I-680 ADVANCED TECHNOLOGY PROJECT COORDINATED ADAPTIVE RAMP METERING CONCEPT RECOMMENDATION

Corridor Evaluation

I-680 between Alameda County Line and Martinez Bridge

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Review History

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3.0	Final revised consolidated report	8/22/22	BP, DH

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List of Acronyms

ATMS	Advanced Traffic Management System
BAIFA	Bay Area Infrastructure Finance Authority
Caltrans	California Department of Transportation
CARM	Coordinated adaptive ramp metering
CCTA	Contra Costa Transportation Authority
CCTV	Closed Circuit Television
CDOT	Colorado Department of Transportation
CHP	California Highway Patrol
CMS	Changeable message signs
CTC	California Transportation Commission
EL	Express Lane
FHWA	Federal Highway Administration
ft	Feet
HCM	Highway Capacity Manual
HOT	High Occupancy Toll
HOV	High Occupancy Vehicle
I-680	Interstate 680
ICM	Integrated Corridor Management
ITS	Intelligent Traffic System
GP	General-Purpose
LCS	Lane control signals
LED	Light Emitting Diode
LUMS	Lane use management systems
MSFR	Maximum sustainable flow rate
MTC	Metropolitan Transportation Commission
PeMS	Performance Monitoring System
PSR	Project Study Report
PTZ	Pan, tilt and zoom
SHOPP	State Highway Operation and Protection Program
STIP	State Transportation Improvement Program
SWITRS	Statewide Integrated Traffic Records System
TIRTL	The Infra-Red Traffic Logger
TMC	Traffic Management Center
TSI	Toll System Integrator
veh/hr	Vehicles per Hour
VicDOT	Victoria Department of Transportation
vphpl	Vehicles per Hour per Lane

1 Introduction

The Contra Costa Transportation Authority (CCTA), in cooperation with the California Department of Transportation (Caltrans) District 4 and the Federal Highway Administration (FHWA) proposes to address congestion on Interstate 680 (I-680) and improve mobility in Contra Costa County by installing coordinated adaptive ramp metering (CARM) and mainline intelligent transportation systems (ITS). CCTA intends to implement CARM technology as one of seven components of its larger Innovate 680 program.

1.1 Background

Caltrans, CCTA and the Metropolitan Transportation Commission (MTC) entered a Memorandum of Understanding to advance the Innovate 680 Program in 2020, and in 2021 Caltrans and CCTA signed a Master Agreement to create the Innovate 680 Innovation Team, which is funded by CCTA and staffed by an integrated team from the two agencies.

CCTA has conducted feasibility studies of implementing CARM on the full length of I-680 in Contra Costa County in both directions and has determined that full deployment would cost approximately $197 million. CCTA intends to implement CARM in a phased manner as funding becomes available and in coordination with the other elements of the Innovate 680 program.

The California Transportation Commission has made $25 million in State Transportation Improvement Program (STIP) funding available to Contra Costa County. CCTA intends to program these funds to implement an initial phase of the CARM project on I-680 northbound south of SR 24. In October 2021, CCTA completed a Project Study Report (EA 04-0Q960) to request programming in the 2022 STIP from the California Transportation Commission (CTC) and indicate its desire to initiate an environmental approval process. Caltrans approved the PSR in November 2021 and CCTA has since initiated the preparation of a Project Approval/ Environmental Document PA/ED to gain the necessary approvals to implement the project.

At the same time, Caltrans has initiated a State Highway Operation and Protection Program (SHOPP) project (EA 04-1Q720) proposing ramp metering improvements at various ramps along I-680 in Contra Costa County. The Caltrans SHOPP Traffic Operations System (TOS)/Fiber/Ramp Metering project is using 2020 funding to install a fiber-optic cable communication trunk line, upgrade the traffic operations system, upgrade ramp metering equipment, and widen selected ramps to provide high occupancy vehicle (HOV) preferential lanes on I-680 in Contra Costa County. It is currently expected that the CCTA CARM Project improvements would be additive to 04-1Q720.

CCTA made the decision to pursue the initial implementation of CARM on I-680 northbound, south of SR-24 in this PSR for the following reasons:

- CCTA's initial feasibility review determined that CARM implementation would be the simplest on I-680 NB south of SR 24 compared to other segments of I-680 in Contra Costa County;
- All civil works can be completed within existing right-of-way; no right-of-way takings are required;
- No significant environmental impacts are anticipated, pending confirmation through the PAED process;
- The entrance ramps at the six contiguous service interchanges form a segment offering functional utility that is long enough for CARM operations to provide discernable benefits;
- The implementation cost aligns with the $25 million in available STIP funding;
- Starting with the simplest segment provides an opportunity to garner lessons learned that can be applied as more complex CARM implementations are pursued in other portions of the corridor; and
- The schedule allows the CARM construction to be integrated with the Caltrans SHOPP TOS/Fiber/Ramp Metering project (EA: 04-1Q720).

While there are additional bottleneck locations in close proximity north of the project limits, CCTA will implement CARM on I-680 northbound south of SR-24 first for the reasons stated above, and then expand implementation into other areas of the I-680 corridor in Contra Costa County as additional funding becomes available. CCTA intends to roll CARM deployment out incrementally, using a systematic approach focused on the identification of recurrent bottlenecks and the complexity and cost of installing the required improvements.

1.1.1 Report Contents

This report assembles the different technical analyses that CCTA has completed on its CARM initiative on the entire length of I-680 in Contra Costa County. It includes the following components:

1. A mainline traffic evaluation documenting current conditions on I-680 in Contra Costa County from Alcosta Boulevard on the Alameda County line to the Benicia-Martinez Bridge
2. A corridor ramp metering analysis utilizing three different methodologies to identify the additional ramp capacity that will be necessary to enable CARM operations at all access ramps to I-680 in Contra Costa County
3. Conceptual designs identifying the civil improvements found to be feasible and the necessary ITS equipment that will be needed to enable CARM operations on all interchanges and along the entire length of I-680 in Contra Costa County
4. Preliminary cost estimates of the civil and ITS improvements needed to implement CARM operations
5. A comparison of the cost, complexity, and efficacy of implementing CARM operations on the following four segments of I-680:
   - Northbound South of SR-24

- Northbound North of SR-24
- Southbound North of SR-24
- Southbound South of SR-24

1.1.2 Purpose of the Report

The purpose of this report is to provide technical information on the CCTA CARM project to facilitate ongoing discussions between Caltrans and CCTA to optimize and coordinate Caltrans' SHOPP ramp metering and the CCTA CARM projects. These discussions will:

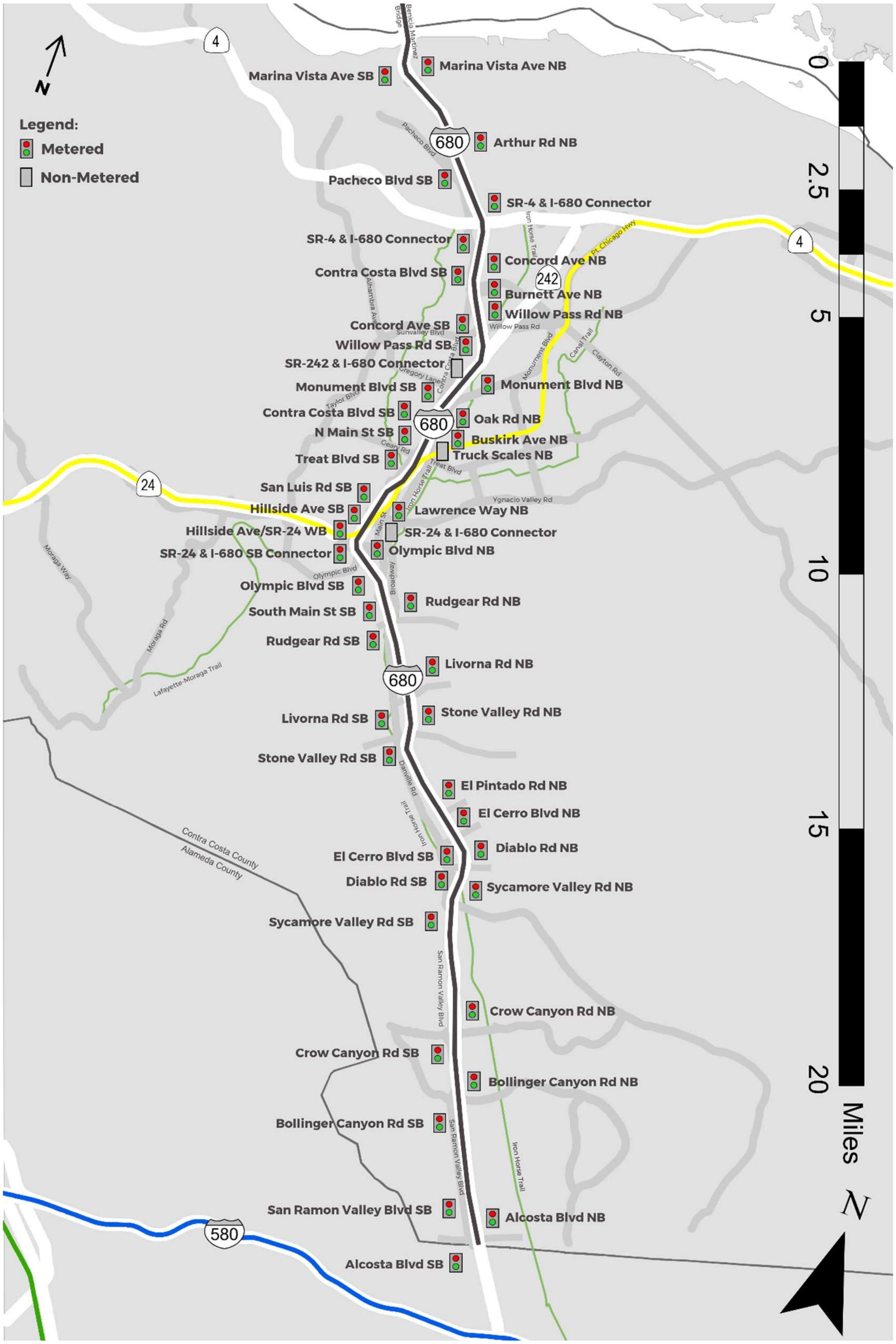
- Compare the civil ramp capacity enhancements required for CARM operations to those proposed for the Caltrans SHOPP ramp metering project
- Consider possible modifications to the Caltrans SHOPP ramp metering project to align with the requirements for CARM operations
- Review and gain concurrence on the feasibility of civil improvements on ramps with site constraints
- Review and gain concurrence on the operational parameters for CARM implementation
- Review and gain concurrence on the funding and phasing of the different elements of both the CARM and SHOPP projects

1.2 The I-680 Corridor

I-680 is a major interstate highway facility within Contra Costa County carrying international, interstate, interregional and intraregional traffic. This area is projected to experience substantial growth for goods movement and passenger vehicle traffic. I-680 is one of the major north-south corridors in Contra Costa County and is listed by MTC as one of the ten most congested freeways in the San Francisco Bay Area. The corridor experiences significant delays and unstable flow of traffic in both directions, and these delays are expected to continue in the foreseeable future.

I-680 traverses north to south through Solano, Contra Costa, Alameda, and Santa Clara Counties in California. It is a heavily traveled commuter route between the East Bay and the South Bay. As shown in Figure 1-1, within Contra Costa County, I-680 is typically an eight-lane freeway providing 23 interchanges northbound and 27 interchanges southbound. It provides system interchanges with SR-24 in Walnut Creek, SR-242 in Concord, and SR-4 in Martinez. Single-lane high occupancy toll (HOT) lanes extend 11 miles between Alcosta Boulevard and Livorna Road northbound, and 25 miles from Marina Vista Avenue to Alcosta Boulevard southbound.

Figure 1-1 I-680 Study Corridor



The I-680 corridor includes the following typical attributes:

- The mainline lanes are 12 feet
- The medians are separated by concrete barrier or guardrails
- The mainline left shoulders range from 2 feet to 10 feet
- The mainline right shoulders range from 8 feet to 10 feet
- The ramp lanes are 12 feet; 12 feet plus on curves with less than 300 feet radius
- The ramp shoulders range from 2 feet to 10 feet.
- Overhead signs mounted on mast arms above the travel lanes

1.3 The Managed Freeway Concept

The managed freeways concept – also known as managed motorways or smart freeways – was initially developed by the Victoria Department of Transport (VicDOT) in Melbourne, Australia in the late 2000s. The managed freeways concept applies a comprehensive, holistic approach to planning, designing and operating freeways to optimize traffic flows and reduce congestion. It relies on advanced, highly precise ITS to monitor traffic flows and control freeway access on a continuing basis using the STREAMS® integrated ITS platform.

VicDOT uses CARM and other harmonious demand management tools to ensure traffic on the freeway achieves optimum flow. STREAMS® provides the platform that allows VicDOT to manage their freeways as a comprehensive, coordinated network to control traffic flows on a proactive basis, which differentiates the managed freeways approach from other advanced traffic management systems (ATMS) where observed traffic conditions trigger a predetermined response when certain conditions occur. Specifically, the ability of the ALINEA and HERO Suite (AHS) of algorithms to balance ramp demand throughout an entire freeway corridor (or network) on a dynamic, real-time basis enables the system to manage and optimize traffic flows, setting this concept apart from other adaptive ramp metering and Integrated Corridor Management (ICM)

Figure 1-2 Managed Freeway Installation on M-1 Monash Freeway, Melbourne, Australia

While the various ITS devices installed in the field and the supporting STREAMS ® control system are prominent features of the VicDOT managed freeways approach, the concept is built upon a multi-faceted strategy that addresses every aspect of planning, design, funding, construction, operations, and maintenance associated with managed freeways implementation.

Table 1-1 summarizes the holistic policy framework developed by VicDOT to guide the implementation of managed freeways systems. By effectively managing traffic flow on the freeway, managed freeways maximize and sustain the traffic performance benefits of significant investments in freeway infrastructure. Reducing congestion also supports the economy by allowing more efficient movement of people and goods making managed freeways extremely cost-effective investments. This supports the business case for their deployment.

Managed freeways are being operated successfully on a network of over 100 centerline miles of freeways in the Melbourne metropolitan area, as well as on freeway corridors in both Brisbane and Perth. A pilot project featuring components of the VicDOT managed freeways concept is was recently tested on a 13-mile section of northbound I-25 near Denver, with the STREAMS® software system from November 1, 2021 to July 29, 2022.

Table 1-1 Managed Freeways Policy Framework

1. A New Understanding	Utilize a contemporary understanding of traffic theory	Define data requirements and employ appropriate analytic tools	Develop a detailed understanding of the nature of traffic flow and associated problems
2. Use a System Approach to Planning and Design	Maximize infrastructure capacity: • Flexibility for future operations • Incorporate considerations for mainline, entry and exit ramps, interchanges, and intersections • Strategic improvements to reduce mainline turbulence	Systems approach to design and architecture to fully integrate appropriate: • Control Systems • ITS Devices • Communication Systems	Implement new design standards and technical specifications: • Address specific problems • Support additional requirements
3. Plan and Design for Operations	Develop and deploy technically effective algorithms	Build necessary technical expertise of personnel: • Requires non-traditional disciplines • Potentially train existing staff or make new hires • Provide ongoing training	Establish an effective maintenance regime: • Support network operational performance • Achieve high-level reliability

1.4 Purpose and Need

1.4.1 Purpose

The purpose of the CCTA Innovate 680 CARM project is to supplement the Caltrans SHOPP TOS/Fiber/Ramp Metering Project 04-1Q720 by adding system functionality and infrastructure improvements to:

- Proactively manage both recurrent and non-recurrent congestion in a coordinated, real-time manner to improve productivity and reliability of the I-680 corridor.
- Balance freeway performance objectives and ramp queues.
- Improve the detection of traffic and incidents to support real-time CARM and other traffic operations strategies.

- Encourage collaboration with local agencies for further implementation of ITS and integrated real-time traffic operations strategies that address regional and local objectives.

1.4.2 Need

The recurrent and non-recurrent congestion on weekdays and weekends along the I-680 corridor in Contra Costa County results in traffic delays, reduction in traffic throughput and inconsistent travel-time reliability. In some instances, this reportedly leads to natural diversion of freeway traffic onto the local street network. This will require that the following needs to be addressed by the proposed project:

- There is currently congestion in the northbound direction beginning at El Pintado Road during the AM peak period and at Treat Boulevard during the PM peak period, with both areas of congestion propagating and ultimately extending south to Sycamore Valley Road.
- Current ramp meter systems used by Caltrans do not automatically operate in response to crashes and lane blocking events on the freeway, coordinate metering rates across multiple ramps, and distribute queues on the ramps.
- Current traffic monitoring infrastructure provides lower resolution information on mainline traffic performance and incident identification.
- Demonstrate to local and regional stakeholders the benefits of advanced ITS and real-time traffic operations strategies including corridor adaptive ramp metering.

2 Mainline Traffic Evaluation

The mainline traffic evaluation identifies locations and factors contributing to the breakdown of traffic flow on I-680 as the basis for determining candidate locations to implement CARM and other managed freeways components. The mainline traffic evaluation involved plotting and reviewing various traffic characteristics such as traffic flow, speed and lane occupancy to identify patterns indicative of factors that could contribute to the observed level of congestion. A combination of INRIX and PeMS data were used for this purpose. DKS Associates prepared plots of INRIX data and WSP staff retrieved PeMS data. Transmax then processed the PeMS data utilizing the STREAMS® report dashboard that facilitates real-time evaluation of existing managed freeways projects. The analysis results are presented in the following sections.

2.1 Corridor Spatial Analysis

A spatial analysis was completed in order to identify the nature of active bottlenecks in both directions along the entire I-680 study area, with a focus on determining where recurring congestion typically begins. This information is critical for locating and reviewing bottleneck locations and then identifying factors that may be contributing to traffic flow breakdown. This information was used to determine a suitable location for an initial CARM deployment and the associated placement of vehicle detection devices.

Heat plots showing traffic intensity were developed using mainline data derived from INRIX. Figures 2.1 and 2.2 present heat plots for all weekdays in the month of October 2018 in the northbound and southbound directions, respectively. These dates were chosen because they represent typical conditions in the study corridor prior to the start of construction on the southbound I-680 express lanes project that is ongoing. These dates also precede the decline in travel demand that has resulted from stay-at-home orders enacted in response to the COVID-19 pandemic.

The heat plots present five-minute average speed data. The vertical axis of each plot represents the spatial location along the I-680 corridor from the Alameda County line at the bottom to the Solano County line at the top of each chart. The horizontal axis represents time of day from midnight on the left to 11:59 PM on the right. The colors shown within each plot represent speeds, with yellow, orange and red indicating areas with reduced speeds (congested conditions) and blue and purple representing high speed (free-flow conditions).

Figure 2-1 I-680 Northbound Speed Contour Heat Plots

(Source: INRIX for weekdays in October 2018)

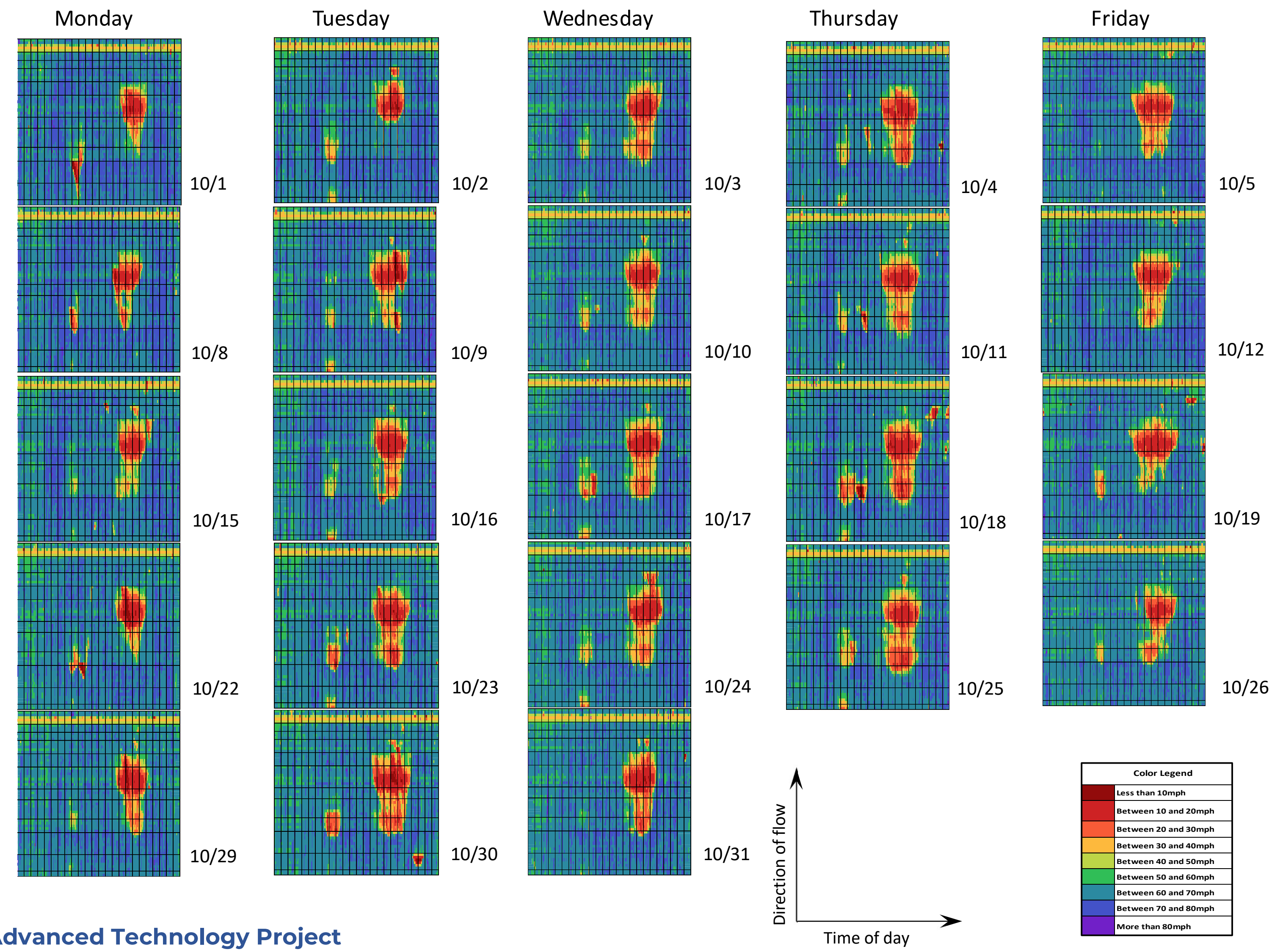
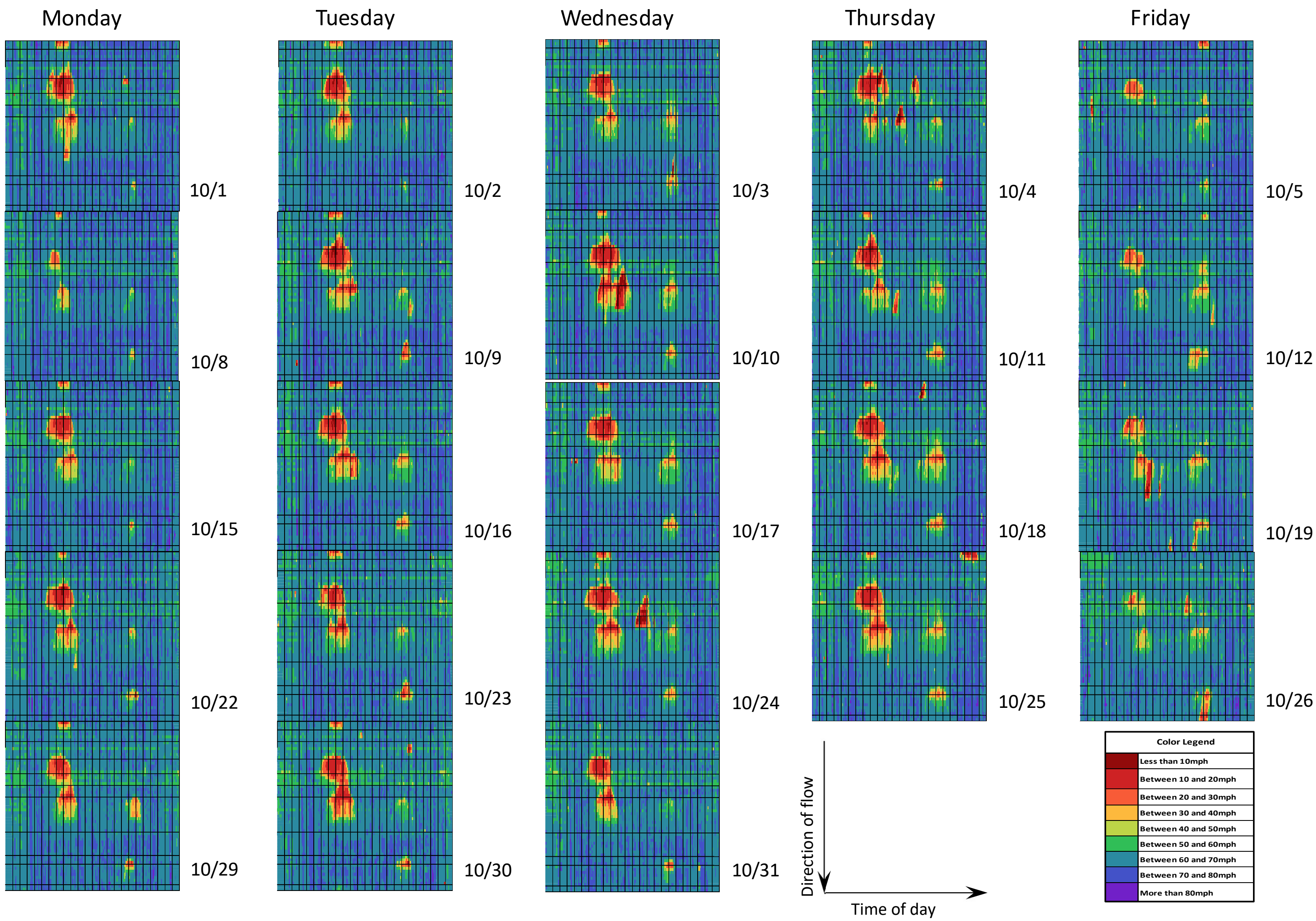


Figure 2-2 I-680 Southbound Speed Contour Heat Plots

(Source: INRIX for weekdays in October 2018)



Figures 2.1 and 2.2 clearly indicate a recurrent pattern of congestion in both the northbound and southbound directions. Recurrent congestion in the northbound direction (as shown in Figure 2.1) is characterized by an isolated area of AM peak period congestion in the southern third of the corridor, and a more prominent area of congestion in the northern half of the corridor during the PM peak, which eventually spreads into the southern half of the corridor reaching the location of the same bottleneck observed in the AM peak period. In the southbound direction (Figure 2.2), recurrent congestion is most prominent in the middle of the study corridor with two notable bottlenecks observed during the AM peak period. Two minor bottlenecks are observed in the southbound direction during the PM peak period.

