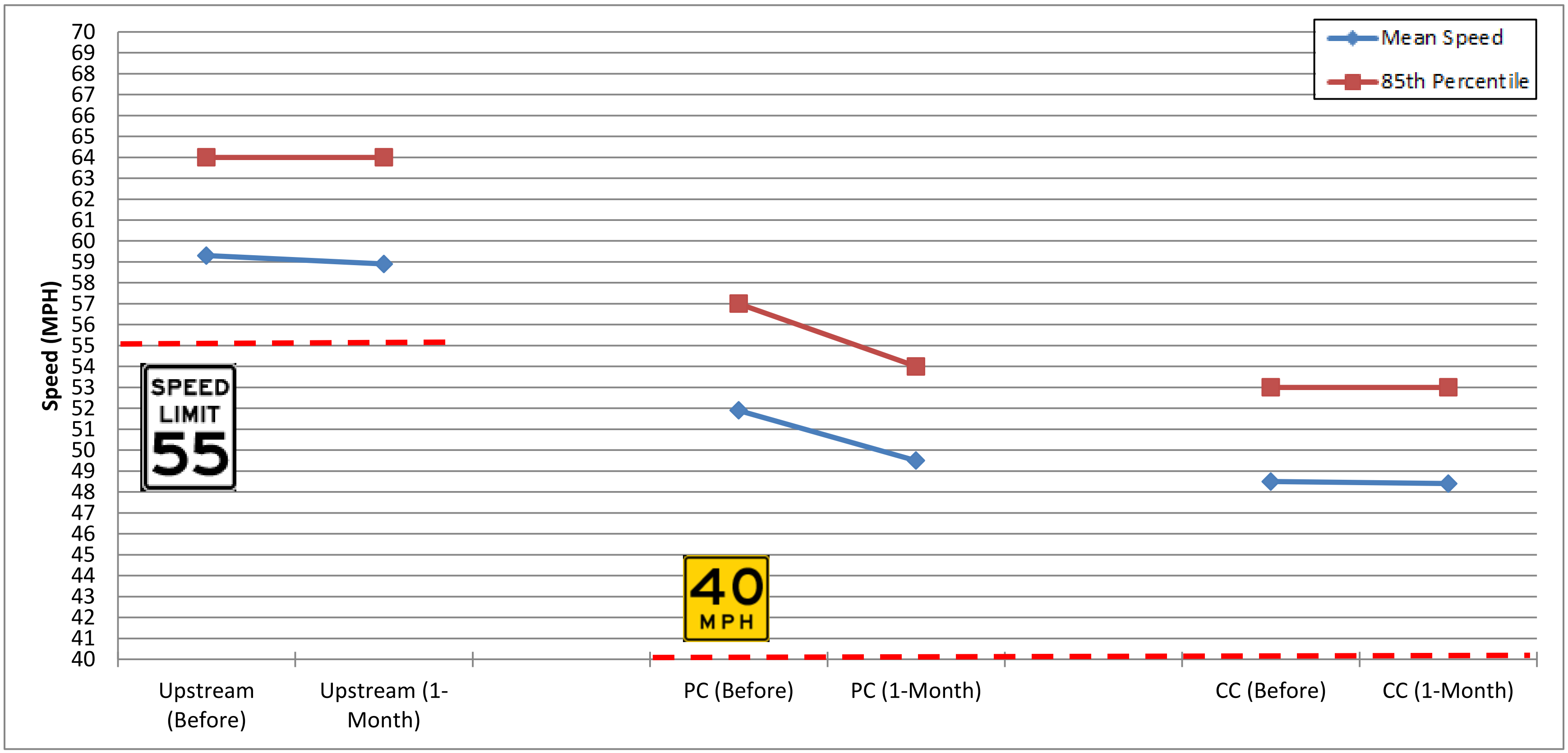
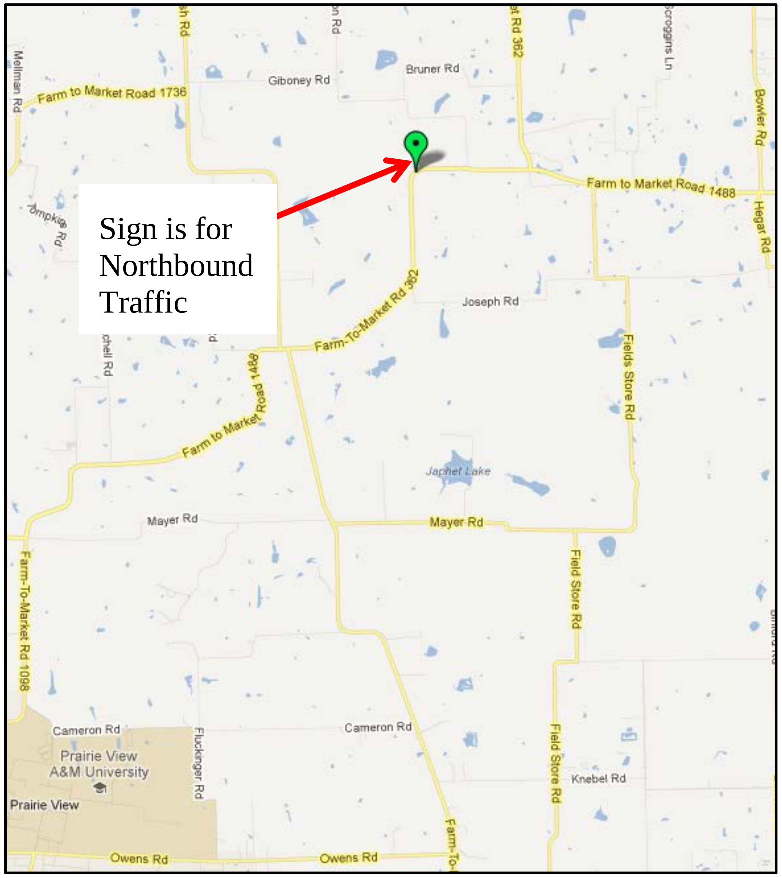