The heat plots also help to identify non-recurrent anomalies in traffic flows resulting from events such as construction and crashes. Examples include midday congestion on October 11 and October 18 in the northbound direction, and more notably late morning congestion on October 10 and midday congestion on October 24 in the southbound direction; all attributable to severe crashes at those respective times and locations.

A review of these plots facilitates the identification of a representative day to support more focused evaluation. In this case, based on a review of these data, Wednesday, October 17, 2018 was chosen for further evaluation. Typical patterns of recurrent congestion were observed in both directions on this date with no indication of atypical, nonrecurrent events. A review of crash records and weather archives confirmed there were no reported crashes resulting in lane closures, or inclement weather conditions observed in the corridor on this date.

Figures 2.3 and 2.4 present speed contour heat plots for Wednesday, October 17, 2018 for both the northbound and southbound directions along I-680, respectively. As shown in Figure 2-3, reduced speeds begin to be observed in the northbound direction during the AM peak period around 7:45 AM in the vicinity of El Pintado Road. Soon afterward, a bottleneck formed, with queuing rapidly extending for several miles to Sycamore Valley Road. In the PM peak period, a significant bottleneck is observed to form in the vicinity of Treat Boulevard around 2:10 PM. Queuing soon extended back past South Main Street, and the congested state was sustained for almost five hours. A second PM peak period bottleneck is observed in the general vicinity of the AM peak period bottleneck. Eventually queuing from the Treat Boulevard bottleneck extended into the area of the second bottleneck as far back as Sycamore Valley Road.

Figure 2-3 I-680 Northbound Speed Contour Heat Plots

(Source: INRIX for Wednesday, October 17, 2018)

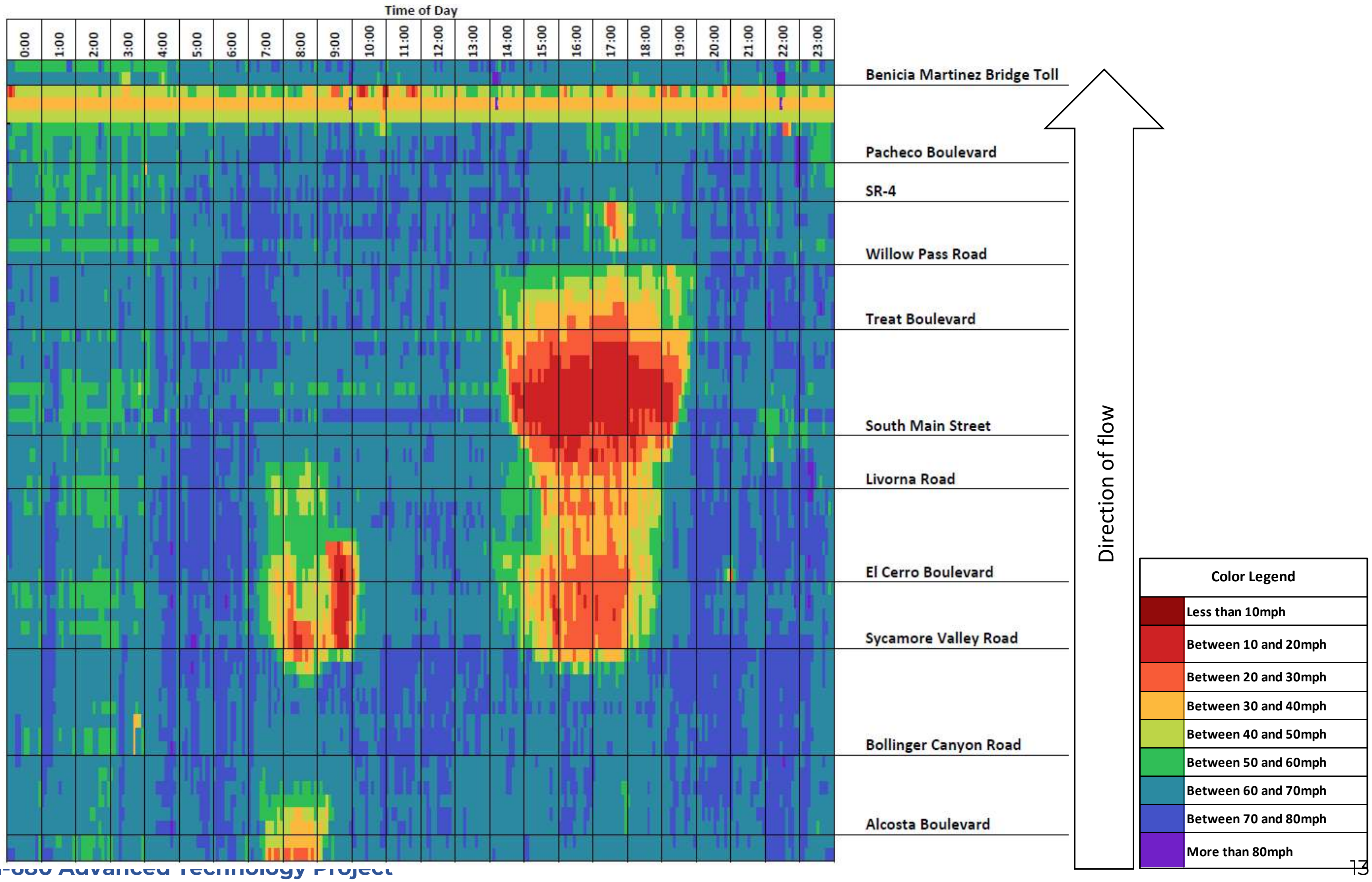
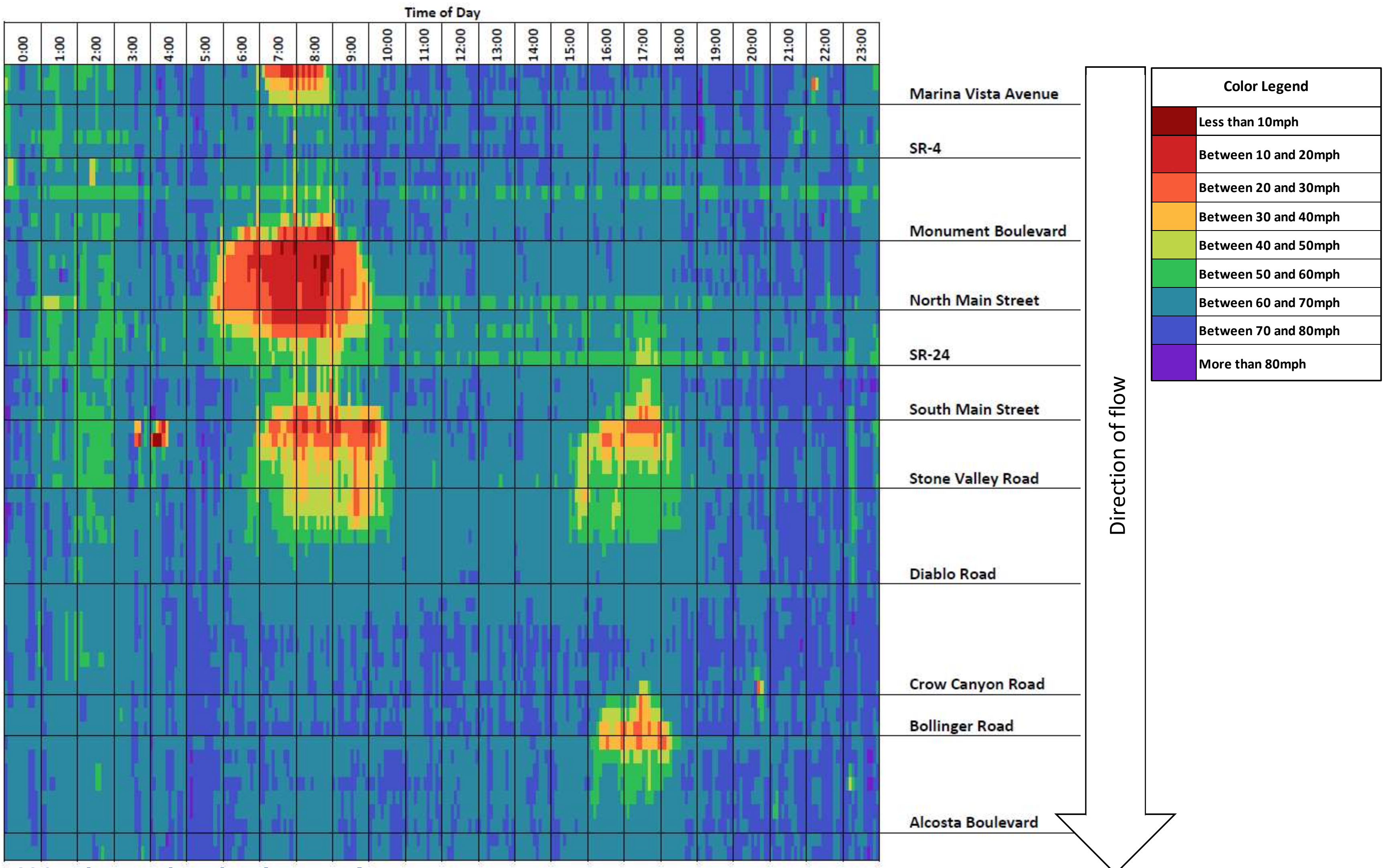


Figure 2-4 I-680 Southbound Speed Contour Heat Plots

(Source: INRIX for Wednesday, October 17, 2018)



The isolated nature of the bottleneck observed in the northbound direction during the AM Peak period (and reforming during the PM peak period) suggests that the northbound direction would be a strong candidate for a CARM demonstration project. The more significant PM peak bottleneck observed in the vicinity of Treat Boulevard, while likely to benefit from the deployment of CARM, is thought to be primarily attributable to weaving in the vicinity of CA-24, Treat Boulevard, North Main Street and the California Highway Patrol (CHP) truck scales. This weave issue is expected to be mitigated with the addition of a collector-distributor or braided ramp system being developed as part of the Express Lane Completion project. Based on these observations, the northbound segment of I-680 from the Alameda County line to CA-24 is determined to be a strong candidate for deployment of CARM. Further evaluation of this segment is provided in subsequent sections.

The southbound heat plot provided in Figure 2.4 shows the formation of a significant bottleneck in the vicinity of North Main Street starting around 6:00 AM and remaining congested until around 10:00 AM. A second bottleneck also forms downstream in the area between South Main Street and Stone Valley Road around 7:00 AM in the vicinity of the existing general-purpose lane drop near Livorna Road. This area remains congested intermittently until around 10:30 AM. In the PM peak period, a similar bottleneck is observed in the area between South Main Street and Stone Valley Road. A second bottleneck is also observed to form immediately downstream of Bollinger Canyon Road.

While the bottlenecks in the southbound direction south of CA-24 could potentially be resolved by CARM, the proximity of CA-24 to the observed congestion in the area between South Main Street and Stone Valley Road complicates the situation. Establishing control of traffic flows would necessitate the introduction of metering on the CA-24 eastbound to I-680 southbound connector and/or upstream service interchanges along I-680 in the vicinity of North Main Street. Ongoing express lanes construction and the complexity of the system and service interchanges upstream of the study area would present challenges to ready deployment of a CARM demonstration north of CA-24 until the construction has been completed and the final lane configuration is operational. A detailed evaluation of southbound I-680 from CA-24 to I-580 was nonetheless conducted to determine the effectiveness of CARM to resolve bottlenecks in the study area.

2.2 Corridor Crash Analysis

In addition to the spatial traffic flow analysis, the team retrieved 2018 crash data from the CHP Statewide Integrated Traffic Records System (SWITRS) and prepared heat plots identifying locations with higher crash on I-680 northbound and southbound, as presented in Figures 2.5 and 2.6.

Figure 2-5 I-680 Northbound Crash Heat Plot

(Source: SWITRS for 2018)

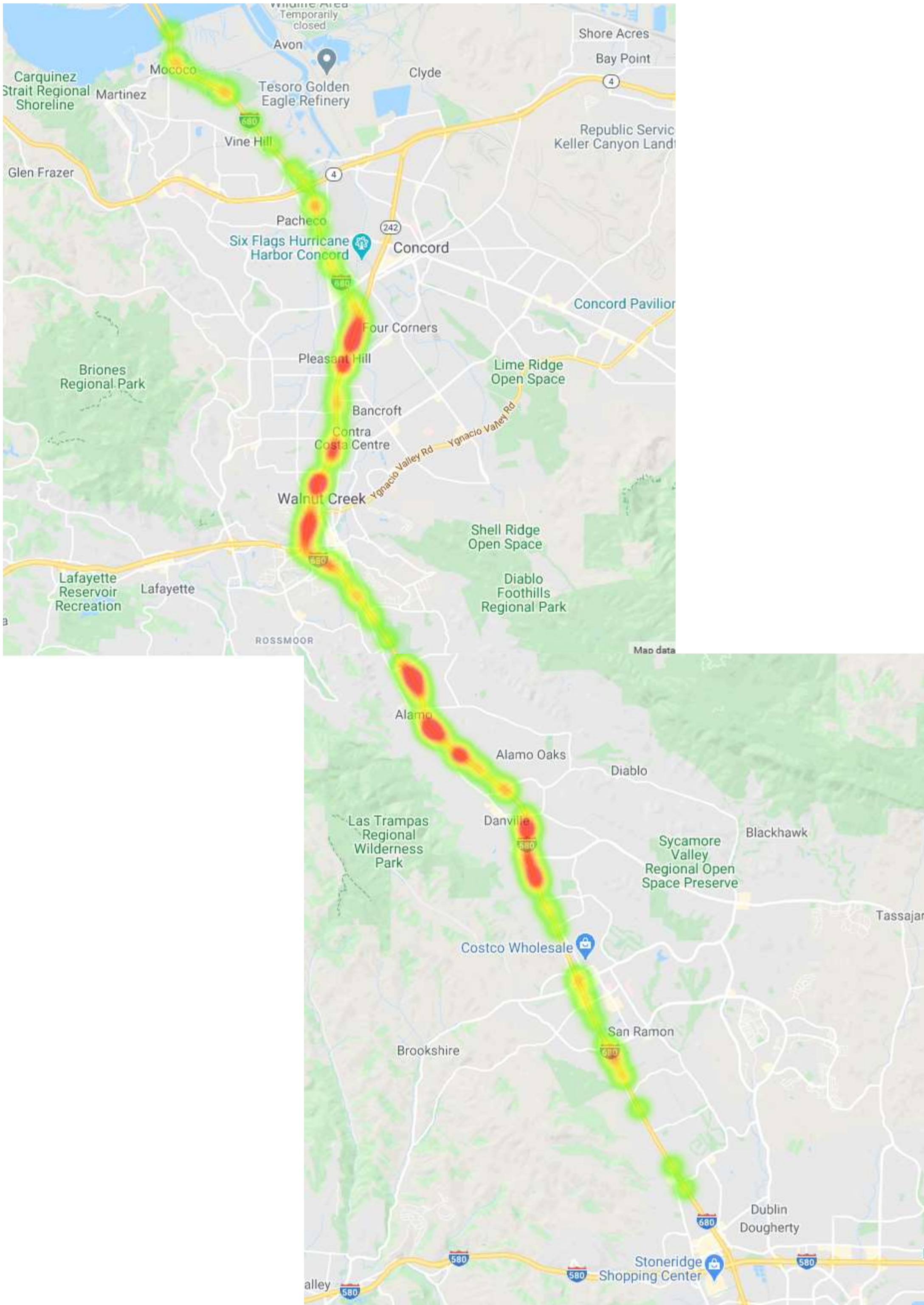
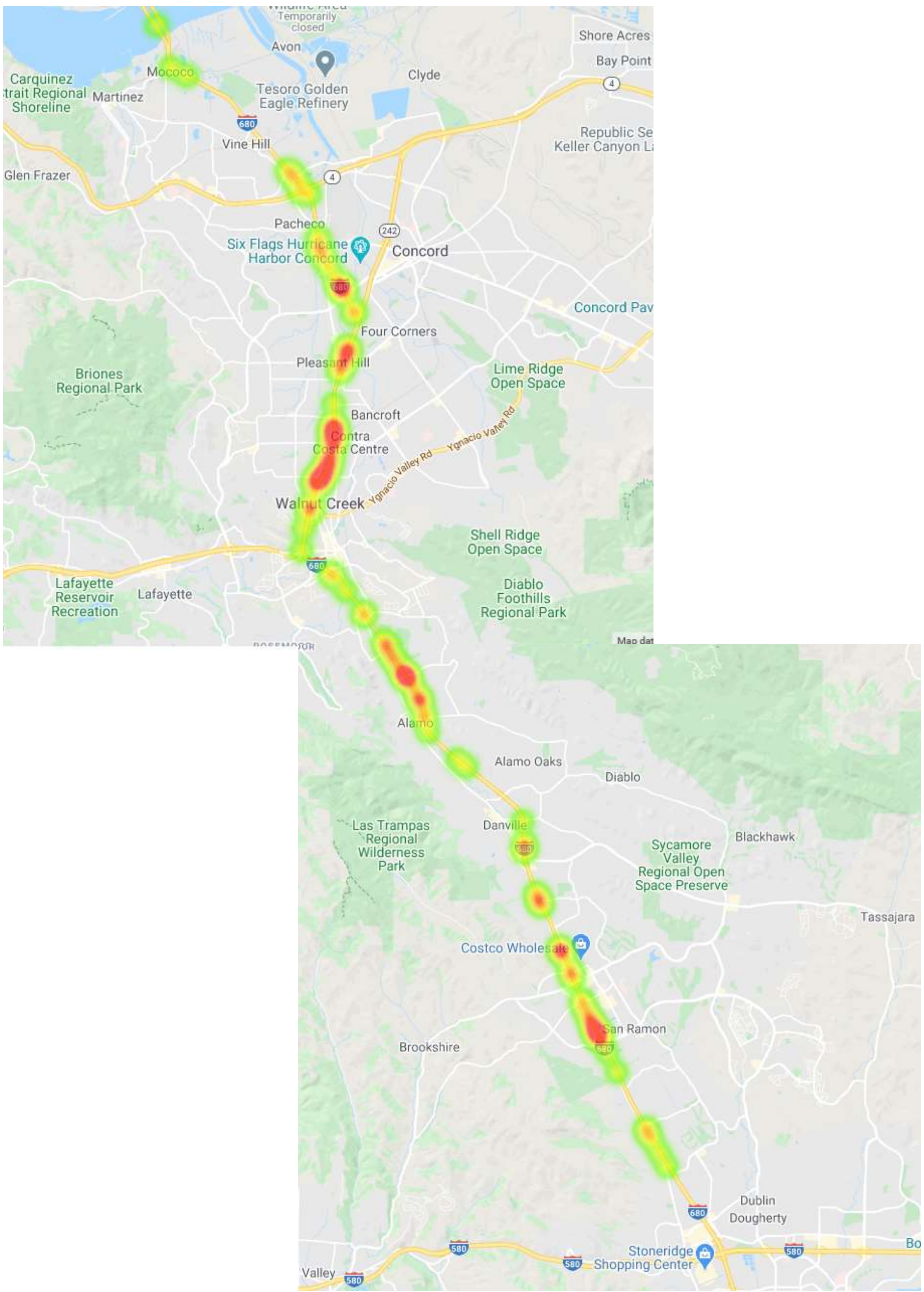


Figure 2-6 I-680 Southbound Crash Heat Plot

(Source: SWITRS for 2018)

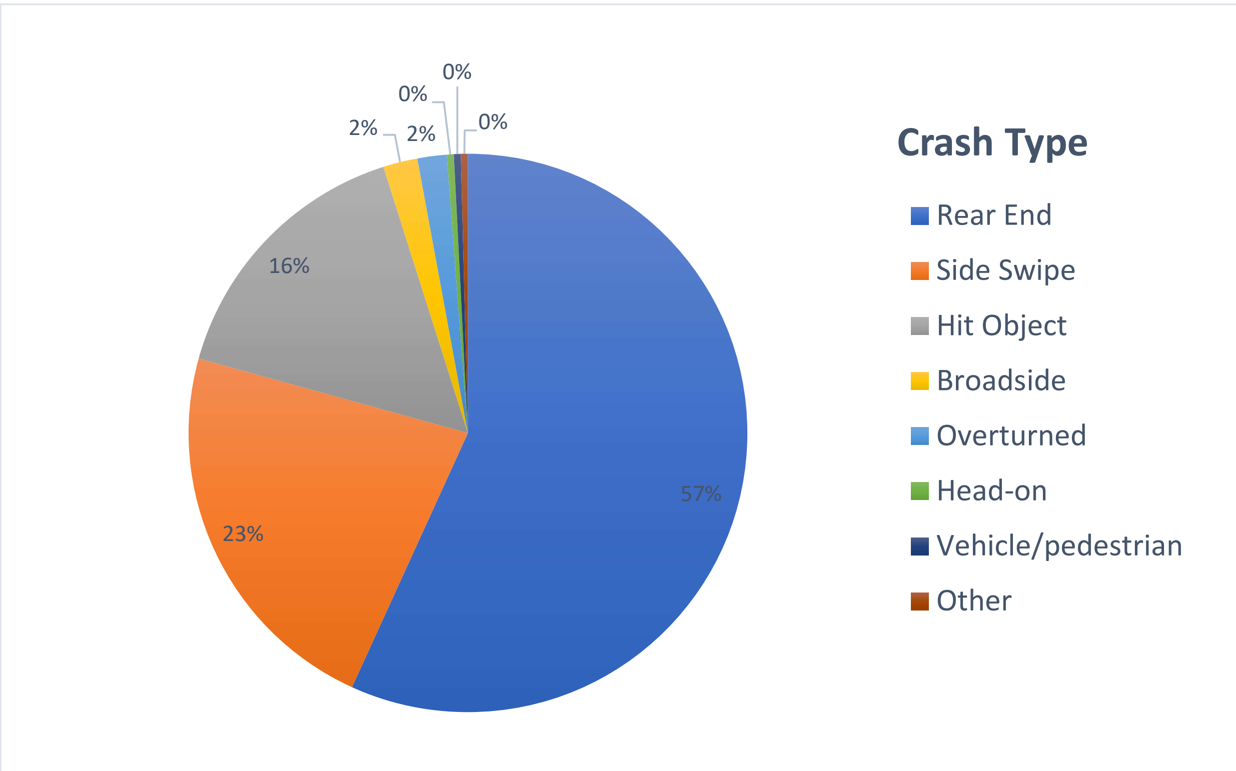


The numbers of crashes at a given location are indicated by a spectrum of color from shades of green and yellow for locations with a relatively lower numbers of crashes, to orange and red for locations with increasingly higher numbers of crashes. A comparison of Figures 2.5 and 2.6 to Figures 2.3 and 2.4 reveals a strong correlation between locations with the highest number of crashes and the areas subject to recurrent congestion.

The correlation between the number of crashes and prevalence of congestion is further reinforced by an examination of the type and severity of crashes. As shown in Figures 2.7, approximately 80% of the crashes in the corridor are either rear-end or side-swipe collisions. High occurrence of these types of crashes is consistent with congested conditions where vehicle conflicts from sudden changes in speeds or excessive lane changing are more prevalent.

Figure 2-7 I-680 Total Crashes by Type

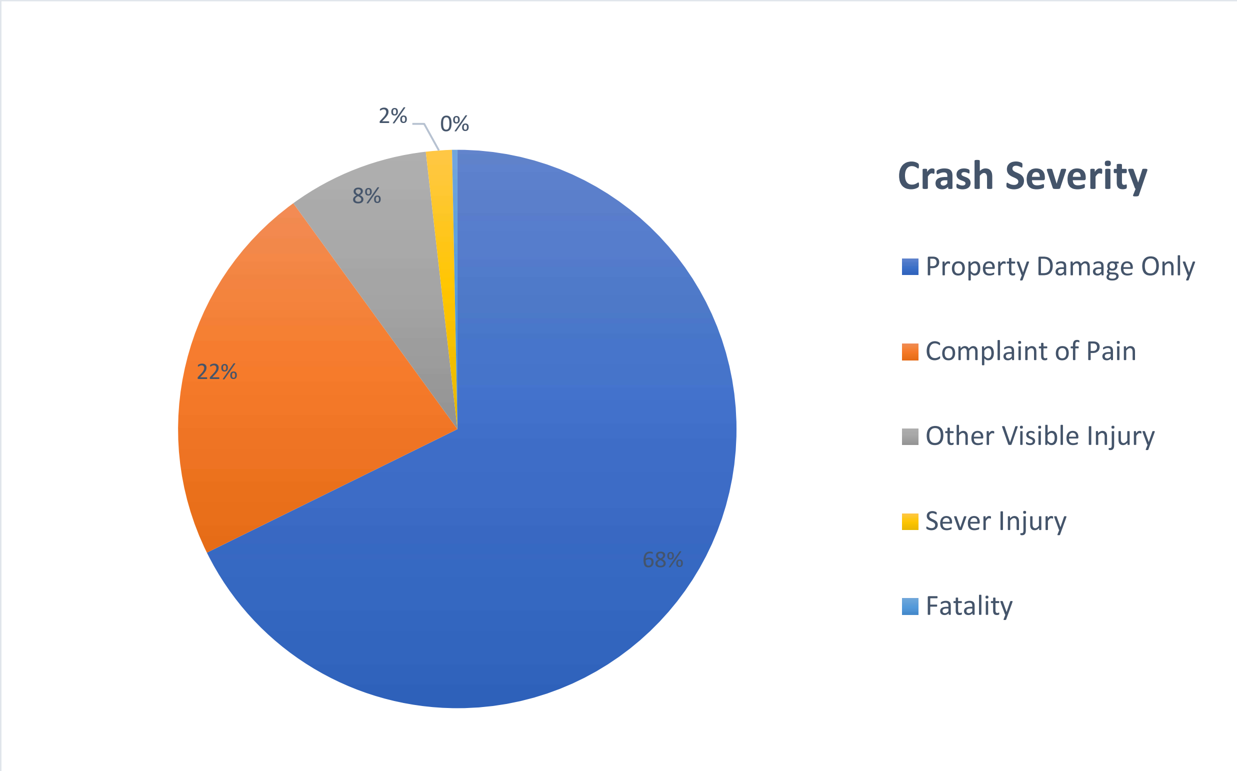
(Source: SWITRS for 2018)



Similarly, a review of crash severity shown in Figure 2.8 indicates that approximately 90% of all crashes in the corridor only resulted in property damage or complaints of pain. This suggests that the majority of collisions occurred at slower speeds, which is consistent with accidents occurring under congested conditions.

Figure 2-8 I-680 Total Crashes by Severity

(Source: SWITRS for 2018)



Resolving recurrent congestion on I-680 from the Alameda County line to CA-24 as part of a CARM demonstration is expected to reduce the number of crashes observed within the study area substantially. By better managing freeway traffic flows, CARM is intended to prevent instability that leads to disruptions in traffic flows and the onset of congestion that in turn contributes to higher numbers of crashes.

The introduction of lane use management systems (LUMS) incorporating variable speed limits, lane control signals and changeable message signs (CMS) has been an effective strategy in mitigating these types of crashes on managed freeways facilities by providing drivers with advanced warning of rapidly changing conditions due to recurrent congestion or non-recurrent conditions (crashes, construction, etc.). Figure 2.9 depicts an example of LUMS utilized on the M2 Tullamarine Freeway that is part of the Melbourne managed freeways network. In this example, lane control signals indicate lane closures to respond to a fallen power line, while variable speed limits have also been utilized to reduce speeds in advance of and through the lane closures. CMSs were also utilized to provide advanced warning of the incident and associated delays allowing drivers to choose alternative routes. LUMS enables better management of traffic during such incidents, reducing the occurrence of secondary crashes and accelerating traffic flow recovery once the disruption is cleared.

Although the use of LUMS is not specifically being included as part of the CARM demonstration, it is an additional component of managed freeways that could be implemented in congested areas with higher crash rates, particularly in advance of the implementation of CARM on I-680 between CA-24 and CA-242.

Figure 2-9 Lane Use Management System on M2 Tullamarine Freeway, Melbourne, Australia

2.3 Focus Area Traffic Flow Analysis

Based on the findings of full I-680 corridor assessment described in the prior sections, further focused analysis of the of I-680 from the Alameda County line to CA-24 was conducted to determine the feasibility to implement CARM. This analysis included further spatial evaluation based on heat plots of raw detector data as derived from PeMS, as well as a traffic analysis reviewing speeds, flow (volume) and lane occupancy in select locations. The findings of these analyses are presented in the following subsections for the northbound and southbound traffic. Chapter 4 presents the results of an analysis of ramp discharge rates in the focus area, as well the findings of a field review. Collectively, this information will inform the development of a conceptual design for the deployment of CARM.

2.3.1 Northbound I-680 Focus Area Spatial Analysis

To support the focus area spatial analysis, PeMS data was processed for analysis using the STREAMS® report dashboard to produce heat plots shown in Figures 2.10 and 2.11. These figures present data aggregated to one-minute averages for Wednesday, October 17, 2018 – a typical weekday, based on the review of Figure 2.1. The vertical axis of each plot represents the spatial location along the I-680 corridor (based on individual vehicle detector locations) with the direction of traffic flow being shown as extending up the axis, while the horizontal axis represents time of day from left to right across the axis. Figure 2.10 shows the four-hour period from 6:00 AM to 10:00 AM, and Figure 2.11 shows the four-hour period from 2:00 PM to

6:00 PM. Each figure includes four heat plots presenting speed, (lane) occupancy, productivity (a product of speed and flow), and flow (volume). The colors transition from darker, indicating speeds slowing (very congested conditions) to lighter, representing high speeds (free-flow conditions). A legend in the lower left specifies the color ranges used in the different heat plots.

It should be noted that there are data gaps at several locations along the corridor, which are indicated in gray for missing data, or a uniform band of either lighter or darker shading for errant data. As previously indicated in Figures 2.1 and 2.2, these data gaps and irregularities represent individual vehicle detectors that were inactive or partially active due to device malfunction, loss of communications, or another unknown reasons.

As shown in Figure 2.10, during the AM peak period, traffic flow breakdown is observed at two separate bottleneck locations in the northbound direction. The speed plot indicates that traffic flow instability is first observed around 7:15 AM near El Cerro Boulevard, with waves of congestion observed to form, indicated by the dark bands of slower speeds extending diagonally upstream along the corridor and to the right over time. A second area of traffic flow breakdown forms soon afterward in the vicinity of Rudgear Road, with the waves of congestion eventually extending several miles upstream along the freeway into the area of congestion that previously formed near El Cerro Boulevard. Around 8:15 AM, traffic flow breaks down completely in the vicinity of Sycamore Valley Road, as evidenced by the light-colored pyramidal shape exhibited downstream of this location in the speed plot, which is indicative of vehicles traveling at free-flow speeds after passing through the congested area exhibited by the dark purple shading. This condition effectively meters the traffic flow downstream clearing the bottleneck previously observed in the vicinity of El Cerro Boulevard.

Figure 2-10 I-680 Northbound Heat Plots

(Source: PeMS for Wednesday, October 17, 2018, 6:00 AM to 10:00 AM)

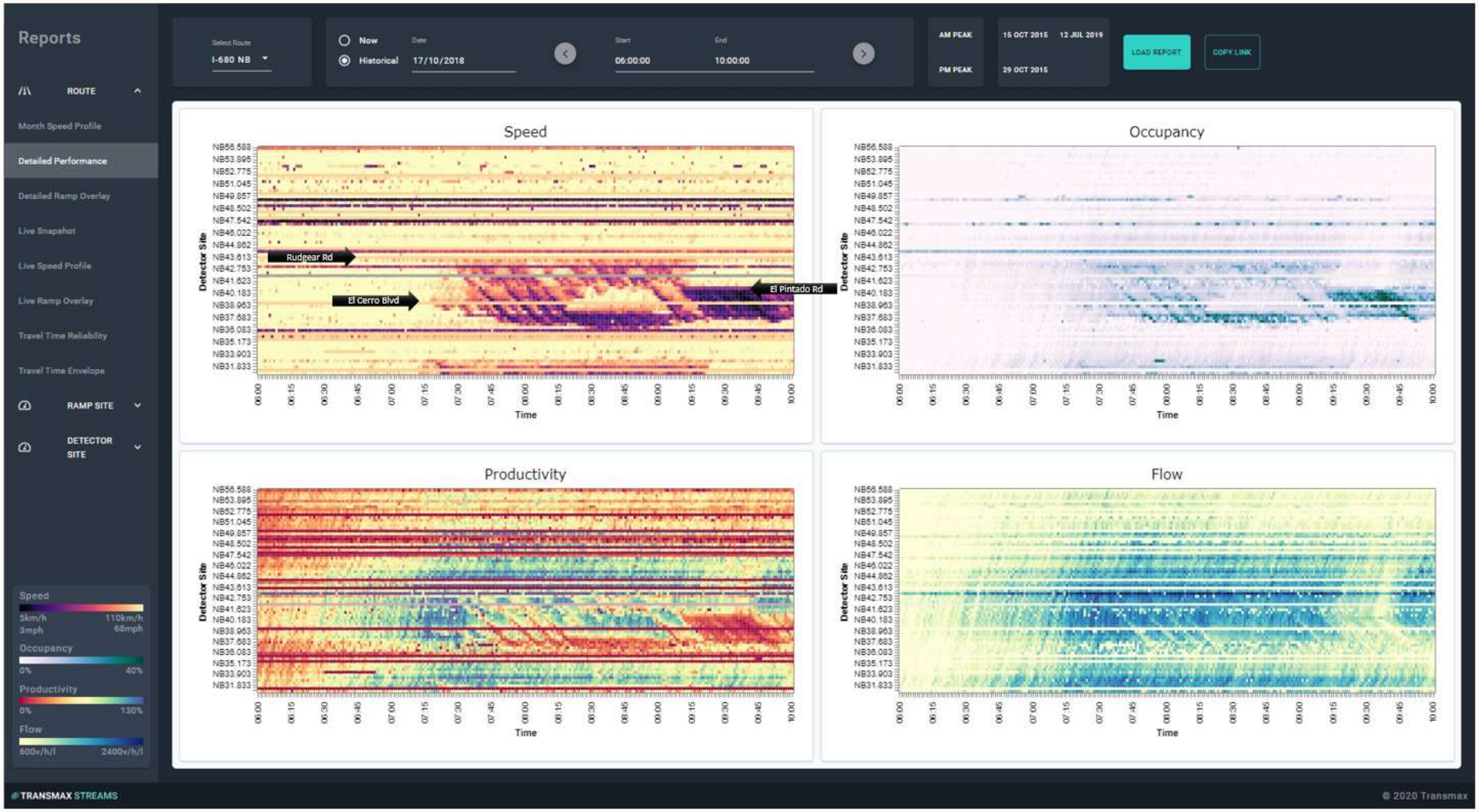
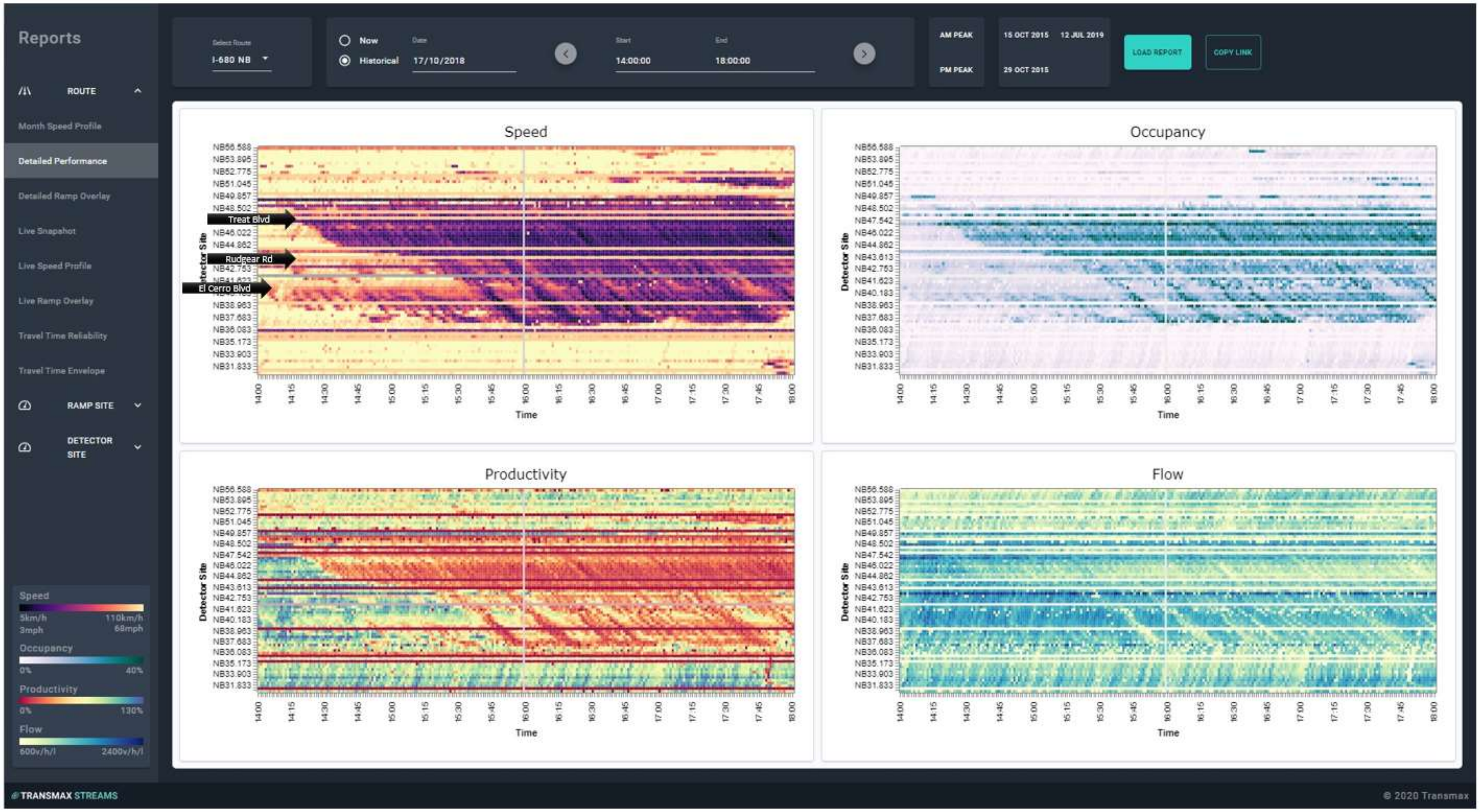


Figure 2-11 I-680 Northbound Heat Plots

(Source: PeMS for Wednesday, October 17, 2018, 2:00 PM to 6:00 PM)



Around 9:00 AM, the bottleneck at Sycamore Valley Road clears but soon afterward traffic flow breaks down completely in the vicinity of El Pintado Road, with a similar pyramid pattern appearing in the speed plot. The breakdown of traffic at this location is likely the result traffic flow flushing following the resolution of the bottleneck at Sycamore Valley Road, which creates flooding downstream that exceeds the maximum sustainable flow rate (MSFR) at the El Pintado Road bottleneck location. The effective metering of traffic at the El Pintado Road bottleneck allows the downstream bottleneck at Rudgear Road to dissipate. However, traffic remains congested at this third bottleneck location until after 10:00 AM when demand in the corridor appears to fall sufficiently for the remaining bottleneck to dissipate and free-flow conditions to resume.

The isolated nature of these AM peak period bottlenecks makes these locations desirable for the application of CARM, which improves the management of traffic flows and balance demand along the corridor, substantially reducing the observed effects of congestion. Furthermore, strategic improvements at the various ramp locations to accommodate CARM would likely assist in resolving the turbulent traffic flows that contribute to the formation of these bottlenecks.

In addition to the major bottlenecks observed during the AM peak periods, additional traffic flow turbulence occurs in the vicinity of Alcosta Boulevard, as evidenced by the darker bands in the bottom few rows of the charts in Figure 2.10. This segment includes a combination of an added lane on the left side of the freeway (the start of the express lane) and an exclusive exit lane (a lane trap) on the right side, which creates heavy weaving to maintain lane balancing. Although the implementation of CARM would not fully control upstream flows into this location, it is anticipated that the installation of metering and associated ramp improvements could contribute to stabilizing traffic flows in this vicinity.

As shown in Figure 2.11, northbound traffic flows in the PM peak period are dominated by a substantial bottleneck and resulting reduced speeds, flow and productivity in the vicinity of Treat Boulevard, approximately 2 ½ miles north of the I-680/CA-24 system interchange. The influence of this bottleneck extends into the northbound focus area, and eventually results in waves of congestion extending almost twelve miles to the vicinity Sycamore Valley Road. There are also secondary bottlenecks that form upstream of Sycamore Valley Road during the PM peak hour that could benefit from the implementation of CARM to reduce the effects of traffic flow breakdown. Furthermore, the application of CARM could also manage traffic flowing into the I-680/CA-24 system interchange and potentially reduce the disruption caused by the Treat Boulevard bottleneck.

As shown in the charts in Figure 2.11, traffic flow instability is observed in the vicinity of El Cerro Boulevard as early as 2:00 PM, eventually resulting in waves of congestion extending upstream. This condition progressively worsens for approximately 90 minutes until the effects of the Treat Boulevard bottleneck reaches this location. Similarly, unstable traffic flows are observed in the vicinity of Rudgear Road as early as 2:15 PM, with isolated waves of congestion continuing to form for approximately 45 minutes until the effects of the downstream congestion reach this vicinity. It is anticipated that the implementation of

CARM could substantially resolve the instability at these secondary bottleneck locations to prevent to onset of congestion until downstream influences reach the focus area.

2.3.2 Northbound I-680 Focus Area Traffic Flow Characteristics Analysis

Several critical locations identified as part of the focus area spatial analyses were further evaluated through a detailed traffic flow characteristics analysis investigating the relationships between traffic flow (volume), speed, and lane occupancy using one- minute PeMS data from individual mainline vehicle detectors. As shown in Figures 2.12 through 2.15, these data were plotted in both line graphs integrating all three measures, and scatter plots arraying pairs of measures. The flow characteristics analysis provides a greater understanding of each problem area. It indicates the typical loss of throughput and the duration of flow breakdown, and also provides an indication of the level of benefit that may be derived from CARM deployment. The analysis was performed using the same PeMS dataset for Wednesday, October 17, 2018 for various critical locations in the study corridor.

Figure 2.12 illustrates AM peak period traffic flow characteristics on northbound I-680 in the vicinity of El Cerro Boulevard (PeMS detector site 401112 at PM 39.813). Based on the review of the heat plots in the previous sections, this location appears to be a critical bottleneck that provides the earliest indication of traffic flow disruption. As shown in the line graph in Figure 2.12, flow/volume (indicated by the blue line) gradually increases after 6:00 AM reaching a peak flow rate of between 1,600 to 1,800 vehicles per hour per lane (vphpl) around 7:15 AM. At that time, speeds (indicated by the magenta line) begin to drop indicating the onset of unstable flows.

By 7:45 AM traffic flow breaks down and waves of congestion become evident with speeds and flow periodically dropping substantially, and lane occupancy (indicated by the teal line) spikes. Under congested conditions, flow rates average between 1,400 and 1,500 vphpl, which is 12% to 17% below peak flow rates, and roughly 25% to 30% below the typical capacity of similar freeway segment.

The congested state remains present until about 8:20 AM when speeds recover; however, flow rates remain reduced to about 1,500 vphpl. This is due to the upstream bottleneck observed in the heat plots that meter the flow of traffic into this location. Around 9:00 AM unstable traffic flows and lower speeds can be observed again, as a new wave of congestion from the downstream bottleneck reaches this location. By 9:15 AM sustained queuing from the downstream bottleneck engulfs this location with speeds and flows dropping substantially and lane occupancy spiking to over 50%, indicating that traffic queues are nearly stationary. The congested state extends beyond the end of the time shown in Figure 2.12, only recovering after 10:00 AM when flows drop sufficiently, allowing congestion to dissipate and free-flow conditions to resume.

A review of the scatter plots included on Figure 2.12 shows well defined curves closely resembling the fundamental diagrams of traffic flow. The scatter plots demonstrate the expected pattern with traffic flows, speeds and occupancy gradually increasing until unstable flows are observed at the peaks of the curves. This is followed by traffic flows falling into a congested state, characterized by a more scattered array of points indicative of repeated waves of congested flow and momentary recovery.

Figure 2.13 shows the AM peak period traffic flow characteristics on northbound I-680 in the vicinity of Sycamore Valley Road (PeMS detector site 400972 at PM 38.243), approximately 1.6 miles upstream from the El Cerro Boulevard detector site. As expected, the influence of the downstream bottleneck is observed at this detector site, with speeds dropping rapidly around 7:30 AM and flows similarly dropping soon thereafter, indicating that queuing from the downstream bottleneck has reached this location. The location then remains in a congested state with speeds averaging around 20 mph, flows averaging between 1,200 and 1,400 vphpl, and lane occupancy between 20% and 30% until after 10:00 AM when traffic flow recovers. This pattern is also observed in the scatter diagrams with an abrupt break between the points indicating stable and congested conditions. This abrupt change is consistent with the effects of downstream queuing crossing the detector location.

These observations indicate the potential to resolve the interrelated bottlenecks in this corridor with the implementation of CARM. Better management of traffic flows to avoid the shock of sudden changes in flow rate and lane occupancy can help to prevent the sudden declines in speeds that result in the breakdown of traffic flow. Avoiding traffic flow breakdown can allow higher flow rates to be sustained and provide higher productivity in the corridor.

Figure 2.14 presents the PM peak period traffic flow characteristics at the El Cerro Boulevard detector site previously discussed. The line chart indicates the onset of congestion soon after 2:00 PM, with sustained waves of congestion throughout the four-hour observation period included in the chart. Around 3:45 PM, the effects of downstream queuing can be observed with an additional abrupt drop in speed and flow as the congestion wave reaches this site. After this time, the additional declines in speeds and flows are sustained until well after 6:00 PM when demand reduces sufficiently to permit recovery. These effects can also be observed in the scatter diagrams, which generally demonstrate only the congested side of the fundamental diagram curves.

Figure 2.15 shows the PM peak period traffic flow characteristics on northbound I-680 in the vicinity of the Newell Avenue undercrossing (PeMS detector site 400025 at PM45.192), approximately 5.3 miles downstream from the El Cerro Boulevard detector site, and approximately 2.7 miles upstream from the Treat Boulevard bottleneck location. As shown in Figure 2.15, traffic flows at the Newell Avenue detector site are characterized by a sudden and substantial drop in speeds around 2:20 PM, followed by a sustained congested state. Traffic flows prior to the onset of congestion only reach an average of about 1,200 vphpl before queuing from the Treat Boulevard bottleneck enters this location reducing average flow rates to below 1,000 vphpl. These effects are reiterated in the scatter plots with points clustered around the lowest parts of the fundamental diagram curves, indicating significant loss of productivity due to the congested state. As mentioned earlier, by 3:45 PM this queuing influences the El Cerro Boulevard detector site. While the proposed CARM demonstration is not intended to resolve the bottleneck at Treat Boulevard, deferring the congestion effects in the vicinity of El Cerro Boulevard is a desired outcome from implementing CARM.