Figure 67. Graph. Impact on vehicle speed - Texas FM 1148.

Texas (FM 1148)

Site Location (Image Source: Google Maps)



Percent Vehicles Exceeding the Posted Speed Limit

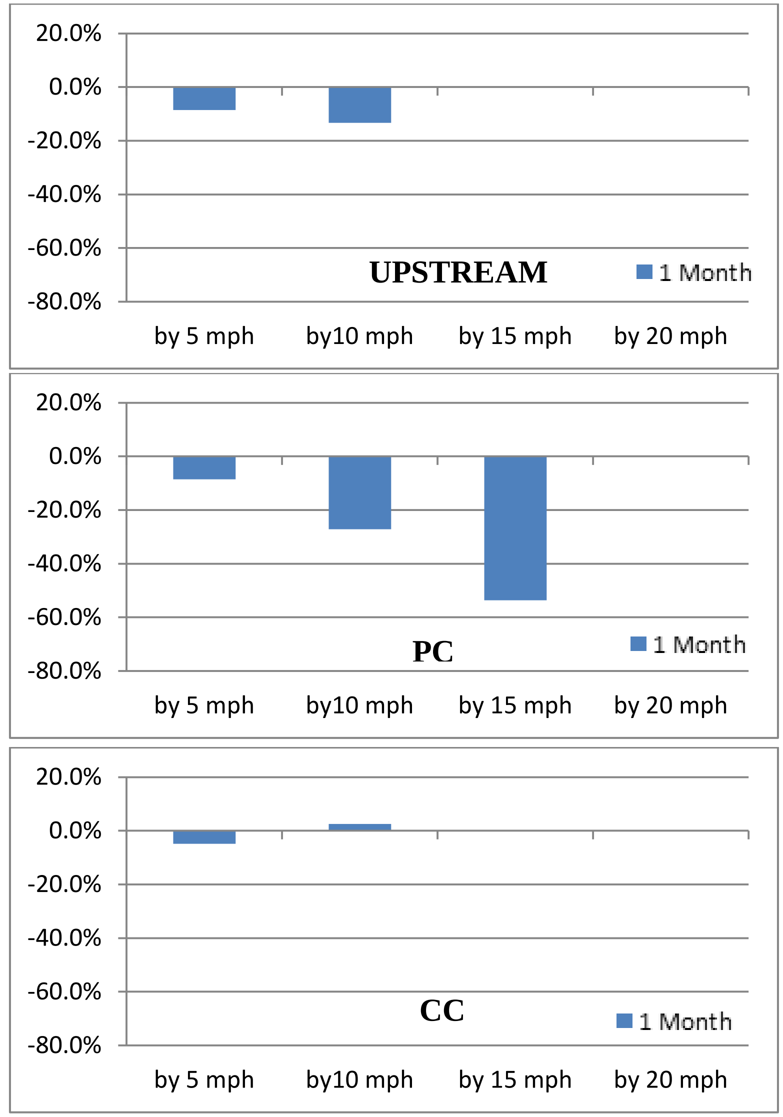


Figure 68. Map and graphs. Location and change in percentile vehicle speed - Texas FM 1148.

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