Figure 2-12 I-680 Northbound at El Cerro Boulevard Traffic Flow Characteristics

(Source: PeMS for Wednesday, October 17, 2018, 6:00 AM to 10:00 AM)

Figure 2-13 I-680 Northbound at Sycamore Valley Road Traffic Flow Characteristics

(Source: PeMS for Wednesday, October 17, 2018, 6:00 AM to 10:00 AM)

Figure 2-14 I-680 Northbound at El Cerro Boulevard Traffic Flow Characteristics

(Source: PeMS for Wednesday, October 17, 2018, 2:00 PM to 6:00 PM)

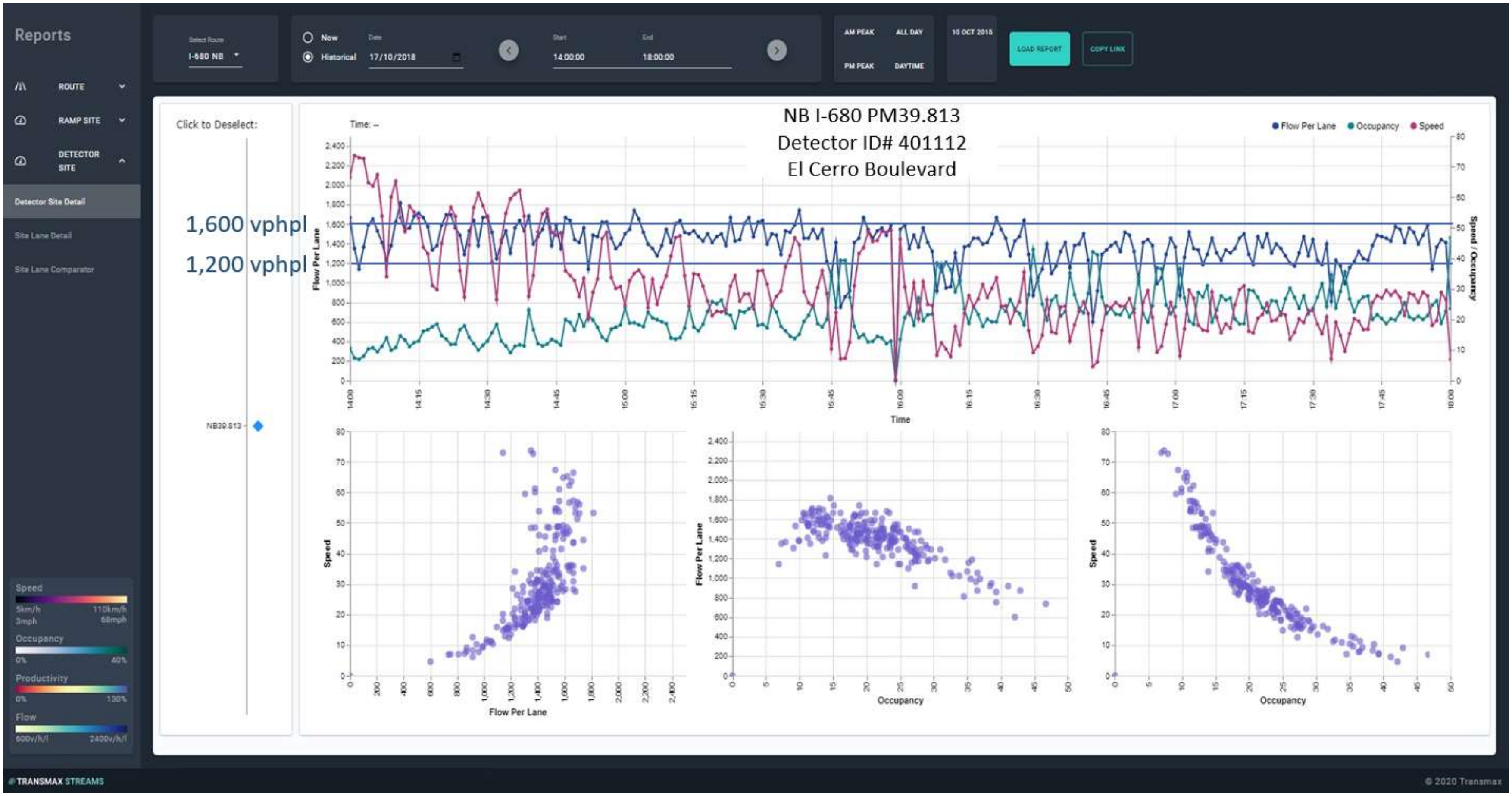


Figure 2-15 I-680 Northbound at Newell Avenue Traffic Flow Characteristics

(Source: PeMS for Wednesday, October 17, 2018, 2:00 PM to 6:00 PM)

2.3.3 Southbound I-680 Focus Area Spatial Analysis

Figures 2.16 and 2.17 provide STREAMS® report dashboard heat plots of PeMS data for southbound I-680 from the Solano County line to the Alameda County line. Like the northbound plots presented previously, these plots present one-minute data for Wednesday, October 17, 2018 with the vertical axis representing the spatial location based on the individual vehicle detector locations along southbound I-680 (with the direction of traffic flow being shown as extending down the axis), while the horizontal axis represents time of day from left to right. Figure 2.16 shows the four-hour period from 6:00 AM to 10:00 AM, and Figure 2.17 shows the four-hour period from 3:00 PM to 7:00 PM. Each figure includes plots presenting speed, (lane) occupancy, productivity (a product of speed and flow), and flow (volume).

As with the northbound data, there are data gaps at numerous locations along the corridor, which are indicated by gray colors (for missing data) or a uniform band of lighter or darker shading (for errant data) in the heat plots. As mentioned previously, these data gaps and irregularities represent individual vehicle detectors that were inactive or partially active because of device malfunction, communications loss or another unknown reason.

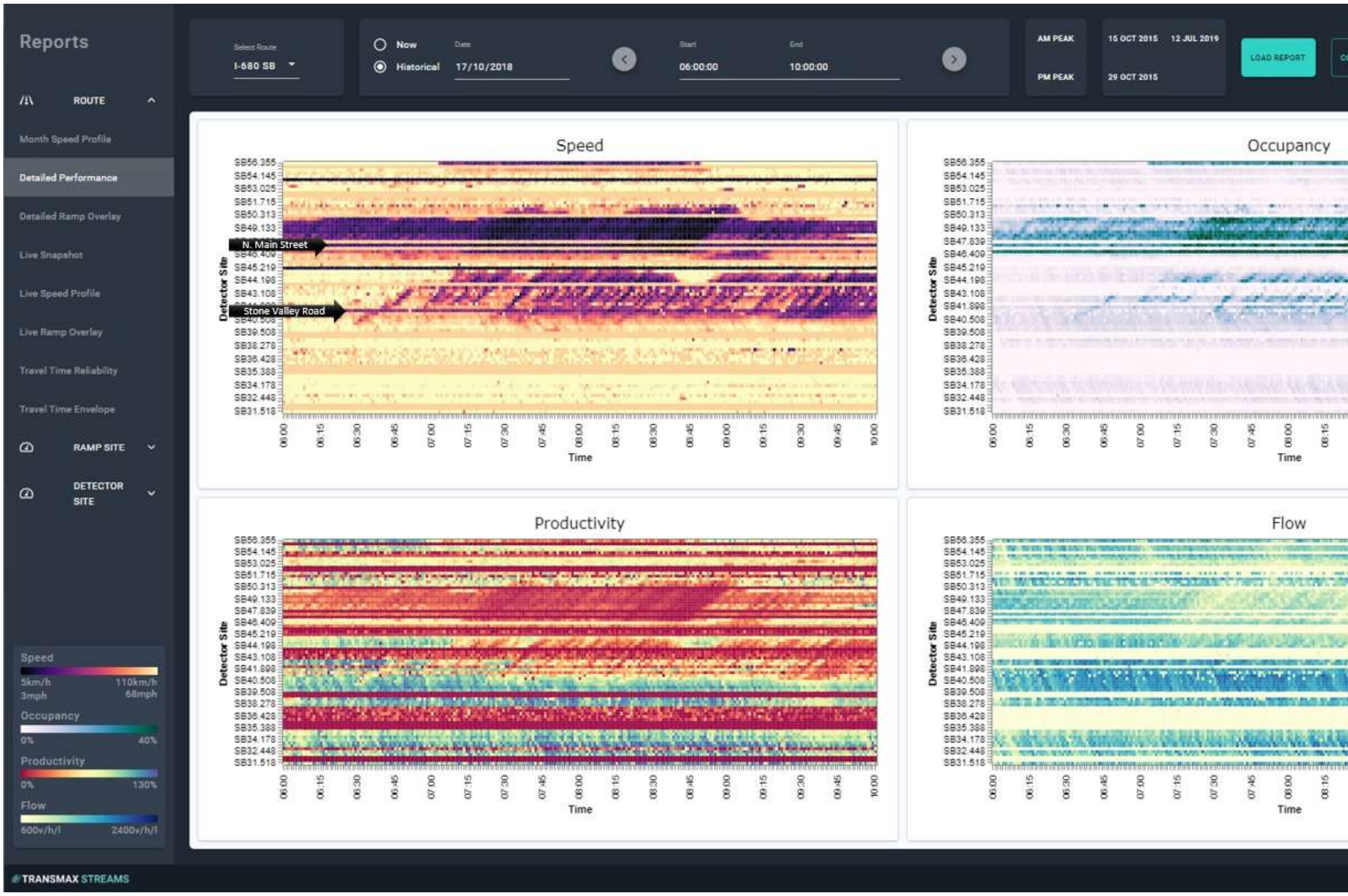
As shown in Figure 2.16, during the AM peak period, significant traffic flow breakdown occurs in the vicinity of North Main Street north of the CA-24 system interchange. This traffic flow breakdown begins well before 6:00 AM and the resulting severe congestion persists until after 10:00 AM. There are multiple factors contributing to the traffic flow disruption including the confluence of multiple service interchanges, the CHP truck scales, lane sorting associated with the approach to the CA-24 interchange, and a configuration that includes up to six general-purpose lanes in the southbound direction – all underscoring the complexity of this bottleneck. Furthermore, under existing (pre-COVID-19 pandemic) conditions, the ongoing construction of the southbound express lane through this area exacerbates the situation, making this location less desirable for a CARM demonstration.

South of CA-24, traffic flow instability is first observed around 6:45 AM downstream of the Stone Valley Road on-ramp. Clearly defined waves of congestion are observed to form (as demonstrated by the dark bands of slower speeds extending diagonally upstream along the corridor and to the right over time) with queuing extending upstream to the vicinity of South Main Street. The congestion remains until after 10:00 AM when demand reduces sufficiently that freeway traffic flows recover.

Although southbound traffic on I-680 is effectively being metered by the North Main Street bottleneck, flow from the eastbound CA-24 system interchange ramp to southbound I-680 combined with traffic entering the freeway at Olympic Boulevard, South Main Street, Rudgear Road and Livorna Road appears to conflict with the traffic entering at Stone Valley Road resulting in the observed traffic flow breakdown. The implementation of a CARM strategy could better manage traffic flows and balance demands along the corridor to potentially resolve the formation of the Stone Valley Road bottleneck. However, it is anticipated that it would be necessary to meter the eastbound CA-24 to southbound I-680 connector to manage traffic flows adequately. The effectiveness of a CARM solution with and without metering on the CA-24 connector is evaluated in a subsequent section of this report.

Figure 2-16 I-680 Southbound Heat Plots

(Source: PeMS for Wednesday, October 17, 2018, 6:00 AM to 10:00 AM)



As shown in Figure 2.17, southbound traffic flows in the PM peak period are most notably affected by traffic flow breakdown at the same location downstream of the Stone Valley Road on ramp. As shown in Figure 2.17, traffic flow instability is first observed just after 3:30 PM downstream of Stone Valley Road and soon results in waves of congestion and queuing that mimics the conditions observed during the AM peak period (although the severity of the congestion does not appear to be as high during the PM peak period, as evidenced by the generally lower lane occupancy as exhibited in the respective figures). Congestion persists until around 6:30 PM when the queue eventually dissipates, and free flow conditions resume.

A second bottleneck Is evident between Alcosta Boulevard and Bollinger Canyon Road. Unstable traffic flows are first observed around 4:00 PM near the San Ramon Valley Boulevard off-ramp. While it is difficult to determine the nature of this instability from the available data, it is possible that traffic decelerating to exit to San Ramon Valley Boulevard is contributing the disruption.

A more prominent bottleneck in this vicinity is observed immediately downstream of the Bollinger Canyon on-ramps, with constant traffic flow disruption indicated by the relatively darker band in Figure 3-17 for the detector located at southbound I-680 milepost 34.178 (adjacent to the Bollinger Canyon Road direct on-ramp). Traffic flow breakdown eventually occurs around 4:10 PM with congested conditions persisting until around 6:15 PM. In addition, the relative instability in traffic flow can be seen to continue beyond the limits of the figure. Unfortunately, the PeMs detectors in the vicinity of Crow Canyon Road appear to have been reporting errant data during this time, so it is not possible to determine the full extent of queuing beyond the Crow Canyon Road service interchange location.

The Bollinger Canyon bottleneck appears to be typical of those often observed in the vicinity of parclo interchanges, with the combined effects of closely spaced on-ramps and relatively short weave distances provided –less than 500 feet and 400 feet, respectively. These factors cause slower traffic entering the freeway to disrupt faster traffic traveling in the right-most lane(s) of the mainline, resulting in the rapid onset of traffic flow breakdown. Consolidation of the ramps into a single weave area with adequate merging distance provided is recommended to address this issue as part of a CARM strategy.

2.3.4 Southbound I-680 Focus Area Traffic Flow Characteristics Analysis

Detailed flow characteristics for the southbound bottlenecks at Stone Valley Road and Bollinger Canyon Road are presented in Figures 2.18 and 2.19. These exhibits display the relationships between traffic flow (volume), speed, and lane occupancy using one-minute PeMS data from individual mainline vehicle detectors.

Figure 2-17 I-680 Southbound Heat Plots

(Source: PeMS for Wednesday, October 17, 2018, 3:00 PM to 7:00 PM)

Figure 2-18 I-680 Southbound South of Stone Valley Road Traffic Flow Characteristics

(Source: PeMS for Wednesday, October 17, 2018, 6:00 AM to 10:00 AM)

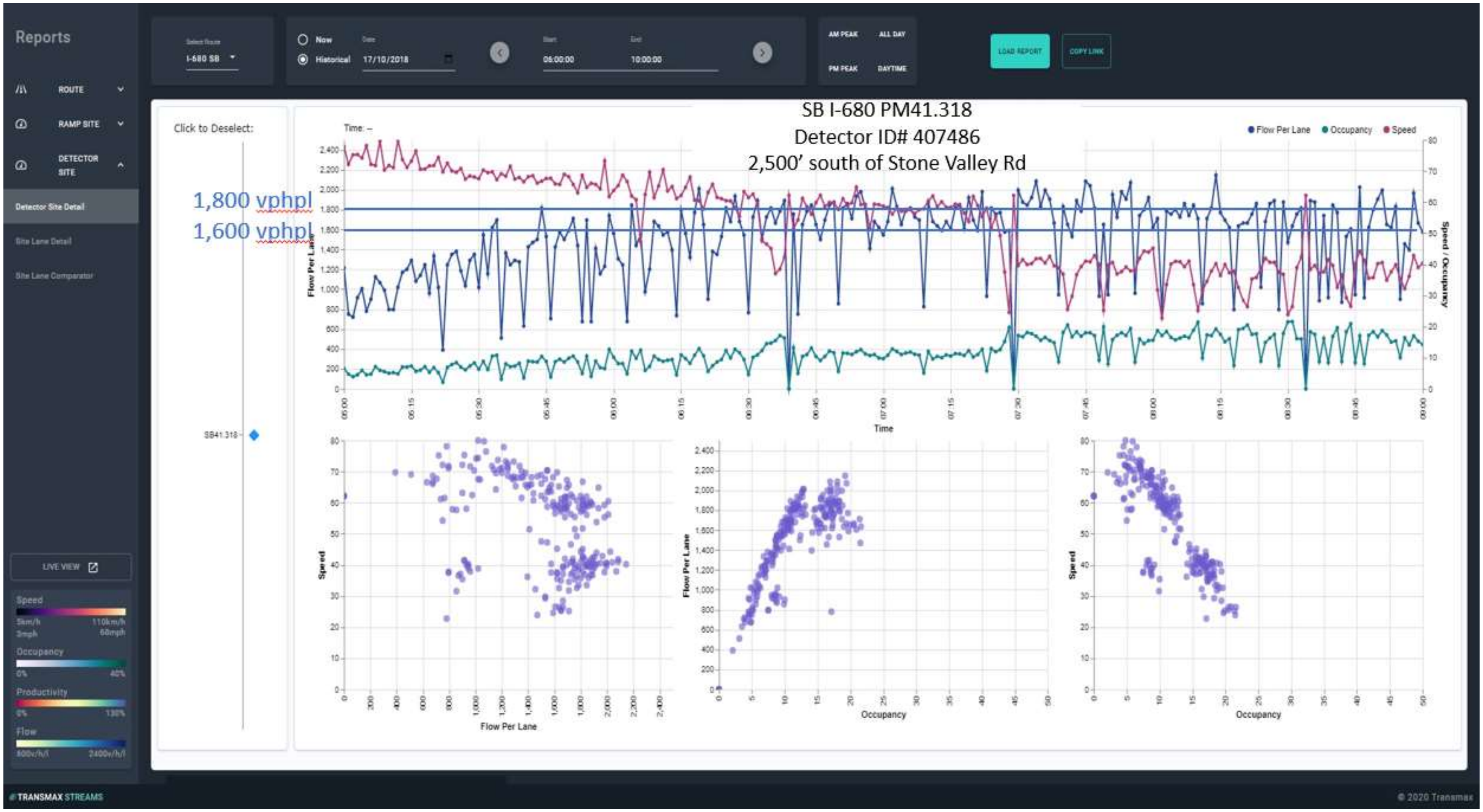


Figure 2-19 I-680 Northbound at Bollinger Canyon Road Traffic Flow Characteristics

(Source: PeMS for Wednesday, October 17, 2018, 2:00 PM to 6:00 PM)

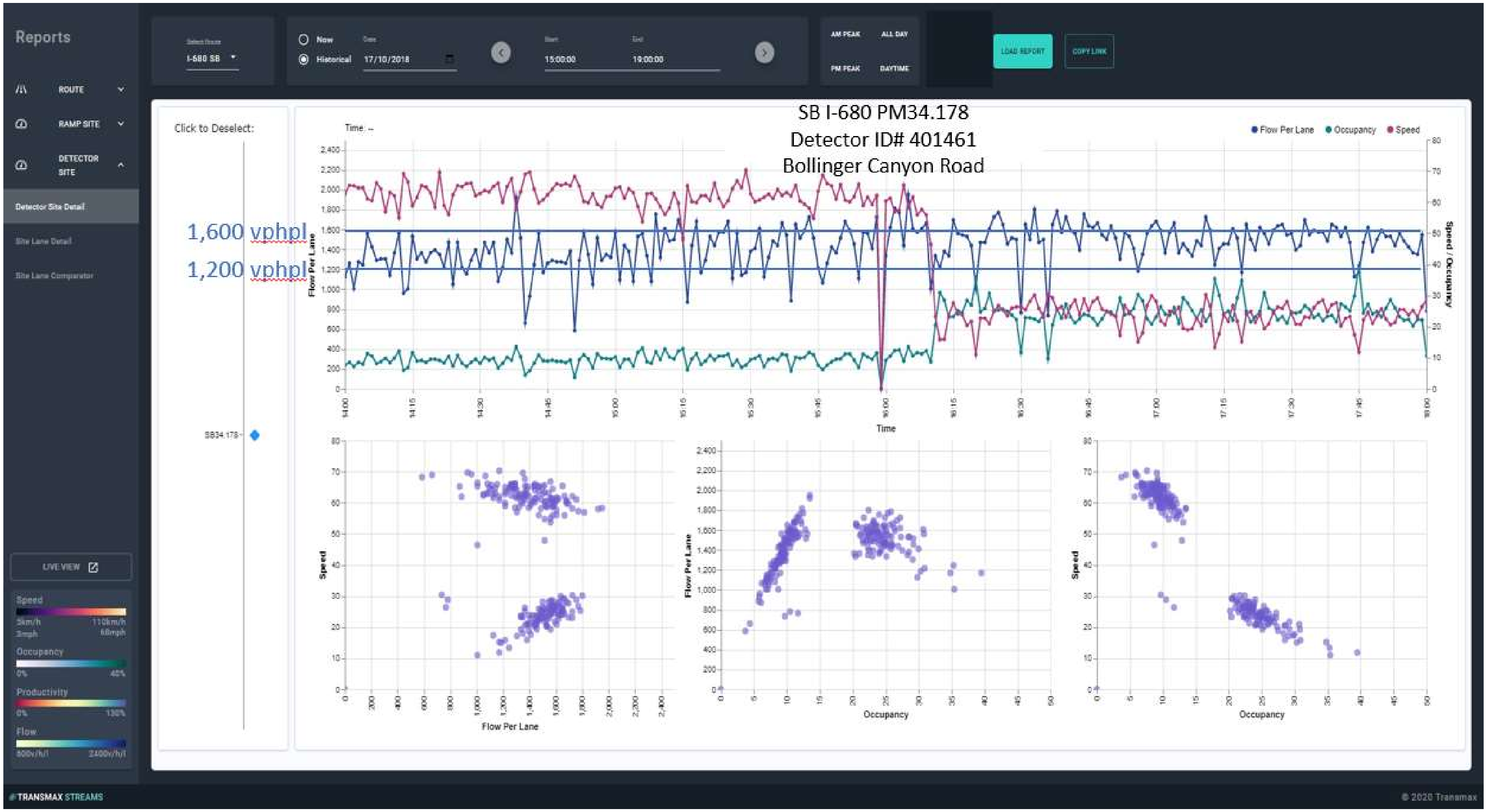


Figure 2.18 provides the AM peak period traffic flow characteristics on southbound I-680 downstream of Stone Valley Road (PeMS detector site 407486 at PM 41.318). Although the data in the plots appear to reflect a detector intermittently failing to report data (illustrated by the periodic abrupt drops in traffic flows with no accompanying drop in average travel speeds), it is possible to observe flow rates gradually building to about 1,800 vphpl by 6:30 AM, at which time speeds start to become unstable and eventually drop substantially at about 7:30 AM, indicating the onset of flow breakdown. Once flows have broken down, speeds continue to oscillate in a pattern indicative of waves of congestion (start-stop conditions) passing this point, although the observed flow rate only drops slightly, generally achieving about 1,600 to 1,700 vphpl. As described previously, this bottleneck eventually results in queues extending several miles upstream, with the freeway remaining in a congested state until well after 10:00 AM.

A review of the scatter plots demonstrates generally well-defined clusters of stable traffic flows (typically the upper and/or right areas of the exhibits) and a scattering of data points moving down and/or to the left, which is more typical of unstable flows. The plots also show a small well-defined cluster outside of the normal fundamental curve distribution, which appears to provide further confirmation of the errant nature of some flow data points, as discussed previously.

Figure 2.19 shows the PM peak period traffic flow characteristics on southbound I-680 in the vicinity of Bollinger Canyon Road direct on-ramp (PeMS detector site 401461 at PM 34178). As described previously, the influence of the platoons of traffic entering the freeway from the Bollinger Canyon Road on-ramps is evident in the relatively unstable flows and speeds observed from 2:00 PM to 4:00 PM when the freeway is generally free-flowing. Just after 4:00 PM, flows begin to spike briefly to between 1,800 vphpl and almost 2,000 vphpl (there appears to be an anomalous data point at 3:59 PM with no speed, volume or occupancy data recorded). At around 4:10 PM, both speeds and flows drop substantially, likely the result of a platoon of traffic entering the freeway from one or both of the Bollinger Canyon Road on-ramps trying to merge with the higher traffic flow on the freeway mainline, resulting in an initial disruption to flows as vehicles in the right lanes on the mainline are forced to decelerate abruptly to make way for slower traffic merging onto the freeway in the relatively short on-ramp merge areas. This sudden disruption causes the freeway to breakdown immediately, with speeds and flows oscillating as waves of congestion pass the detector location. The freeway eventually recovers at around 6:15 PM.

The effects of this bottleneck can also be observed in the scatter diagrams, which generally demonstrate two clear clusters of generally free-flowing and congested traffic conditions, respectively, with no clear path of deterioration during transition from a free-flow to congested state. This pattern can often be observed when a downstream queue moves over a detection point; however, a review of the heat plots indicates no such queuing affecting this location. Therefore, this finding supports the conclusion that the friction between traffic entering the freeway from Bollinger Canyon Road and the increased flow of traffic on the mainline results in a sudden breakdown of traffic flow creating a bottleneck and the onset of congestion.

3 Corridor Ramp Metering Analysis

3.1 Overview

CARM is the primary ITS tool that allows managed freeways to maintain optimal throughput on the freeway mainlines by regulating the flow of traffic entering the freeway so that traffic density on the mainline (typically measured as lane occupancy for managed freeways purposes) does not increase to the point where flow breakdown occurs. By implementing adaptive ramp metering using a comprehensive, coordinated, advance traffic management system, ramps coordinate with each other to minimize the probability of excessive queues forming at any one ramp. While ramp queues would not directly impact mainline speed or throughput, if uncontrolled they can spill back beyond the beginning of the ramp and impact arterial flow near the ramp entrance. Longer queue lengths also result in an excessive wait time for drivers entering the freeway. A ramp experiencing especially heavy flows has two options in a system where the ramps are not coordinated:

1. maintain its metering rate and cause excessive queues that can adversely impact the arterial network, or

2. increase the metering rate (or flush the ramp) and adversely impact traffic flow, and ultimately vehicle throughput on the mainline.

As a foundational component of a managed freeway, the concept of CARM includes an integrated data collection system along the roadway and advanced system management tools to monitor and control real-time traffic conditions to ensure a higher, more consistent level of freeway performance. By utilizing intelligent information, communications, and control systems, CARM synchronizes the flow of vehicles entering a freeway to those already on the mainline, to match the freeway's operational capacity. This real-time, comprehensive flow management results in considerable improvement to freeway performance and safety, thereby helping to maximize the overall efficiency of the facility.

Historically, ramp metering is a proven, cost-effective operational strategy to manage freeway traffic conditions and has been in use in the United States since the 1960s. In general, there are three types of ramp metering strategies:

1. Pre-timed metering, where vehicles are released onto the mainline at pre-determined intervals

2. Local, isolated metering, where local traffic conditions solely determine the metering rates; and

3. System-wide, coordinated metering, where the rates are decided based on system-wide information.

Of the three strategies, the system-wide approach provides more options and flexibility in managing freeway mainline flow and reducing overall system delay. With CARM – which is a system-wide, coordinated metering strategy – adequate storage space on ramps and mainline capacity are critical for successful implementation. When the ramp queues exceed the available storage space due to insufficient mainline capacity, ramp metering algorithms will either "flush the queue" by significantly increasing the metering rate, or simply turn off the ramp metering signals so that the queues do not back up to arterial streets and impact surface traffic. While common, this practice almost always affects freeway traffic flows adversely, often triggering severe breakdowns at the next downstream bottleneck, substantially diminishing the performance of the freeway and the impacting the overall system.

While CARM is a proven strategy for managing and adapting to different freeway traffic conditions, it is worth noting that like all other ramp metering strategies, CARM, is only able to maintain traffic throughput at a level that can be supported by corridor geometrics. Although CARM can prevent flow breakdown due to congestion, it cannot increase flow beyond the flow rate that the geometric characteristics of the facility can handle. A detailed discussion of the maximum sustainable flow rates on I-680 in Contra Costa County is provided in Appendix A of the Evaluation Report.

Although CARM is a relatively low-cost, high-benefit strategy, it requires the evaluation and the installation of ITS improvements that might not be universally present on the I-680 freeway corridor today. Ramp storage requirements may also necessitate reconfiguration of select on-ramps to provide adequate vehicle storage capacity. In addition, existing freeway sensors and detection equipment may need to be augmented in order to maximize the benefits of the CARM algorithms.

3.2 Determining Ramp Storage Capacity for CARM

Providing adequate storage space for vehicles queuing on freeway access ramps is essential to the success of CARM deployments. To keep the connected local roadways free from the adverse impacts of the entrance ramp queue overspill, adequate storage length should be provided to contain the entrance ramp queue within the entrance ramp. At individual metered locations, the storage needs can be calculated as:

Estimated Storage = (Demand Rate-Discharge Rate) *Average Vehicle Length

In the short term, both demand rate and vehicle length can be treated as constants. Thus, the storage needs are correlated to the ramp meter discharge rates, which are determined based on the capacity and traffic conditions on the mainline and the system-wide metering strategies.

CCTA has utilized three different methodologies to calculate storage requirements for all ramps on I-680 northbound and southbound in Contra Costa County. They include

- A time/demand-based calculation developed by VicDOT, which is used as the industry standard for calculating CARM ramp storage requirements
- A statistical modeling approach specifically design for CARM applications that is designed to be indicative of the 95^{th} percentile of ramp cueing requirements using

the R language to analyze multiple scenarios based on traffic demand, varying metering rates and the physical characteristics of the corridor

- A standard Caltrans ramp metering methodology as described in the Caltrans Ramp Metering Design Manual (RMDM) that assumes that the capacity of new or reconstructed ramps should be designed to hold seven percent of the peak hour demand at any given ramp.

3.2.1 VicDOT Ramp Storage Requirement Methodology

As the developers of the initial managed freeways projects featuring the CARM solution utilizing the AHS of algorithms, VicDOT has subsequently developed comprehensive guidance for emulating their solution to freeway traffic management. The *Managed Motorway Design Guide* is a series of publications that explains the role, theory and science of traffic optimization and details principles and tools for planning and designing managed freeways projects. This VicDOT guidance represents the primary reference for designing managed freeways components, including specific considerations for ramp storage and discharge recognizing the unique needs and anticipate benefits of CARM. For this reason, the VicDOT guidance has been most closely followed to inform design consideration for CARM in the I-680 corridor.

The VicDOT methodology for determining CARM storage and capacity correlates ramp discharge capacity with the number of lanes at the stop line, the ramp arrival flow, the ramp arrival rate assumed in the design (q_{ra}), the number of vehicles per lane and an appropriate average design cycle time (C_r) to meter the traffic entering the mainline.[1] On high demand freeways, the desirable minimum cycle time adopted for design and capacity analysis averaged over the design peak hour should typically be not less than:

- 7.5 seconds for ramps merging with the mainline, or
- 6.5 seconds for ramps with an added lane, added lane plus merge or two added lanes entering the mainline

These average cycle time values over the design hour make allowance for real time operational flexibility.

VicDOT uses a desirable minimum standard of a four-minute total wait time to determine the total length of ramp storage between the stop line and the ramp entrance, i.e. a ramp queue delay q_{ra} of 4. For the purpose of storage design considerations, the ramp entrance is defined as starting clear of the location where pedestrians would cross at the intersection (either marked or unmarked crossing) and excludes the left or right turning lanes leading to the ramp.

[1] Managed Motorway Design Guide, Volume 2: Design Practice, Part 3: Motorway Planning and Design; Victoria Department of Transport: Kew, Victoria, Australia, October 2019, p. 76

This standard shall be provided by lengthening existing ramps when it is economically feasible within design constraints, e.g. no downstream bridge or exit taper. This facilitates operational flexibility to:

- Limit vehicle entry to the freeway when the ramp merge or downstream freeway is at or approaching capacity
- Balance queues and waiting times between adjacent ramps in the coordinated system
- Reduce the likelihood of overflow queues extending onto the surface road
- Provide for short term variations and spikes in traffic demand within the peak period
- Accommodate uncertainties in traffic growth, future forecast volumes or changes in travel patterns, and
- To limit vehicle entry to the freeway during an incident and to facilitate recovery after an incident.

The length of the desirable ramp storage, L_{rDes} is calculated from the number of vehicles in the maximum wait time queue, n_{rMax}-wait, the maximum wait time, t_{Max}-wait, and the average length of the ramp queue vehicle storage space, L_{vs} as shown in Equation 1:

Equation 1 Desirable Ramp Storage Length

$$L_{rDes} = n_{rMax\text{-}wait} \times L_{vs}$$

where the typical vehicle length is 28 feet, or 29.5 feet on ramps with high truck volumes.

The number of vehicles in the queue based on the wait time, $_{nrMax\text{-}wait}$, is calculate from the ramp arrival (demand) flow, q_{ra} and the maximum wait time, which is generally four minutes, as shown in

Equation 2 Number of Vehicles in Queue

$$n_{rMax\text{-}wait} = (q_{ra} \times t_{Max\text{-}wait}) / 60$$

Table 6.1 provides a summary of the required ramp storage length and cycle times to achieve the four-minute storage standard for various ramp volumes. This table was utilized to calculate storage requirements assuming 2019 volumes on all access ramps to I-680 in Contra Costa County.

Table 3-1 VicDOT Recommended CARM Ramp Storage Capacity and Cycle Times

Indicative Layout [5]	Ramp Design Flow [5] (pc/h)	Total Storage Required (Lane-metres)	Ramp Storage [3] and Cycle Time [7] Relative to the Number of Lanes at the Stop Line							
			1 Lane		2 Lanes		3 Lanes		4 Lanes	
			Average Storage per Lane (m)	Ave. Cycle Time (s)	Average Storage per Lane (m)	Ave. Cycle Time (s)	Average Storage per Lane (m)	Ave. Cycle Time (s)	Average Storage per Lane (m)	Ave. Cycle Time (s)
Single lane merge [6]	200	113	113	18.0						
	300	170	170	12.0						
	400	227	227	9.0						
	500	283	283	7.2	142	14.4				
	600	340	340	6.0	170	12.0				
	700	397			198	10.3				
	800	453			227	9.0				
	900	510			255	8.0	170	12.0		
	1,000	567			283	7.2	189	10.8		
	1,100	623			312	6.5	208	9.8		
	1,200	680			340	6.0	227	9.0		
Added lane entering the freeway or Two lane merge	1,300	737					246	8.3	184	11.1
	1,400	793					264	7.7	198	10.3
	1,500	850					283	7.2	213	9.6
	1,600	907					302	6.8	227	9.0
	1,700	963					321	6.4	241	8.5
	1,800	1,020					340	6.0	255	8.0
Added lane entering the freeway plus a merging lane	1,900	1,077							269	7.6
	2,000	1,133							283	7.2
	2,100	1,190							298	6.9
	2,200	1,247							312	6.5
	2,300	1,303							326	6.3
	2,400	1,360							340	6.0
	2,500	1,417							354	5.8
	2,600	1,473							368	5.5
	2,700	1,530							383	5.3
	2,800	1,587							397	5.1
	2,900	1,643							411	5.0
	3,000	1,700							425	4.8

Notes:

1. *Max wait / vehicle (min.): 4*
2. *Storage per vehicle (m): 8.5*
3. *Average storage per lane assumes lanes of equal length. Not applicable with auxiliary lanes at the stop line.*
4. *No. vehicles/green/lane: 1*
5. *Ramp layout and design flow are subject to the mainline capacity and mainline / ramp configuration.*
6. *A single lane merge layout may be satisfactory for higher flows, e.g. a ramp flow of 1400 veh/h entering mainline with adequate capacity.*
7. *Numbers shown in Orange would only be appropriate when the mainline analysis indicates ramp demands are accommodated with spare capacity for several downstream interchanges.*

3.2.2 R Model Methodology

As described previously, when mainline access must be restricted to prevent traffic flows from exceeding MSFR, the ability of ramps to store and discharge vehicles is critical to the success of the CARM concept. Once capacity on the mainline becomes available, the ramps must be capable of moving large numbers of vehicles onto the corridor quickly.

The objective of the R-Model is to estimate the optimal ramp metering discharge rate to maintain maximum throughput and productivity on the mainline, while striving to minimize and balance vehicle wait time and queueing across the corridor. In doing so, the R-Model effectively provides a back-check of ramp operations to indicate if CARM can operate within the parameters of the proposed ramp configuration. The R-Model uses Monte-Carlo simulation, also referred to as multiple probability simulation, to model the probability of different outcomes by introducing random variables to the calculations to determine likely operational conditions based on many alternative scenarios. The results of the R-Model analysis are compared to ramp design recommendations based on the VicDOT guidance to highlight any locations where the recommended design of the ramps may not accommodate CARM operations.

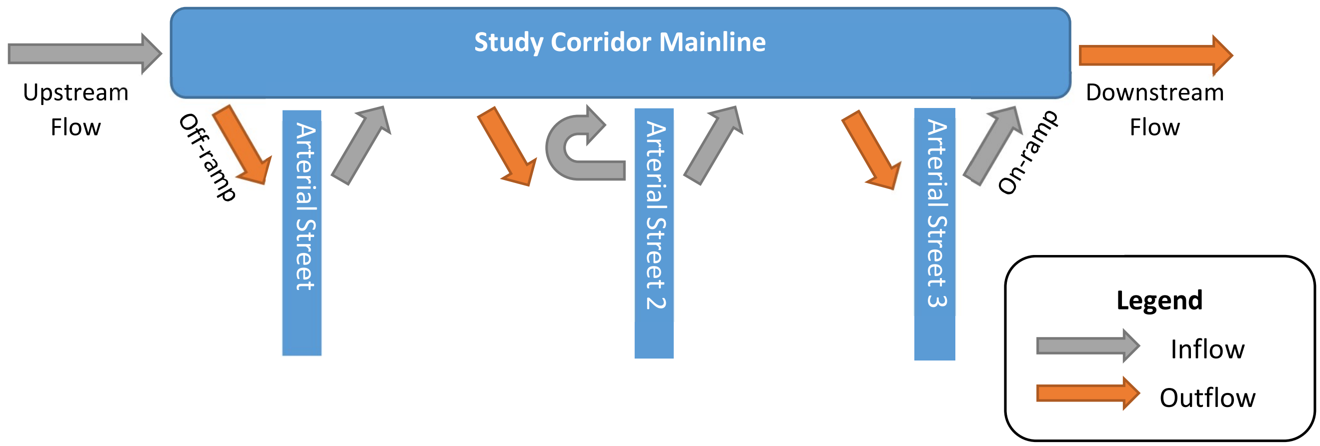
Boundary Selection

The first step in analyzing CARM strategies using the R-model is to confirm the study corridor and its boundaries. With the study limits set, the freeway system can be treated as an isolated system with multiple inflows and outflows forming the analysis network, as shown in the illustrative example in Figure 3-1. Ideally, the upstream and downstream locations should have little or no congestion even during the peak periods. This is to ensure that most of the demand can be captured using the traffic volumes observed at the boundary detector locations. As described earlier, the focus area bottlenecks are generally isolated within the limits of the study area during the AM peak period, satisfying this requirement. During the PM peak period, downstream queuing impacts the focus area, although the objective of the analysis is to address the independent bottlenecks within the focus area to defer the onset of congestion until downstream queuing influences these locations.

Existing Traffic Volumes

Balanced traffic volumes (flows) were provided by DKS Associates as part of their data collection and processing effort. The balanced traffic volumes were obtained from video counts conducted in the corridor during non-holiday weekdays in November 2019, with the raw data (collected over multiple different days) being post-processed to balance flows across freeway segments based on the changes in traffic entering and exiting the freeway. These data are used as an input to the R-model to evaluate the feasibility and effectiveness of CARM to manage traffic in the corridor. They are also consistent with the volumes used in DKS Associates' microsimulation and model validation tasks.

Figure 3-1 R-Model Network Example Layout



R-Model Simulation Settings

To take advantage of the R-Model's Monte-Carlo simulation capacity, certain simulation settings under which the study corridor is expected to operate must be explicitly defined. The simulation settings for the I-680 analysis are shown in Table 3-2.

Table 3-2 R-Model Simulation Settings

Settings	Value Used
Maximum Wait Time (minutes)	4
Max. Wait Time Difference (minutes)	2
On-ramp Flow Variance (%)	5
On-Ramp Capacity (vphpl)	500
Simulation Runs	100
Simulation Period	6 AM – 10 AM, 3 PM – 7 PM
Output Range	Median (50th Percentile) and 95th Percentile
Feasible Criteria	CARM strategy is deemed feasible if the R-model finds the optimal solution in more than 80% of the simulation runs

It should be noted that separate R-model analyses were conducted for CARM on I-680 south of SR-24 and I-680 north of SR-24. This is a result of CCTA's initial approach of assessing the feasibility of CARM deployment south of SR-24 and their subsequent decision to expand the assessment to the remainder of the corridor in Contra Costa County. The R-Model assessments assumed that the CARM system was ***not*** operating on the other segment. The analysis of CARM on I-680 south of SR-24 assumed that CARM was not installed north of SR-24. Similarly, the assessment of CARM on I-680 north of SR-24 assumed that CARM was not in place to the south of SR-24. As a result, northbound traffic flows entering the segment of I-680 to the north of SR-24 were more congested than they would have been if the assumption were made that CARM was deployed in the entire corridor. The same is true for southbound mainline traffic entering the segment of I-680 south of SR-24. The result of this assumption is that the model results are conservative and may result in a slight overestimate the amount of ramp storage capacity to meet the 95th percentile of ramp queuing requirements.

3.2.3 Caltrans Methodology

The Caltrans *Ramp Metering Design Manual* (RMDM) advises that the minimum queue storage length design for new or reconstructed ramps should be sufficient to accommodate seven percent of the peak hour demand for the chosen design year.[2] Furthermore, the Caltrans RMDM states "a minimum of one metered lane must be provided for every 900 VPH of traffic demand. However, two General Purpose (GP) lanes may be considered to increase queue storage within the available ramp length when entrance ramp peak hour volumes exceed 500 VPH." Caltrans generally calculates the storage capacity of general-purpose and HOV ramp lanes separately. However, given that for the purposes of achieving the most effective CARM operations it is anticipated that all ramp lanes will be available to all vehicles, this distinction was not considered as part of the following evaluation.

The analysis utilizes Caltrans' observed average vehicle spacing for each queued vehicle at a metered entrance ramp of 29 feet, measured from front of one vehicle to the front of the next vehicle. Caltrans advises that greater average vehicle spacing should be considered for metered entrance ramps on long and substantial downgrades, or metered entrance ramps that serve a significant percentage of trucks, buses, or recreational vehicles. The Caltrans methodology treats all ramps identically and is based on the premise that each ramp will need to operate independently. The Caltrans methodology makes no accommodation for the CARM system's ability to balance queues and waiting times among different ramps in the coordinated system. For this reason, the Caltrans methodology typically yields storage requirements approximately 8% above those resulting from the VicDOT methodology for the same traffic demand.

3.3 Findings: Ramp Storage Capacity Requirements

The findings from the three different ramp storage capacity assessments are summarized in Tables 3-3 through 3-6. The findings are presented separately for the segments of I-680 south of SR-24 and north of SR-24 due to the assumption in the analyses that CARM would only be operational on one segment. This means that for the segment south of SR-24, it is assumed that southbound traffic flows entering the segment would not be metered as the cross SR-24 and could be more congested as a result. Similarly, in the northbound direction, the analysis assumes that northbound traffic flows will not be metered as they enter I-680 north of SR-24 and could also be more congested as a result. This section presents the ramp storage capacity requirements for the four analysis segments in the following order:

1. I-680 northbound, south of SR-24
2. I-680 southbound, south of SR 24
3. I-680 northbound, north of SR 24
4. I-680 southbound, south of SR 24

[2] Ramp Metering Design Manual, Caltrans: Sacramento, CA, April 2016, p. 2.

The same organizational structure is also used later in this report to present the design feasibility assessment and the cost estimates for both civil works and ITS installations.

3.3.1 Ramp Storage Requirements: I-680 Northbound, South of SR-24

Table 3-3 presents the recommended ramp storage capacities using the three methodologies described in Section 3.2. The grey columns on the left provide 2019 peak hour vehicle volumes on the 13 ramps on I-680 northbound south of SR-24, together with the existing number of lanes at each ramp, the exiting vehicle storage capacity of the ramps in lane feet, and the number of lanes proposed for the ramps in the SHOPP Project Initiation Document (PID).

Table 3-3 Recommended Ramp Storage Capacities: I-680 Northbound South of SR-24

On Ramp Location *(South to North)*	Volume *(veh/hour)*	Existing Number of Lanes	Existing Storage *(lane feet)*	Lanes Proposed in SHOPP Project	Caltrans Storage Requirement *(lane feet)*	R Model Lanes at Stop Bar	R Model 95th Percentile Storage *(lane feet)*	VicDOT Number of Lanes	VicDOT Storage *(lane feet)*
Alcosta Boulevard	889	2	2,500	3	1,805	2	510	2	1,673
Bollinger Canyon Road Loop Ramp	418	1	570	2	849	2	260	1	781
Bollinger Canyon Road Direct Ramp	940	2	2,464	3	1,908	3	1,040	3	1,748
Crow Canyon Road Loop Ramp	880	1	1,550	2	1,786	2	970	2	1,636
Crow Canyon Road Direct Ramp	974	2	1,650	3	1,977	3	770	3	1,813
Sycamore Valley Road	1,434	1*	1,610	2	2,911	3	1,550	3	2,661
Diablo Road Loop Ramp	282	1	700	2	572	1	200	1	558
Diablo Road Direct Ramp	289	1	670	2	587	1	280	1	558
El Cerro Boulevard	598	1	800	2	1,214	2	790	2	1,115
El Pintado Road	179	1	420	2	363	1	190	1	371
Stone Valley Road	700	1	1,190	2	1,421	2	970	2	1,299
Livorna Road	475	1	440	2	964	2	280	2	932
Rudgear Road / Danville Boulevard	777	1*	1,655	2	1,577	2	310	2	1,451
Olympic Boulevard	1,445	2	1,675	2	2,933	3	390	3	2,692

** 2 initial lanes merge into 1 lane*

The recommended ramp storage capacities using the VicDOT methodology are shown on the right and shaded in green in Table 3-3, together with the recommended number of lanes. The resulting ramp storage capacities range from a low of 371 lane feet at El Pintado Road to a high of 2,692 at Olympic Avenue. As shown in Table 3-3, the existing ramps at six out of the 14 ramps – Alcosta Boulevard, Bollinger Canyon Road direct ramp, Diablo Road loop and direct ramps, El Pintado Road and Rudgear Road/ Danville Boulevard have adequate capacity to accommodate CARM operations in their current configurations. The remaining ramps would require additional capacity in order to accommodate CARM operations.

With the proposed improvements from the SHOPP project in place – assuming that they are feasible to implement – 14 out of the 16 on ramps to I-680 south of SR-24 would have adequate storage capacity to enable CARM operations. The Livorna Road and Olympic Boulevard interchanges are the only two where the SHOPP project would not provide adequate capacity for optimal CARM operations. In addition, as shown in Table 3-3, the following five interchanges would provide one lane in excess of the capacity required for

CARM operations with the proposed SHOPP improvements: Alcosta Boulevard, Bollinger Canyon Road loop ramp. The Diablo Road loop and direct ramps and El Pintado Road.

As shown in Table 3-3, the VicDOT ramp storage requirements are higher than those derived from the R-model analysis – shaded in pink. This is due to the fact that the R-Model is emulating the effect of CARM operations to maximize the flow of vehicles onto the mainline (e.g., minimizing wait times), while maintaining acceptable mainline flows. The R-Model results indicate the VicDOT recommended ramp capacities and storage would be adequate for successful CARM operations under the assessed conditions. The ramp storage requirements using the Caltrans methodology are shaded in blue in the table and are the highest of the three forecasts. As stated previously, this reflects the fact that the Caltrans approach assumes each ramp is operating independently (local control) and does not assume any cumulative travel service benefits from the adaptive and coordinated features of CARM operations.

3.3.2 Ramp Storage Requirements: I-680 Southbound, South of SR-24

Table 3-4 summarizes the ramp requirements for I-680 southbound south of SR-24. As mentioned earlier, the traffic volumes and resulting ramp storage capacities shown in Table 3-4 assume that the southbound mainline traffic accessing I-680 to the north of the segment would be metered as vehicles access the mainline. As shown in the green-shaded columns, the ramp storage capacities for the 16 I-680 southbound south access ramps south of SR-24 would range from a low of 558 lane feet at South Main Street to a high of 3,163 at Alcosta Boulevard.

As shown in Table 3-4, only the SR-24, Olympic Boulevard and South Main on-ramps provide adequate capacity in their current configurations to support CARM operations. However, with the proposed SHOPP improvements in place, 11 out of the 14 southbound access ramps south of SR-24 would have adequate capacity for CARM operations. The three ramps where this would not be the case are Diablo Road, and the Bollinger Canyon Road loop and direct ramps. As with I-680 northbound, the analysis shows that the VicDOT ramp capacities reflect an assumed wait times of up to four minutes, are higher than those for the R model, but lower than those derived from the standard Caltrans ramp storage capacity calculation. This demonstrates that the VicDOT storage requirements are conservative and would accommodate future growth in traffic levels, all while requiring less ramp storage than a traditional Caltrans ramp metering installation.

Table 3-4 Recommended Ramp Storage Capacities: I-680 Southbound South of SR-24

On Ramp Location *(North to South)*	Volume *(veh/hour)*	Existing Number of Lanes	Existing Storage *(lane feet)*	Lanes Proposed in SHOPP Project	Caltrans Storage Requirement *(lane feet)*	R Model Lanes at Stop Bar	R Model 95th Percentile Storage *(lane feet)*	VicDOT Number of Lanes	VicDOT Required Storage *(feet)*
SR-24	1,563	2	7,440	3*	3,173	4	2,140	3	2,943
Olympic Boulevard	530	1^	2,630	2^^	1,076	2	260	2	987
South Main Street	280	1	1,680	2	568	1	370	1	558
Rudgear Road / Danville Boulevard	796	1	1,255	2	1,616	2	1,100	2	1,490
Livorna Road	581	1	780	2	1,179	2	570	2	1,115
Stone Valley Road	826	1	780	2	1,677	2	730	2	1,545
El Cerro Boulevard	590	2	730	2	1,198	2	600	2	1,115
Diablo Road	763	1	670	2	1,549	2	630	2	1,451
Sycamore Valley Road	753	2	980	2	1,529	2	610	2	1,413
Crow Canyon Road Loop Ramp	833	1	1,220	2	1,691	2	120	2	1,551
Crow Canyon Road Direct Ramp	683	1	830	2	1,386	2	30	2	1,299
Bollinger Canyon Road Loop Ramp	1,371	1	510	2	2,783	3	140	3	2,554
Bollinger Canyon Road Direct Ramp	560	1	400	2	1,137	2	90	2	1,042
Alcosta Boulevard	1,660	2	2,255	3	3,370	4	260	4	3,163

3.3.3 Ramp Storage Requirements: I-680 Northbound, North of SR-24

To the north of SR-24, I-680 extends for approximately 11 miles in Contra Costa County to the Benicia-Martinez Bridge across the Carquinez Strait. There are 12 interchanges in this segment of I-680 in the northbound direction, several of which have more constrained settings compared to conditions to the south of I-680. The feasibility assessment of implementing CARM on this segment of I-680 northbound has assumed that ramp metering would not be installed at the SR 24 connector due to driver expectations that could compromise safety conditions if motorists were required to stop. In addition, it has also been assumed that ramp meters would not be installed at the on-ramp from the truck scales located downstream of the Lawrence Way / Penniman Way / North Main interchange. The evaluation has assumed that ramp meters would be installed at the remaining 10 interchanges.

Table 3-5 summarizes the ramp storage requirements for the northbound I-680 interchanges that would be equipped for CARM operations in the segment to the north of SR-24. Using the VicDOT methodology, the resulting ramp capacities would range from a low of 781 linear feet at Arthur Road to a high of 3,089 feet at the Lawrence Way / Penniman Way / North Main interchange. As shown in Table 3-5, only the SR-4 interchange would provide adequate storage capacity to enable CARM operations in its current configuration. With the proposed SHOPP improvements in place, only three on-ramps to northbound I-680 would be able to accommodate CARM operations without further capacity expansions: Concord Avenue, SR-4, and Arthur Road. Chapter 4 discusses the feasibility of providing the additional ramp capacity at the remaining on-ramps to I-680 northbound, north of SR-24, while Chapter 5 presents cost estimates for doing so.

Table 3-5 Recommended Ramp Storage Capacities: I-680 Northbound North of SR-24

On Ramp Location (South to North)	Volume (veh/hour)	Existing Number of Lanes	Existing Storage (lane feet)	Lanes Proposed in SHOPP Project	Caltrans Storage Requirement (lane feet)	R Model Lanes at Stop Bar	R Model 95th Percentile Storage (lane feet)	VicDOT Number of Lanes	VicDOT Storage (lane feet)
SR-24	4,400	3	NA	3	NA	NA	NA	NA	NA
Lawrence Way / Penniman Way / North Main	1,660	2	1,140	2	3,370	4	2,800	4	3,089
Truck Scales	40	1	NA	NA	NA	NA	NA	NA	NA
Buskirk Avneue / Treat Boulevard	1,330	1	177	2	2,700	3	2,330	3	2,474
Oak Road / Elena Court / Coggins Drive	850	1	414	2	1,726	2	1,070	2	1,581
Monument Boulevard	1,180	1	400	2	2,395	3	1,270	3	2,234
Willow Pass Road	1,040	2	930	3	2,111	3	120	3	1,935
Burnett Avenue	670	1	309	2	1,360	2	30	2	1,244
Concord Avenue	710	1	674	2	1,441	2	60	2	1,318
SR-4 Interchange	1,330	1	3,551	2	2,700	3	150	3	2,474
Arthur Road	420	1	428	2	853	1	60	1	781
Marina Vista / Waterfront Road	590	1	300	2	1,198	2	60	1	1,097

As with the other analysis segments, the storage requirements derived using the R Model are lower than those generated using the preferred VicDOT approach indicating that CARM could operate effectively subject to completing the recommended ramp capacity and storage improvements. As expected, the results using the standard Caltrans ramp metering approach are slightly higher than the VicDOT values.

3.3.4 Ramp Storage Requirements: I-680 Southbound, North of SR-24

Table 3-6 identifies the 14 interchanges providing access to I-680 southbound north of SR-24, together with their storage requirements in order to support CARM operations. Using the VicDOT methodology, the storage requirements range from a low of 502 linear feet at the Geary Road / Treat Boulevard on-ramp to a high of 4,315 linear feet at the SR-4 interchange. The feasibility assessment has assumed that ramp meters would be installed at all ramps in the corridor, with the exception of the SR-242 direct connector due to the expectation of most motorists that they would not be required to stop on a highspeed straight connector ramp. The analysis has also considered the possibility of metering the ramp from Hillside Avenue to the SR-24 connector to prevent the SR-24 from backing up on the mainline. However, this possibility has not been analyzed quantitatively.

Of the remaining 13 access ramps, only two – Marina Vista Avenue / Waterfront Road and SR-4 – have adequate capacity as currently configured to support CARM operations. However, the SR-4 ramp would require four lanes at the threshold in order to function optimally. With the SHOPP improvements, CARM operations would be possible at an additional seven interchanges. However, it would not be possible to operate CARM in an optimal manner due to capacity constraints at four interchanges, including Contra Costa Boulevard, Boyd Road / Contra Costa Boulevard, North Main Street / Sunnyvale Avenue / Truck Scales, and San Luis Road / North Main Street. The Chapter 4 Conceptual Design and Cost Estimate assesses the feasibility of providing the necessary capacity at these ramps in order to facilitate optimal CARM operations.

Table 3-6 Recommended Ramp Storage Capacities: I-680 Southbound North of SR-24

On Ramp Location *(North to South)*	Volume *(veh/hour)*	Existing Number of Lanes	Existing Storage (lane feet)	Lanes Proposed in SHOPP Project	Caltrans Storage Requirement *(lane feet)*	R Model Lanes at Stop Bar	R Model 95th Percentile Storage *(lane feet)*	VicDOT Number of Lanes	VicDOT Storage *(lane feet)*
Marina Vista Avenue / Waterfront Road	580	1	1,250	2	1,177	2	290	2	1,079
Pacheco Boulevard	850	1	1,170	2	1,726	2	120	2	1,581
SR-4	2,320	1	4,667	2	4,710	5	200	4	4,315
Contra Costa Boulevard	730	1	312	2	1,482	2	730	2	1,356
Concord Avenue / Chilpancingo Pwy	360	1	514	2	731	1	370	1	670
Willow Pass Road / Sunvalley Boulevard Loop Ramp	500	1	543	2	1,015	2	510	2	932
Willow Pass Road / Sunvalley Boulevard Direct Ramp	620	1	715	4*	1,259	2	560	2	1,152
SR-242	3,640	2	NA	NA	7,389	NA	NA	NA	NA
Monument Boulevard	870	1	835	2	1,766	2	400	2	1,618
Boyd Road / Contra Costa Boulevard	820	1	608	2	1,665	2	450	2	1,526
North Main Street / Sunnyvale Avenue / Truck Scale	1,020	1	152	2	2,071	3	900	3	1,898
Geary Road / Treat Boulevard	270	1	296	2	548	1	230	1	502
San Luis Road / North Main Street	1,060	2**	1,300	2	2,152	3	280	3	1,972
Hillside Avneue / Ygnacio Valley Road	1,350	1	1,332	2	2,741	3	120	3	2,510
Hillside Avenue to SR-24 Connector	NA	1	225	NA	NA	NA	NA	NA	NA

4 Conceptual Design

4.1 Ramp Improvements

The final step in assessing the feasibility of implementing a CARM system in the I-680 corridor involved a design feasibility analysis to determine if the necessary amount of ramp storage and the required number of lanes at the ramp meter could be provided. In some cases, this work involved the preparation of design diagrams. In others, the feasibility of completing the necessary physical works was made based on a review of aerial photography, existing plans, and field inspection.

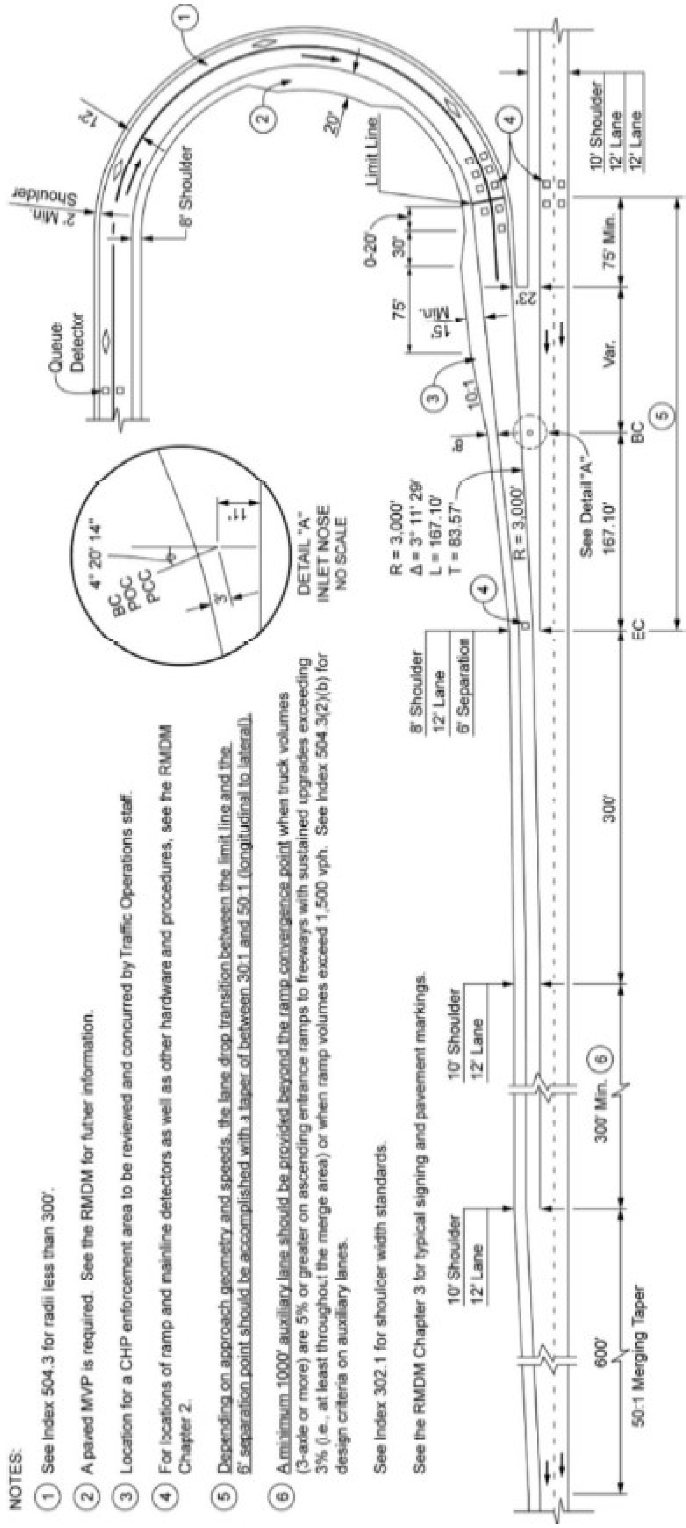
The conceptual designs generally comply with Caltrans full design standards along the ramp and freeway mainline. These typically include lane width, shoulder width, and stopping sight distance. **Error! Reference source not found.** through 5-3 below are used as a template for the conceptual design and cost basis. Most ramps are designed with a standard 30:1 lane merge beyond the limit line. However, certain ramps are designed with a merge taper between 15:1 and 30:1; these require a design exception to an underlined Caltrans standard.

Conservative, high-level cost estimates were subsequently developed for improvements needed to meet the ramp storage requirements and provide the necessary number of lanes at the ramp meter. Major costs were estimated based on quantities required to implement the civil works at the interchanges to I-680. They include pavement, retaining walls, concrete barrier, and striping. These unit costs are taken from the Caltrans Contract Cost Database.

The filters typically used to obtain relevant unit costs were "District 4" and "awarded" bidder. The most recent winning bids were considered to get the "adjusted average price per unit." This price was rounded up to the nearest dollar. Retaining wall and bridge costs are taken from recent project study reports in northern California. Drainage and utility costs are estimated as each being 5% of the roadway costs. Where necessary, the designs use 4:1 slopes up until 10' from the right-of-way where a new retaining wall will be constructed. Shoulder widths are reduced where necessary to avoid impacts to bridge abutments and/or columns. As is typical for a Caltrans conceptual level feasibility study, an overall contingency cost of 35% has been applied.

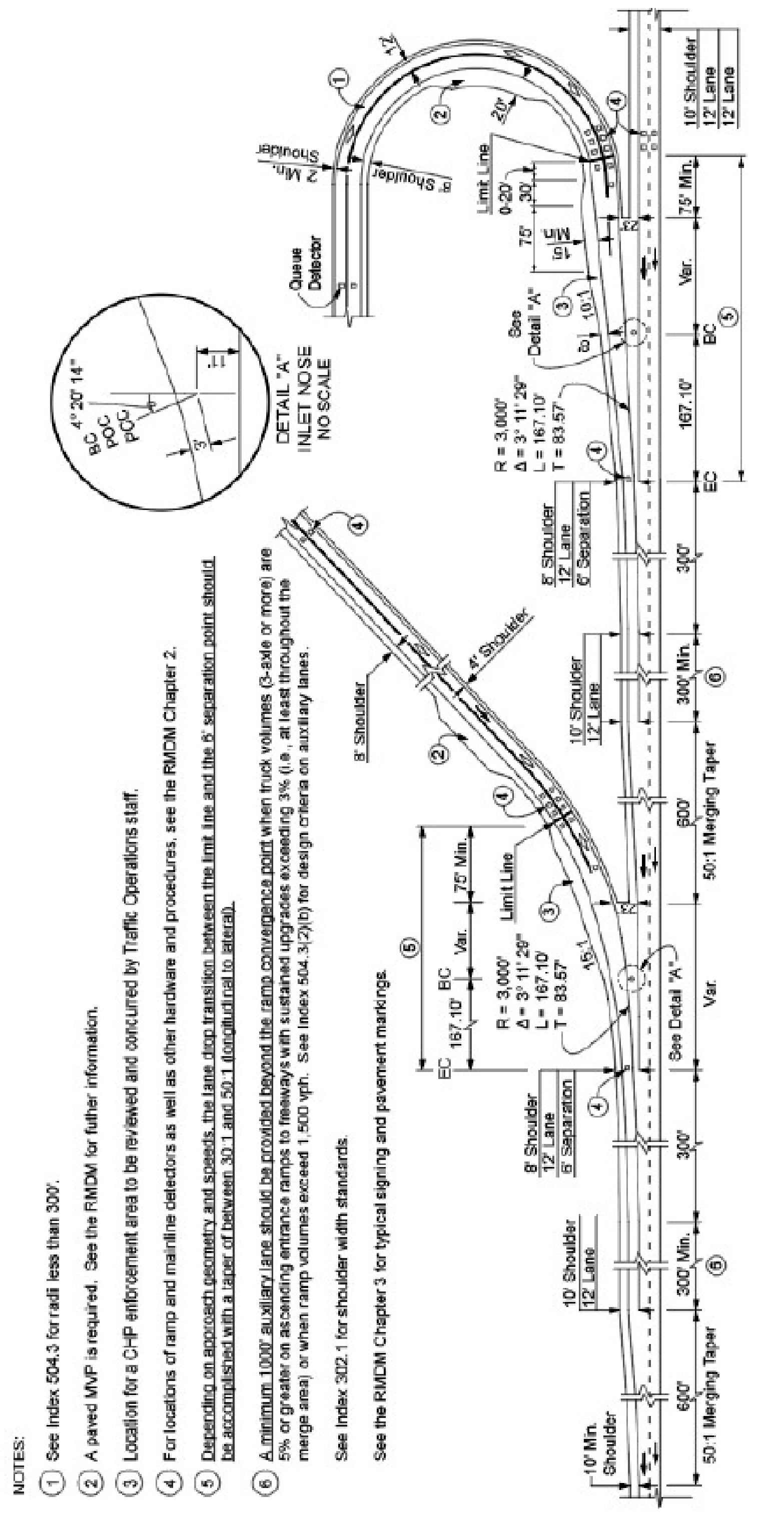
By intent, the conceptual designs and corresponding estimates do not reflect any of the improvements that will ultimately be provided through the Caltrans SHOPP project. The purpose of the analysis is to identify all of the physical improvements necessary for implementing CARM, together with a corresponding cost. This information is intended to facilitate coordination between CCTA and Caltrans as the CARM and SHOPP projects advance.

Figure 4-1 Typical Freeway Entrance Loop Ramp Metering (1GP Lane + 1 Preferential Lane



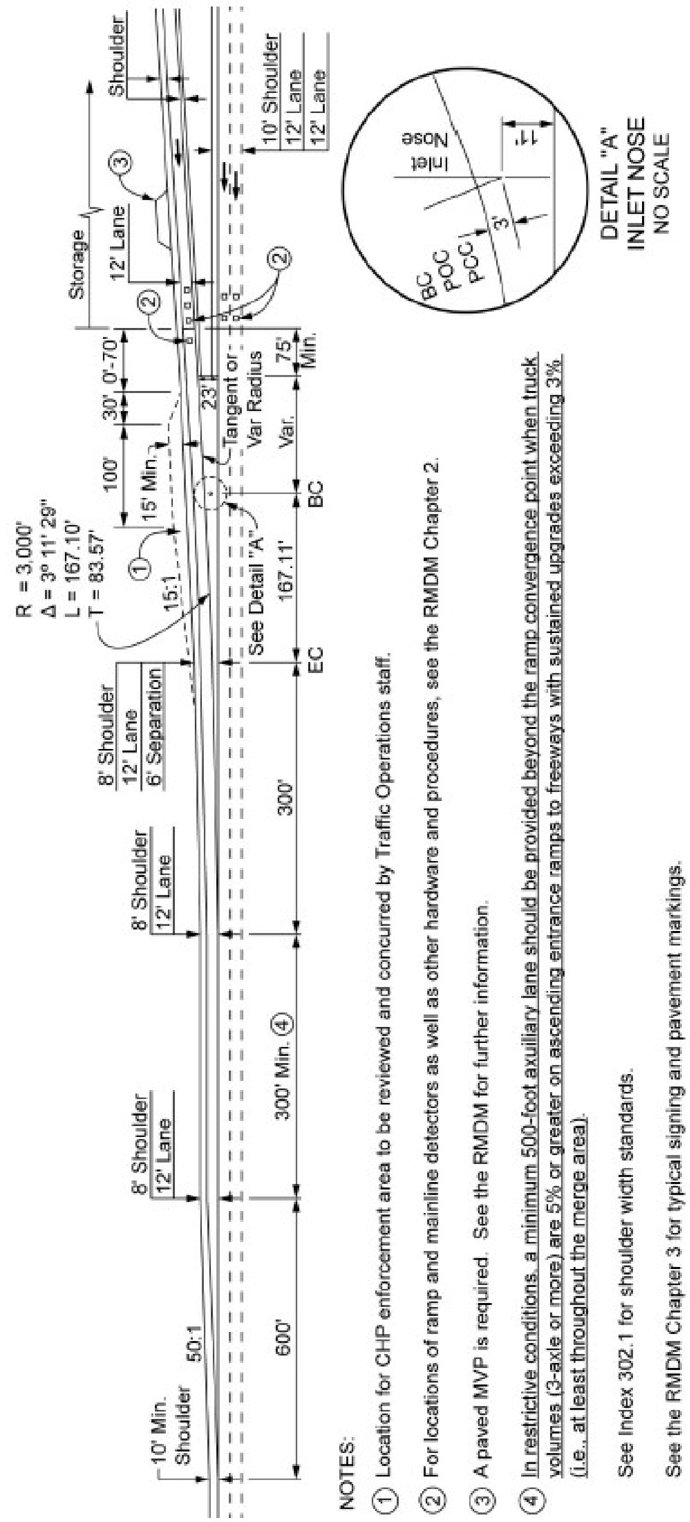
Source: Caltrans Highway Design Manual, Figure 504.3A, July 2020

Figure 4-2 Typical Successive Freeway Entrance Ramp Metering (1 GP Land + 1 HOV Preferential Lane)



Source: Caltrans Highway Design Manual, Figure 504.3B, July 2020

Figure 4-3 Restrictive Condition Freeway Entrance Ramp Metering (1 GP Lane)



Source: Caltrans Highway Design Manual, Figure 504.3C, July 2020

4.1.1 Discharge Lanes

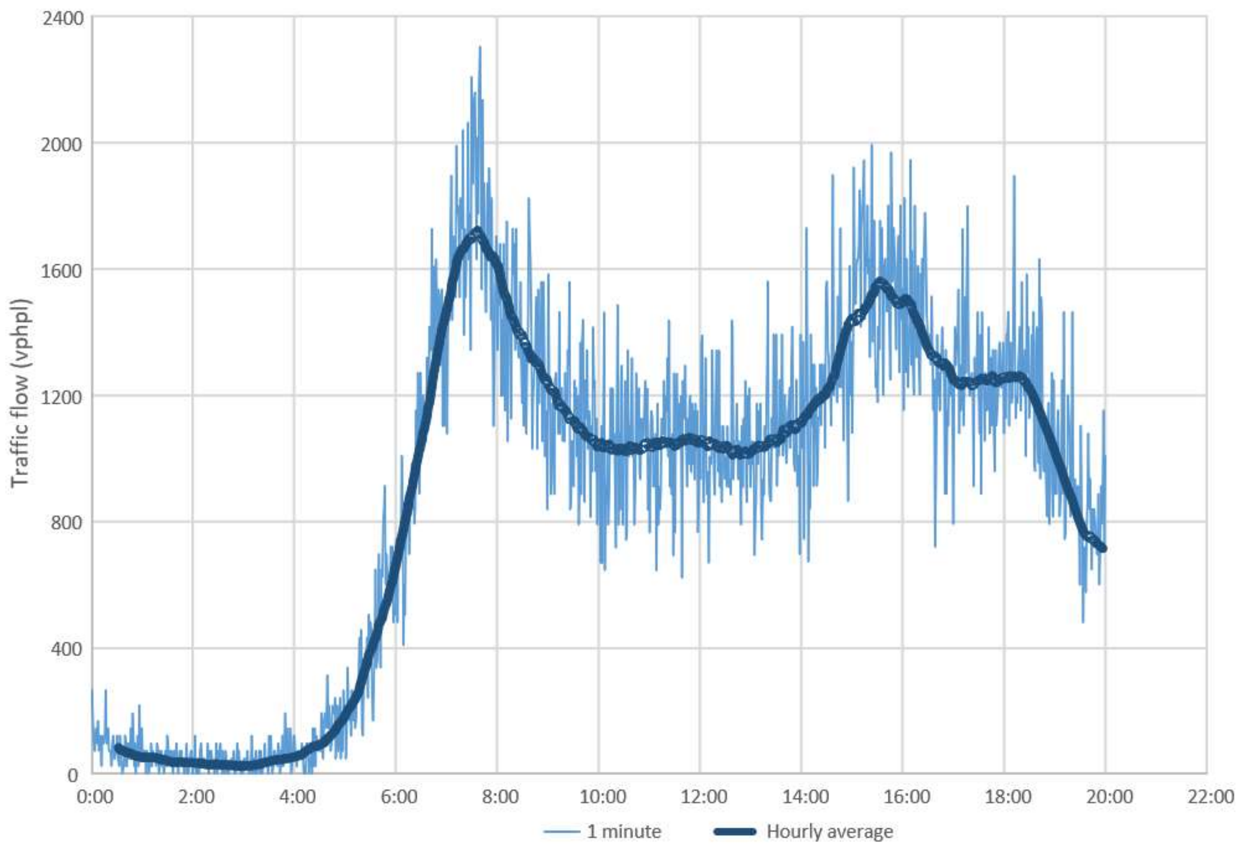
Traditionally, ramp metering is viewed as a strategy for holding and storing traffic on entrance ramps that would otherwise potentially enter the freeway in platoons that can cause disruption during merging and lead to traffic flow breakdown and the onset of congestion. In traditional applications, ramp metering effectively breaks these traffic platoons by regulating the discharge of individual vehicles onto the freeway creating vehicle spacing that is intended to provide more orderly and manageable merging.

In a managed freeway system replicating the VicDOT approach, CARM is used for the primary purpose of controlling the rate of flow of vehicles entering the freeway to synchronize the demand for vehicles entering with the volume of vehicles already on the freeway and the volume of vehicles exiting the freeway. The CARM approach also strives to ensure equity of access by balancing demand for traffic entering the freeway across all ramps along a corridor in order to better manage ramp queuing and wait times. The goal of this strategy is to maintain stable traffic flows along the freeway mainline and to avoid allowing too many vehicles to enter the freeway potentially leading to oversaturation with too many vehicles, instability in traffic flows at critical bottlenecks, traffic flow breakdown and the onset of congestion. By sustaining stable traffic flows along the freeway mainline, CARM allows managed freeways to achieve greater productivity by moving more vehicles over time than is otherwise possible when freeway traffic flows breakdown.

Like traditional ramp metering, CARM for managed freeways necessitates adequate entrance ramp storage capacity to hold back and store vehicles, as needed, to regulate the rate of discharge of vehicles onto the freeway mainline. However, unlike traditional ramp metering, for managed freeways CARM it is equally important to be able to rapidly discharge vehicles onto the facility when the freeway has capacity to accept traffic. Through strategic detector placement and regular detector frequency, a managed freeways ATMS can recognize when the opportunity to move traffic onto the roadway exists and will vary the metering rates of ramps to respond quickly. This is a somewhat unique feature of the CARM solution using AHS and is critical to the ability to manage ramp queue lengths and wait times while not adversely impacting mainline traffic flows.

Figure 4-4 shows data collected near Denver, Colorado during testing of The Infra-Red Traffic Logger (TIRTL) point vehicle detection device that was deployed as part of the Colorado Department of Transportation (CDOT) SMART 25 managed freeways pilot project. The figure showcases both the hourly average arrival rate (dark blue) and minute by minute arrivals (light blue). Minute by minute volumes fluctuate significantly compared with overall average traffic flow. While it is understood that little or no additional traffic should be allowed onto the freeway during periods of high demand, it is equally important that traffic should rapidly be moved onto the freeway during low demand periods. For this reason, some of the ramp improvements focus on providing more lanes at the stop bar even if additional storage is not needed. These additional lanes build flexibility in how the CARM ATMS can manage demand and maintain productivity along the corridor by allowing vehicles to be moved quickly from the ramps onto the freeway mainline when a momentary reduction in mainline volume is being observed adjacent to a particular ramp.

Figure 4-4 Volume Fluctuation Over Short Time Periods



4.1.2 Proposed CARM Ramp Improvements – I-680 Northbound South of SR-24

The following paragraphs summarize the proposed ramp improvements necessary to accommodate CARM operations on I-680 northbound south of SR 24. The descriptions are presented from south to north, providing textual descriptions of conceptual designs contained in Appendix D.

Alcosta Boulevard

With a peak hour volume of 889 vehicles, a total of three lanes will be required at Alcosta Boulevard. Currently the ramp provides two lanes of capacity for approximately 900 feet to the location that corresponds with the position of the stop bar at a standard Caltrans ramp metering site (hereafter referred to as a standard Caltrans stop-bar location) before merging into a single lane. As shown in Figure 4-5, the ramp provides a wide right shoulder that is cross-hatched out. A conceptual design for the reconfiguration of the Alcosta Boulevard ramp is provided in Drawing L-2 in Appendix D. The existing pavement is wide enough to accommodate an additional lane, so the ramp will be restriped to provide three lanes to the stop bar. The reconfigured ramp would also provide a CHP enforcement area downstream of the stop bar and join the northbound I-680 mainline with a standard 600-foot merge.

Figure 4-5 Additional Paved Area on Alcosta Boulevard On-Ramp

Bollinger Canyon Road

The existing Bollinger Canyon Road interchange with I-680 northbound includes a one-lane loop ramp from Bollinger Canyon Road eastbound with a peak period volume of 418 vehicles per hour, and a separate, two-lane direct ramp from Bollinger Canyon Road westbound accommodating 940 vehicles in the peak hour. As shown in Figures L-3 and L-4 in Appendix D, the CARM project proposes to reconfigure the loop ramp with a smaller 135-degree radius turn to allow it to be separated from the mainline with a barrier and extended to merge with the two-lane direct ramp to provide a single confluence with the mainline into the existing auxiliary lane located downstream of the existing direct on-ramp. The combined ramps will provide three travel lanes for 100 feet up to the stop bar. The barrier separating the loop ramp from the mainline will end at the stop bar. A CHP enforcement area will be provided downstream of the stop bar and the ramp will meet the mainline with standard merge.

Crow Canyon Road

The existing Crow Canyon Road interchange is similar in configuration to the existing Bollinger Canyon Road interchange with two separate ramps and access points to the mainline from eastbound and westbound traffic on Crow Canyon Road. The loop ramp from serving eastbound local traffic has a peak volume of 880 vehicles per hour, while the direct ramp providing westbound local traffic with access to the mainline has peak hour volumes of 974 vehicles. As shown in Figures L-7 and L-8 in Appendix D, the CARM project proposes to reconfigure the interchange by realigning the loop ramp from Crow Canyon Road eastbound just north of the Crow Canyon Road overcrossing. The original merge on to the mainline will be eliminated and the ramp will be extended to merge with the direct ramp from Crow Canyon Road westbound before the combined lanes enter the freeway on the existing auxiliary lane downstream of the existing direct ramp. The extended ramp will be protected from the mainline by a new barrier. The combined ramps would have a peak hour volume of 1,854 vehicles. While it would be preferable from an operational perspective to provide four lanes at the stop bar, the proximity of the Fostoria Way overcrossing to the ramp meter stop bar constrains the ability to provide four lanes at the stop bar without substantial civil and structural works. Therefore, it is recommended the reconfigured Crow Canyon Road interchange will provide 3 lanes at the stop bar with the single lane from the loop ramp and two lanes from the direct ramp merging approximately 100 feet upstream of the stop bar. A CHP enforcement area is proposed downstream of the stop bar and the ramp would meet the mainline with a standard merge.

Sycamore Valley Road

The existing Sycamore Valley Road northbound on-ramp currently provides two lanes of capacity for approximately 385 feet before merging to a single lane for an additional 240 feet to reach the standard Caltrans ramp metering stop-bar location. The ramp serves 1,434 vehicles during the peak hour. As shown in Figure L-11 in Appendix D, the CARM project proposes to add capacity to the line by widening to the right. The second travel line would be extended to the stop bar and a 100-foot third lane would be added to the right as the ramp approaches the stop bar to increase throughput. A CHP enforcement area is proposed downstream of the stop bar, and the ramp would taper to a single lane before joining the mainline.

Diablo Road

The Diablo Road interchange has a partial clover leaf configuration, with a one-lane loop ramp to I-680 northbound servicing eastbound traffic on Diablo Road and a separate direct ramp serving westbound traffic. Peak hour traffic volumes on these two ramps are low, with 282 vehicles per hour on the loop ramp and 289 vehicles per hour on the direct ramp. While each ramp has its own confluence with I-680 northbound with only 250 feet of weave distance between them, the narrow (approximately eight-foot) right shoulder on the existing I-680 overcrossing structure at Diablo Road (see **Error! Reference source not found.**), existing sound walls, and adjacent embankments constrain the ability to merge the two ramps. As shown in Figures L-13 and L-14 in Appendix D, given these constraints together with its low traffic volumes, the CARM project proposes no civil improvements at the Diablo Road interchange, other than adding a CHP enforcement area downstream of the stop bar on the direct ramp.

Although the existing, single-lane ramps have more than adequate storage capacity for CARM operations, the SHOPP project proposes widening both ramps to two lanes to accommodate the addition of an HOV lane on each ramp.

El Cerro Boulevard

The existing El Cerro Boulevard interchange with I-680 northbound features a direct on-ramp servicing local traffic traveling in both directions. The existing ramp has no visible evidence of ITS installations. The El Cerro Boulevard ramp has a peak hour volume of 598 vehicles and provides two lanes for approximately 150 feet and then tapers to a single lane. As shown in Figure L-15 in Appendix D, the CARM project proses to lengthen the ramp to two lanes for an addition 400 feet to the stop bar. After the metering point, the ramp would narrow to one lane and join the mainline. A CHP enforcement area would be provided downstream of the stop bar.

El Pintado Road

The existing El Pintado Road interchange has a half-diamond configuration with a one-lane direct ramp providing both eastbound and westbound local traffic with access to I-680 northbound. The existing ramp has a peak period volume of 179 vehicles per hour, which is the lowest volume of any access ramp to I-680 in Contra Costa County. The existing El Pintado Road on-ramp provides a tapered single lane of capacity with a five- to eight-foot shoulder for approximately 420 feet to the standard stop bar location. Although the SHOPP project proposes to widen the ramp to two lanes to accommodate an HOV lane, the existing, single-lane ramp has adequate storage capacity for CARM operations in its current configuration. As shown in Figure L-17 in Appendix D, the CARM project would make no physical modifications to the ramp, other than adding a CHP enforcement area downstream of the ramp meter location.

Stone Valley Road

The existing Stone Valley Road interchange provides a one-lane direct ramp to I-680 northbound serving eastbound and westbound local traffic. The ramp has peak hour volumes of 700 vehicles and extends for approximately 950 feet to the standard stop bar location, curving around a loop ramp for traffic exiting I-680 northbound at Stone Valley Road. The interchange also includes a dedicated right turn lane for eastbound vehicles on Stone Valley Road. As shown in Figure L-18 in Appendix D, the CARM project would provide two lanes to the stop bar by widening the ramp to the left as it approaches and traverses the curve around the loop ramp and then widening to the right from the curve to the stop bar. A CHP enforcement area is proposed downstream of the ramp meter location, where the ramp would taper to a single lane before joining the mainline with a standard 600-foot merge.

Livorna Road

The Livorna Road interchange with I-680 northbound provides a direct ramp accommodating both eastbound and westbound local traffic. The existing on-ramp provides a single lane of capacity extending approximately 440 feet to the stop bar and carries 475 vehicles per hour during peak periods. As shown in Figure L-20 in Appendix D, to facilitate CARM operations the ramp would be widened to the right to provide two travel lanes and an eight-foot shoulder. The ramp would taper to one lane after the stop bar and arrive at the mainline with a standard merge. A CHP enforcement area would be provided after the stop bar.

Rudgear Road / Danville Boulevard

The Rudgear Road / Danville Boulevard service interchange with I-680 northbound features an offset ramp from Danville Boulevard west of the freeway mainline and slightly north of the Rudgear Road undercrossing accommodating local traffic operating in both directions. The interchange also includes a 225-foot dedicated right turn lane on Danville Boulevard. The ramp has peak hour volumes of 777 vehicles and provides two travel lanes for approximately 480 feet as it passes below I-680. The ramp then merges into a single lane and extends approximately 475 feet to the standard stop bar location. As shown in Figure L-23 in Appendix D, the CARM project will provide two travel lanes to the stop by widening the ramp to the right around the curve. This portion of the ramp will be restriped and will also feature a four-foot left shoulder and an eight-foot right shoulder. A CHP enforcement area will be added after the stop bar and the ramp narrow to a single lane and will join the mainline.

The Iron Horse Regional Trail also runs parallel to the initial portion of the Rudgear Road / Danville Boulevard interchange as it crosses below I-680.

Olympic Boulevard

The Olympic Boulevard interchange provides a direct ramp to I-680 northbound accommodating both eastbound and westbound traffic from Olympic Boulevard. The interchange also includes a 579-foot dedicated right turn lane along westbound Olympic Boulevard. The two-lane ramp has a peak hour volume of 1,445 vehicles and crosses below a structure carrying traffic traveling from I-680 northbound to westbound SR-24. The existing on-ramp provides two lanes of capacity for approximately 553 feet to the standard stop bar location. As shown in Figure L-27 in Appendix D, the CARM project proposes to extend the final 150-feet of the ramp to three lanes as it approaches the stop bar, restriping the ramp and widening it to the left. A CHP enforcement area would also be provided after the stop bar, as the ramp tapers to a single lane before joining the mainline.

4.1.3 Proposed CARM Ramp Improvements – I-680 Northbound North of SR-24

The following sections summarize the proposed ramp improvements necessary to accommodate CARM operations on I-680 northbound north of SR 24. The descriptions are presented from south to north, providing textual descriptions of conceptual designs contained in Appendix D.

SR-24

Due to safety concerns and driver expectations of uninhibited travel while driving on the direct connector between SR-24 and I-680 northbound, this interchange will not have a CARM installation.

Lawrence Way / Penniman Way / North Main

The Lawrence Way / Penniman Way / North Main service interchange with I-680 northbound currently provides two travel lanes and serves peak hour volumes of 1,660 vehicles. In order to facilitate CARM operations, the on-ramp to I-680 northbound would need to be widened to four lanes. As shown in Figure L-30 in Appendix D, the CARM project proposes to accomplish this by widening the existing ramp to the right to four lanes from the entrance to the stop bar. Doing so would require a partial acquisition from the paved parking area behind the Walnut Creek Parks Division maintenance building. After the stop bar, lanes one and two and lanes three and four, respectively, would join the mainline separately, each with a standard 600-foot merge. Both merges would place motorists in an auxiliary lane on I-680 northbound. A CHP enforcement location would also be provided downstream of the stop bar.

Truck Scales

Due to the low traffic volumes, the effective metering of trucks entering by virtue of using the truck scales, and the desire to let trucks accelerate as much as possible before entering the freeway mainline, ramp metering is not proposed at this on-ramp.

Buskirk Avenue / Treat Boulevard

The existing ramp to I-680 northbound at Buskirk Avenue is also a collector/distributer road providing 2 travel lanes and a dedicated right turn lane for vehicles tuning east on to Wayne Drive. The left travel lane provides access to I-680 northbound, while the right travel lane extends north and east to intersect with Oak Road. As shown in Figures L-32 and L-33 in

Appendix D, in order to accommodate CARM operations Buskirk Avenue would be widened to four lanes. This would require taking parking stalls from the commercial properties located along the east side of Buskirk Avenue. The left travel lane and the two inner travel lanes would be metered and would provide access to I-680 northbound, while the right travel lane would extend to Oak Road, as it does today. The proximity of the fourth lane precludes the possibility of including a CHP enforcement area downstream of the stop bar. Access from Wayne Drive would be by right turn only, as it is today.

Oak Road / Elena Court / Coggins Drive

As shown in Figure L-33 in Appendix D, the CARM project proposes to widen the existing one lane ramp to I-680 northbound at Oak Road from one lane to two lanes. The ramp would be widened primarily from the right and a CHP enforcement area would be provided downstream of the stop bar. The widening would not affect the existing vertical bridge abutment at the Oak Park Boulevard overpass shown in Figure 4-6. However, drainage near the abutment would be impacted.

Figure 4-6 Bridge Abutment Near the I-680 Oak Road / Elena Court / Coggins Drive Merge

Monument Boulevard

As shown in Figure L-36 in Appendix D, traffic detectors will be added at the Monument Boulevard on-ramp to I-680 northbound to integrate it with the CARM system. However, no new storage capacity will be needed at the ramp, so the existing configuration of the ramp will remain unchanged.

Willow Pass Road

The existing Willow Pass Road interchange with I-680 northbound provides two direct lanes from the west and one from the east that merge immediately into two-lanes. As shown in Figure L-38 of Appendix D, the CARM project proposes to widen the existing ramp to the right to create three lanes to the stop bar. A CHP enforcement area would be provided downstream of the stop bar, with the ramp narrowing first to two lanes and then to a single lane before joining the mainline. The widening would require a partial taking of a strip of vegetated land between the ramp and the Willows Shopping Center parking lot in the vicinity of the merge.

Burnett Avenue

The existing Burnett Avenue interchange with I-680 northbound provides a single-lane hook ramp serving westbound traffic on Burnett Avenue. The merge area with the mainline is located on the Concord Avenue overpass structure, which can be seen in Figure 4-7. As shown in Figure L-39 of Appendix D, the Burnett Avenue on-ramp would need to be widened to two lanes to accommodate CARM operation. The CARM project proposes to widen the ramp to the right and provide a CHP enforcement area downstream of the stop bar. The ramp would join the mainline as it traverses the Concord Avenue overpass. This would require widening the overpass structure to the outside.

Figure 4-7 The Existing Burnett Avenue On-Ramp Merge and Concord Avenue Overpass

Concord Avenue

The existing interchange with I-680 northbound at Concord Avenue includes a dedicated right turn bay on Concord Avenue and turns into a single-lane ramp rising at a slight incline to meet the I-680 mainline. As shown in Figure L-41 in Appendix D, the CARM project proposes to widen the ramp to the outside to provide two travel lanes to the stop bar. After the stop bar, the ramp would taper to a single lane as it travels past a CHP enforcement area to join the mainline. No right-of-way or new structures or retaining walls would be required.

SR-4 Interchange

The existing SR-4 service interchange with I-680 northbound has a partial cloverleaf configuration with a single-lane direct ramp from SR-4 westbound to I-680 northbound and a loop ramp from eastbound SR-4 that merges with the direct ramp before joining the mainline. As shown in Figures L-42 and L-43 in Appendix D, the CARM project proposes to widen the direct ramp from SR-4 westbound to the outside to provide three lanes. The loop ramp configuration would remain unchanged, providing a total of four ramps at the stop bar.

The ramp would taper to two lanes as it passes a CHP enforcement area downstream of the stop bar. Each of the lanes would join the mainline in a separate, standard 600-foot merge.

Arthur Road

The existing single-lane ramp at the Arthur Road service interchange with I-680 northbound provides adequate storage capacity to facilitate CARM operations. As shown in Figure L-44 in Appendix D, detection equipment will be installed to integrate the Arthur Road interchange with the CARM system. However, no physical changes will be required, other than providing a CHP enforcement area downstream of the stop bar.

Marina Vista / Waterfront Road

The Marina Vista / Waterfront Road interchange provides a single-lane loop ramp on a structure rising to meet I-680 northbound approximately 950 feet upstream of the Benicia Martinez Bridge toll plaza. Given that the ramp is on structure, the CARM project does not propose to widen it. However, as shown in Figure L-50 in Appendix D, the dedicated right turn lane on Waterfront Road would be extended by 375 feet to provide additional storage capacity. No other changes are proposed, aside from the installation of detection equipment to integrate the interchange with the CARM system.

4.1.4 Proposed CARM Ramp Improvements – I-680 Southbound North of SR-24

The following sections summarize the proposed ramp improvements necessary to accommodate CARM operations on I-680 southbound north of SR 24. The descriptions are presented from north to south, providing textual descriptions of conceptual designs contained in Appendix D.

Marina Vista Avenue / Waterfront Road

The Marina Vista Avenue / Waterfront Road service interchange with I-680 southbound provides a single-lane direct ramp with standard shoulders and access controlled by a traffic signal on Marina Vista Avenue. As the ramp curves to south, there is limited clearance to the right. Further down the ramp the terrain to the right slopes down to an adjacent wetland. As shown in Figure L-49 in Appendix D, the CARM project proposes to widen the ramp to the right to create two lanes. This will require a small parcel take on a narrow strip of land between the ramp and Laguna Street near the Martinez Refining company. This could be avoided should non-standard shoulders be approved in this area. Both lanes will continue to the stop bar, after which they merge into a single lane as they pass a CHP enforcement area and then meet the mainline.

Pacheco Boulevard

The Pacheco Boulevard service interchange with I-680 southbound currently provides a single-lane on-ramp with standard shoulders. The ramp is a continuation – or trap – of a spur of Pacheco Boulevard, where both eastbound travel lanes feed directly into the ramp and then merge into a single lane. As shown in Figures L-47 and L-48, the CARM project will widen the ramp to the right to provide two travel lanes to the stop bar. The lanes will merge into a single travel lane and pass by a CHP enforcement area downstream of the stop bar before joining the mainline. The two lanes will merge at a 30:1 taper to avoid impacting Grayson Creek.

SR-4

The SR-4 service interchange with I-680 southbound has a partial clover leaf configuration with a single-lane direct ramp with wide shoulder extending from SR-4 westbound and a single-lane loop ramp from SR-4 eastbound. The two ramps merge into a single lane before extending approximately 1,500 feet to meet the mainline. As shown in Figures L-45 and L-46 in Appendix D, the CARM project proposes to widen both sides of the existing direct ramp to provide a total of three lanes. The loop ramp does not require widening. The stop bar will extend across all four lanes of traffic just downstream of the merge. After the stop bar, lanes 1 and 2 would merge together, as would lanes 3 and 4, with each of the lanes joining the mainline in separate 600-foot merges. The existing structure over Grayson Creek is located in the merge area and would need to be widened to accommodate the two ramps. A CHP enforcement area will be placed just downstream from the stop bar to the right of the travel lanes.

It should be noted that the I-680/SR-4 Interchange Improvement Project proposes to reconfigure this interchange specifically including the southbound on-ramp to I-680. The preliminary design for this ramp has been reviewed by the CARM team and has been determined to effectively accomplish the required improvements to support CARM operations.

Contra Costa Boulevard

The I-680 Southbound Service Interchange at Contra Costa Boulevard consists of a direct hook ramp with a wide shoulder of 12 or more feet. The-ramp is accessed from a dedicated right-turn bay on Contra Costa Boulevard eastbound and a signalized intersection on Contra Costa Boulevard westbound, with the two access points merging immediately into a single lane. As the ramp approaches the mainline merge it crosses Concord Avenue on a structure extending approximately 150 feet, with a downward sloping embankment to the west (Figure 4-8.)

Figure 4-8 Contra Costa Boulevard On-Ramp Merge with I-680 Southbound

As shown in Figure L-40 in Appendix D, the CARM project would widen the Contra Costa Boulevard on-ramp to two lanes, providing entering traffic from the right and the left with their own lane. To achieve this, the existing ramp would be widened to the right. The stop bar would be located on the Concord Avenue undercrossing, which would need to be widened. A new retaining wall would also be required for approximately 200 feet as the ramp approaches the undercrossing. A CHP enforcement area would be provided just downstream of the stop bar and the ramp would also need to be extended before merging with the mainline

Concord Avenue / Chilpancingo Parkway

The Concord Avenue / Chilpancingo Parkway service interchange with I-680 southbound is located in Concord, CA and provides a single-lane direct access ramp to the mainline. While the access ramp has standard shoulders, there is limited right-of-way due to the close proximity of a series commercial buildings and parking lots extending to the west side, as shown in Figure 4-9. The ramp carries peak period volumes of only 360 vehicles per hour, so it will not be widened. However, as shown on Figures L-39 and L-40 in Appendix D, the existing stop bar will be moved approximately 260 feet to the south to provide 660 linear feet of storage. A CHP enforcement area will be located downstream of the stop bar, before the ramp joins the mainline.

Figure 4-9 Concord Avenue / Chilpancingo Parkway On-Ramp (looking north)

Willow Pass Road / Sunvalley Boulevard

The Willow Pass Road / Sunvalley Boulevard service interchange with I-680 southbound has a partial cloverleaf configuration, with single-lane loop ramp from Sunvalley Boulevard westbound and a direct ramp from Sunvalley Boulevard eastbound, each with separate merge locations with the mainline. As shown in Figure L-37 in Appendix D, the CARM project proposes to keep the current configuration. The loop ramp will be widened to the inside to provide two travel lanes. The Sunvalley Boulevard undercrossing will also need to be widened to allow the ramp to be widened to the right downstream of the stop bar to accommodate a CHP enforcement area before merging with the mainline.

The direct ramp will also be widened to two lanes after the right turn from Sunvalley Boulevard. A CHP enforcement area will be provided to the right after the stop bar and the ramp will join the mainline with a standard, 600-foot merge.

SR-242

SR-242 is a three-mile, north-south highway that links I-680 north of Pleasant Hill with SR-4 in Concord, CA. SR-242 joins I-680 southbound on a three-lane direct connector ramp that merges to two lanes prior to joining the I-680 mainline. At the confluence of the two facilities, I-680 southbound provides four travel lanes. The SR-242 direct connector ramp joins I-680 to the right but does so on a direct straight alignment effectively continuous to the mainline of SR-242 adding two lanes to the southbound mainline with no reduction in travel speeds. Due to driver expectation of uninterrupted full highway speed travel and no apparent change in alignment from SR-242 between the two facilities, the CARM project does not propose to introduce metering on the SR-242 service interchange.

Monument Boulevard

The Monument Boulevard service interchange with I-680 southbound provides a single-lane direct ramp to the mainline. The ramp is accessed from a right turn direct lane on Monument Boulevard and two, signalized left turn lanes from Monument Boulevard westbound. The three direct lanes merge immediately into a single lane that is approximately 22 feet wide with a 12-foot-wide right shoulder and a four-foot left shoulder. As shown in Figure L-35 in Appendix D, the CARM project proposes to widen the Monument Boulevard on-ramp to the outside to provide two lanes to the stop bar. A CHP enforcement area will be provided downstream of the stop bar to the right as the two lanes merge before joining the mainline.

Boyd Road / Contra Costa Boulevard

The Boyd Road / Contra Costa Boulevard service interchange with I-680 southbound provides a single-lane slip ramp with standard shoulders that extends approximately 950 feet from Contra Costa Boulevard to the mainline. As shown in Figure 4-10, the ramp passes below a structure carrying the two lanes of Contra Costa Boulevard northbound, with the columns supporting the overcrossing restricting the ability to widen the ramp. As shown in Figure L-34 in Appendix D, the CARM will provide access to the Boyd Road / Contra Costa Boulevard ramp from a single lane on Contra Costa Boulevard delineated by a solid line. The existing ramp would be widened to the left to provide two travel lanes for 500 feet to the stop bar, after which it will narrow to a single lane to pass below the Contra Costa Boulevard overcrossing – Bridge 28.0325K – and the join the mainline in a standard merge. A CHP enforcement area would also be provided immediately downstream of the stop bar.

Figure 4-10 Boyd Road / Contra Costa Boulevard Access Ramp to I-680 Southbound (looking north)

North Main Street / Sunnyvale Avenue / Truck Scales

The North Main Street / Sunnyvale Avenue / Truck Scales service interchange with I-680 southbound provides a 420-foot, single-lane hook-ramp to the mainline. The ramp has standard shoulders and an additional point ramp from the truck scales approximately 200 feet downstream of the arterial entrance. The on-ramp provides limited storage capacity and weave distances and, as shown in Figure 4-11, is extremely constrained by an existing commercial building and retaining wall abutting the west side of the approach to the mainline. Given these constraints, the CARM project does not propose to add any capacity to the existing ramp. It will install the necessary ITS equipment to facilitate CARM operations.

Figure 4-11 Commercial Building and Retaining Wall at the North Main Street / Sunnyvale Avenue On-Ramp

Geary Road / Treat Boulevard

The Geary Road / Treat Boulevard service interchange with I-680 southbound provides a single-lane, direct access ramp to the mainline with standard shoulders and embankments extending along both sides. With only 270 vehicles using the Gear Road / Treat Boulevard interchange during peak periods, there is no need to provide additional capacity to facilitate CARM operations. Therefore, as shown in Figure L-31, the CARM project will add detection equipment and a ramp meter and also lengthen the merge area with the mainline

San Luis Road / North Main Street

The San Luis Road / North Main Street service interchange with I-680 has a direct ramp that is nearly 1,300 feet in length and curves around loop exit ramps from the mainline to North Main Street. The existing ramp provides two lanes for approximately 400 feet and then narrows to a single lane with standard shoulders and a sound wall to the right (Figure 4-12). As shown in Figure L-29 in Appendix D, the CARM project proposes to reconstruct the right curb from San Luis Road to the meter line in order to provide three lanes. After the stop bar the ramp will narrow to a single lane and join the mainline in a standard merge. The ramp will also include a CHP enforcement area downstream of the stop bar. The widening will require the demolition of the existing noise wall. The wall would be reconstructed based on a new Noise Abatement Design Report. The widening would also necessitate the acquisition of a strip of right-of-way from a parking area at the Alvarado Place apartment complex on the outer edge of the ramp as it approaches the merge with the mainline.

Figure 4-12 Existing San Luis Road / North Main Street Sound Wall and Merge with I-680 SB

Hillside Avenue / Ygnacio Valley Road

The Hillside Avenue / Ygnacio Valley Road service interchange with I-680 southbound provides a two-lane direct access ramp immediately south of the split between I-680 southbound and SR-24 Direct Connector ramp. As shown in Figure 4-13, the ramp abuts a retaining wall securing the embankment carrying the SR-24 Direct Connectors to the right, rising up to meet the mainline, which is on an elevated structure and embankment. The proximity of the two elevated roadways with the ramp in between would preclude any additional widening. As indicated in Figure L-28 in Appendix D, work at this interchange will be limited to the installation of detection and metering equipment and the necessary communication lines.

Figure 4-13 Existing I-680 Southbound On-Ramp at Hillside Avenue / Ygnacio Valley Road

Hillside Avenue to SR-24 Connector

There is an additional service interchange to the SR-24 Connector from Hillside Avenue. The ramp is it is located 1,450 feet downstream of the I-680 southbound / SR-24 Connector split. It is possible that friction with traffic from the ramp could cause congestion on the connector that could possibly backup onto I-680 southbound and disrupt traffic flows. Therefore, it is considered beneficial to deploy ramp metering on the direct connector ramp. As shown in Figure 4-14, the interchange provides a 1,200-foot, single-lane loop ramp with standard shoulder that rises up on an embankment and crosses Hillside Avenue on structure to meet the SR-24 connector. The ramp is accessed from a dedicated right turn lane that extends for over 300 feet on Hillside Avenue westbound, as well as an un-signalized direct on-ramp from Hillside Avenue eastbound. As shown in Figure L-28 in Appendix D, the CARM project proposes to provide detectors on the ramp to integrate with the CARM system. However, there would be no widening or other civil works.

Figure 4-14 SR-24 Connector Southbound Service Interchange at Hillside Avenue

4.1.5 Proposed CARM Ramp Improvements – I-680 Southbound South of SR-24

The following sections summarize the proposed ramp improvements necessary to accommodate CARM operations on I-680 southbound south of SR 24. The descriptions are presented from north to south, providing textual descriptions of conceptual designs contained in Appendix D.

SR-24

The eastbound SR-24 to southbound I-680 movement is served by a two-lane connector at the I-680/SR-24 system interchange. The connector provides three lanes as it diverges from SR-24 and then tapers to two lanes and continues to the gore at the merge with I-680 southbound. Due to the substantial contribution of traffic from eastbound SR-24, metering of the freeway-to-freeway connector at this location is recommended as part of a coordinated adaptive ramp metering implementation. The concept of metering system interchange connectors, while relatively rare in the United States, is not unprecedented in California, and includes examples in Caltrans District 4. Most notably, freeway-to-freeway ramp meters are currently installed on the southbound I-680 systems ramps to both eastbound and westbound I-580 in Alameda County, immediately south of Contra Costa County.

As shown in Figures L-26 and L-27 in Appendix D, the CARM project proposes to widen the connector to four lanes as it approaches the stop bar, which will be located just upstream of the Olympic Boulevard undercrossing. This will be accomplished by widening and adding a lane to each side. Downstream of the meter the connector tapers to two lanes, with lanes 1 and 2 merging, as would lanes 3 and 4. A concrete barrier will be added to the outside to provide separation between the mainline and the connector as it approaches the meter line. The SR 24 system interchange will not include a dedicated CHP enforcement area.

Olympic Boulevard

The Olympic Boulevard service interchange with I-680 southbound has a partial cloverleaf configuration, with a single lane loop ramp serving westbound traffic on Olympic Boulevard and a single lane direct ramp carrying eastbound traffic from Olympic Boulevard. Both ramps merge into a single lane approximately 650 feet before joining the mainline. The on-ramp continues as an auxiliary lane for approximately 1,300 feet to the South Main Street off-ramp.

The CARM project does not propose any physical changes to the Olympic Boulevard interchange. There will be no widening and a CHP enforcement area will not be provided. Work will be limited to installing detectors and ramp metering equipment. The sound wall after the Las Trampas Creek Brides (280162K) will not be impacted.

South Main Street

The South Main Street interchange provides a loop ramp extending from southbound South Main Street. As shown in Figure 4-15, the interchange was reconstructed in late 2021 to provide two lanes of capacity for 840 feet with lane markings, including a metering stop bar. However, given the ramp’s low traffic volumes, only one lane is necessary for CARM operations. It is anticipated that ramp metering ITS will be installed prior to the CARM project. The CARM project will add a CHP enforcement area and mid-queue detectors and any other ITS installations necessary for CARM operations.

Figure 4-15 The Widened South Main Street Loop Ramp

Rudgear Road / Danville Boulevard

The Rudgear Road service interchange provides a direct ramp with dedicated turn lanes for east and westbound traffic on Rudgear Road at a traffic signal. There is no corresponding off-ramp from I-680 to Rudgear Road. As shown in Figure 4-16, the Rudgear Road on-ramp was reconstructed in late 2021 to include two lanes general purpose lanes, plus a third HOV lane. A standard Caltrans stop bar has been installed, together with the supporting infrastructure required for ramp metering. The CARM project will add a CHP enforcement area downstream of the stop bar, as well as the supplemental detection equipment and signage required for CARM operations. The Rudgear Road on-ramp only needs two lanes to enable CARM operations.

Figure 4-16 ITS Installations at the Reconstructed Rudgear Road On-Ramp

Livorna Road

The Livorna Road service interchange with I-680 southbound provides a single-lane direct on-ramp that has a sound wall and a steep embankment adjacent to the right shoulder along San Ramon Creek. There is also a sound wall and embankment to the left shoulder adjacent to the mainline. As shown in Figure L-21 in Appendix D, the ramp will be widened to the outside to provide two lanes. The sound wall to the right of the existing ramp will need to be reconstructed based on a Noise Abatement Design Report and up to 15 trees will be taken. The CARM project will add a CHP enforcement area downstream of the stop bar, where the ramp will taper to one lane and join the mainline in a standard 600-foot merge.

Stone Valley Road

The Stone Valley Road service interchange with I-680 southbound has a direct on-ramp accessed from dedicated turn lanes in both directions of travel on Stone Valley Road. The ramp immediately tapers to a single lane and curves around a loop off-ramp to reach the mainline. As shown in Figure L-19 in Appendix D, the CARM project proposes to widen the ramp to the right to provide two travel lanes. The widening will disturb some trees and vegetation, requiring the area between with edge of the shoulder and the right-of-way line to be regraded. Both lanes will extend to the stop bar. From there, the ramp will taper to one lane as it passes a CHP enforcement are and then meet the mainline in a standard merge.

El Cerro Boulevard

The El Cerro Boulevard service interchange with I-680 southbound provides a direct on-ramp to the mainline. The first 160 feet of the ramp has two lanes, after which it tapers to a single lane. As shown in Figure L-16 in Appendix D, the CARM project proposes widening the ramp to the right to provide two lanes to the stop bar. The widening would impact some vegetation, so the vegetated downward slope to the right of the paved area will likely need to be re-graded. The ramp will narrow to a single lane after the stop bar as it passes a CHP enforcement and then joins the mainline. A maintenance vehicle pullout will be provided upstream of the meter line.

Diablo Road

The Diablo Road service interchange with I-680 southbound provides access to the mainline from a single-lane direct on-ramp. Th ramp crosses above San Ramon Creek on a single lane structure with narrow shoulders and a sound wall on the right side (Figure 4-17). As shown in Figure L-13 in Appendix D, the CARM project proposes to widen the ramp to the right to provide an additional lane to the stop bar. This would necessitate either widening or reconstructing the San Ramon Creek Undercrossing (Bridge 28-0197), which was built in 1975. The stop bar would be placed downstream of the bridge, after which the ramp would taper to a single lane and traverse a new CHP enforcement area before joining the mainline with a standard merge. Some vegetation would likely be disturbed by the widening.

Figure 4-17 Diablo Road On-Ramp Crossing San Ramon Creek

Sycamore Valley Road

The service interchange between Sycamore Valley Road and I-680 southbound has a partial cloverleaf configuration, with a direct on-ramp from Sycamore Valley Road bending around a loop-off ramp from the mainline. The on ramp has a single access lane from Sycamore Valley Road east bound and two access lanes receiving westbound traffic entering at a signalized intersection. Both lanes continue to a stop bar, after which they merge. As shown in Figure L-12 in Appendix D, the CARM project proposes to widen the direct on-ramp to the right to provide two lanes to the stop bar. Following the stop bar, the ramp will narrow to a single lane as it passes a CHP enforcement area and merge with the mainline.

Crow Canyon Road

The existing Crow Canyon Road service interchange with I-680 southbound includes a loop ramp from Crow Canyon Road eastbound and a direct ramp serving westbound traffic on Crow Canyon Road. Both ramps join I-680 southbound in separate merges. The loop ramp provides two travel lanes through the 270-degree curve, after which it narrows to a single lane. The existing direct ramp has a single lane.

As shown in Figures L-9 and L-10 in Appendix D, the CARM project proposes to widen the direct ramp to the right to provide two travel lanes to the stop bar. It also proposes to extend the loop ramp to merge with the direct ramp shortly upstream of the ramp meter to provide three lanes at the stop bar. A barrier would be added to the loop ramp from the Crow Canyon Road Overcrossing and extent to the meter to separate the loop ramp from the mainline. The loop ramp would not be widened.

After the stop bar, lanes 2 and 3 would merge as the ramp passes by a CHP enforcement area and then narrow to a single lane and join the mainline as the existing auxiliary lane downstream of the direct ramp. A number of trees are likely to be taken in the merge and CHP enforcement area requiring the soil to be regraded from the edge of the pavement to the right-of-way limit.

Bollinger Canyon Road

The Bolliger Canyon Road service interchange with I-680 has a partial cloverleaf configuration with a loop ramp serving eastbound arterial traffic and a direct ramp serving westbound traffic on Bollinger Canyon Road. Both ramps have a single lane, as well as separate merges with the mainline. As shown in Figures L5 and L6 in Appendix D, the CARM project proposes to widen the direct ramp to the right to provide two travel lanes to the stop bar. It will also extend the loop ramp to merge with the direct ramp and widen the ramp to two lanes prior in advance of the stop bar, providing a total of four lanes at metering point. The CARM project would also add a retained abutment at the Bollinger Canyon Road undercrossing to provide adequate width for the realigned loop ramp. A barrier would also be built to separate the loop ramp from the mainline along its entire length to the stop bar. The widened direct ramp would also require a retaining wall to stabilize the grade change between the between the direct ramp and the adjacent parking lot as the grade slopes down to the pavement.

After the stop bar, lanes 1 and 2 would merge as the ramp passes a CHP enforcement area. Lane 3 would merge with the mainline, with the remaining lane joining the mainline further downstream. Any areas with disturbed vegetation would require regrading and planting. It may be desirable to use additional shoulder space downstream of the direct ramp to extend the merge lane for some distance to provide a more orderly merge.

San Ramon Valley Boulevard

San Ramon Valley Boulevard service interchange with I-680 southbound provides an offset hook ramp. The ramp has three lanes, one extending from a dedicated access lane from San Ramon Valley Boulevard northbound, and two accommodating southbound traffic turning onto the ramp from a signalized intersection. The three lanes continue for approximately 600 feet and then taper to a single lane to pass through the Alcosta Boulevard undercrossing (Figure 4-18. The ramp then merges with the Alcosta Boulevard on-ramp before joining the mainline. The CARM project proposes to widen the San Ramon Valley Boulevard on-ramp to two lanes as it approaches the shared stop bar with the Alameda Boulevard on-ramp.

Figure 4-18 San Ramon Valley Boulevard On-Ramp Lane Merge and Alcosta Boulevard Undercrossing

Alcosta Boulevard

The Alcosta Boulevard service interchange with I-680 southbound is located in Alameda County, immediately south of the Contra Costa County line. Given the integral role of this ramp in the operation of the I-680 corridor and its position as the final access point upstream of the I-580 interchange, this ramp must be included to ensure the effectiveness of the CARM system in improving traffic operations along southbound I-680 and managing congestion in the approach to I-580, which is a significant bottleneck.

The Alcosta Boulevard interchange with I-680 southbound provides a directional on-ramp with two lanes extending for approximately 310 feet before merging into a single lane. The ramp has a retaining wall to the right as it extends down a slope to merge with the San Ramon Boulevard on-ramp. It then continues as an auxiliary lane on I-680 southbound for approximately one mile to the off-ramps for both eastbound and westbound I-580.

As shown in Figures L1 and L2 in Appendix D, the CARM project proposes to widen the Alcosta Boulevard on-ramp to two lanes. This will require building a new retaining wall to the right (Figure 4-19). An additional lane will also be added immediately downstream of the merge with the San Ramon Boulevard on-ramp to accommodate the high traffic volumes entering from San Ramon Valley Boulevard and provide a total of four lanes at the stop bar. A CHP enforcement area will be provided downstream of the stop bar. Lanes three and four will merge and then join the mainline. Lanes one and two will merge and then continue as an auxiliary lane for approximately one mile to the I-580 interchange.

Figure 4-19 Retaining Wall at the Alcosta Boulevard On-Ramp Approaching the Merge with the San Ramon Valley Boulevard On-Ramp

As shown in **Error! Reference source not found.**, two detector loops are installed at the Alcosta Boulevard interchange.

4.2 ITS Installations

The ITS equipment needed at the ramps and in the mainline in order to replicate the VicDOT managed freeways approach has been preliminarily identified. This exercise has not distinguished between the components that would be installed as part of the Caltrans SHOPP project and the CCTA CARM project. The intent of this exercise is to provide an entire inventory of the necessary equipment to help inform discussions between Caltrans and CCTA regarding which elements will be provided by each of the two projects, respectively.

The review of ITS requirements for CARM have been built on the following assumptions:

- The CARM system will be connected to the existing backbone fiber network for ATMS communications purposes
- The analysis assumes all new ramp ITS infrastructure will be installed at each ramp meter installation, including cabinets, pull boxes, conduit, mast arms, signal heads, etc.
- It is recommended that full matrix light emitting diode (LED) changeable message signs are placed at the entrances to all ramps included in the CARM system
- It is assumed that the system will have vehicle detection equipment on both on-ramp and off-ramps. Inductive loop detectors, or alternatively magnetometer sensors can be utilized for this purpose
- More frequent and highly precise mainline detection will be provided using TIRTL devices

4.2.1 Exit Ramp Detection

When a freeway maintains productivity, a result not often considered is the potential for more vehicles to consistently leave the freeway facility. With this additional demand, the need to monitor the queue on exit ramps is important to ensure ramp terminal signals can process the increased number of exiting vehicles. For this reason, exit ramp detectors are recommended at all exit ramps on the facility. With these improvements, the system can monitor and notify local operators if arterial signal systems require adjustments to maintain safe and efficient operations.

4.2.2 Mainline Detection

Currently, Caltrans owns and operates PeMS to monitor operating conditions on its freeways statewide. The PeMS system uses inductive loop detectors spaced at 0.25 to 0.5 mile intervals to monitor traffic flows at all times. The data is used by the TMCs and for various planning and traffic performance reporting needs. There are, however, two major concerns with the existing detection system along the I-680 corridor:

- Due to ongoing improvements in the corridor over time, the locations of the current PeMS detectors do not capture conditions at critical bottlenecks that need to be monitored with CARM operations
- Based on an initial scan of available PeMS data, there are concerns regarding the health and precision of existing loop detectors in the I-680 corridor

To achieve the required level of precision for a managed freeways approach, VicDOT uses TIRTLs for mainline vehicle detection in its managed freeway corridors. Colorado DOT has also installed TIRTLs on the I-25 corridor in Denver for use as part of the SMART 25 managed freeway pilot project. TIRTLs are also recommended for mainline detection in the I-680 corridor to support CARM operations.

TIRTL is a point detection device that utilizes infrared light cones to detect traffic using transmitters and receivers on opposite sides of the road. Once in place and calibrated, two light cones are projected across the roadway by the transmitter to the receiver. The system detects breaks and makes in the light beam pathways to determine traffic volume, vehicle speed, classification, axle count, axle configuration, vehicle length, lane position, headway, and gap.

Point devices have functionality similar to inductive loops with the highest degree of accuracy and faster processing time for advanced freeway management applications, while also being less intrusive to install. A key benefit of these devices over loops is that all maintenance can be performed outside of travel lane. Unlike other side mounted vehicle detection devices, like microwave radar devices, vehicle occlusion is not a noted limitation of TIRTL as they typically project beneath the body of the vehicle to detect the wheels of the vehicles passing the detection site. Utilizing dual light cones allows the device to triangulate breaks and makes across a matrix of four beam pathways to detect the lane position of the vehicle thereby eliminating double counting or miscounting vehicles straddling lanes, which is a known issue with inductive loops and magnetometers.

For a managed freeway, mainline detector placement is also a critical factor to consider in order to provide the ability to observe changes in traffic flows and respond accordingly to maintain productivity. The key locations for mainline detector placement outlined in VicDOT guidance are:

1. Downstream of an entry ramp,
2. Upstream of an entry ramp,
3. Downstream of an exit ramp,
4. At identified critical bottleneck locations; and
5. Regularly and evenly spaced between the locations described in 1 through 4

Based on these guidelines, 92 northbound and 88 southbound TITRL sites are recommended along the I-680 corridor to monitor traffic flows and provide the data necessary to optimize corridor performance as part of the deployment of CARM in the I-680 corridor. It should be noted that these sites will need to be field verified during the design phase and prior to device installation to confirm site conditions are adequate for each TIRTL to function (i.e. the slope or crown of the roadway does not occlude the ability for the TIRTL receiver to detect the light cones from the transmitter).

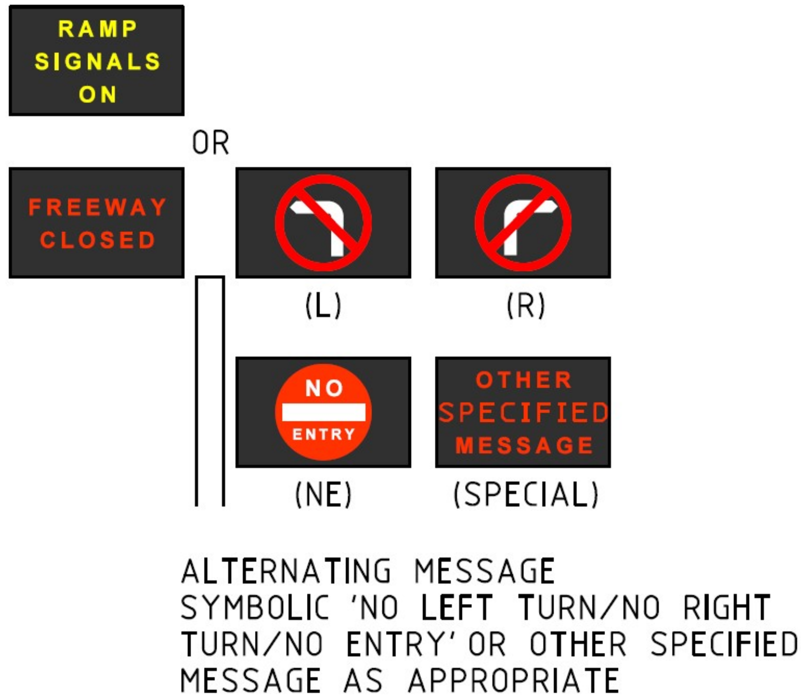
While not shown, it should also be noted that the Bay Area Infrastructure Finance Authority (BAIFA) owns several Wavetronix microwave radar detector sites along the corridor to monitor general purpose and express lanes traffic flow. These sites are maintained by the toll system integrator to ensure consistent and continuous operations of the express lanes. Additionally, BAIFA owns several overhead read point sites along the corridor that detect and record toll tag usage in the express lanes.

4.2.3 Entry Ramp Signage

As part of the managed freeway concept, full matrix, changeable light emitting diode (LED) signs are recommended at all ramp entrances. The signs are places immediately prior to the entrance of the ramp, or at the last available decision point along the arterial corridor. One sign should be placed at each approach to notify drivers on the current status of the ramp meter or the condition of the entrance ramp and/or freeway mainline. The signs are not always active and display a message only when applicable.

Figure 4-20 is an excerpt from the VicDOT Standard Drawings and shows the various messages that can be displayed on ramp entry signs. The range of typical messages displayed include informing motorist of ‘Ramp Signals On’ and supporting incident management activities by displaying ‘Freeway Closed” and symbolic No Right / No Left Turn, No Entry, or other messages as appropriate. Alternating messages can also be utilized to reiterate ramp or freeway status (e.g. ‘No Right Turn’ alternating with ‘Freeway Closed’ and ‘Find Alternate Route’)

Figure 4-20 VicDOT CARM Entrance Ramp Signage Example



4.2.4 Arterial Changeable Message Signs

In addition to signs at freeway entry ramps, additional signage is recommended on nearby arterial corridors based on discussions with Caltrans staff. These signs are intended to enhance traveler information by displaying real time updates so that the drivers can interpret and decide which path is the best to reach their destination. Such signs are found in advance of entrance ramps, providing downstream travel time information, freeway conditions, weather alerts, etc., and can inform the traveling public of a ramp closure or alternative route information based on the current driving conditions. The sign is a full matrix color LED display that is larger than those at the entry ramps so that it can provide up to three lines of text and/or graphics.

Figure 4-21 VidDOT Arterial Signage Example

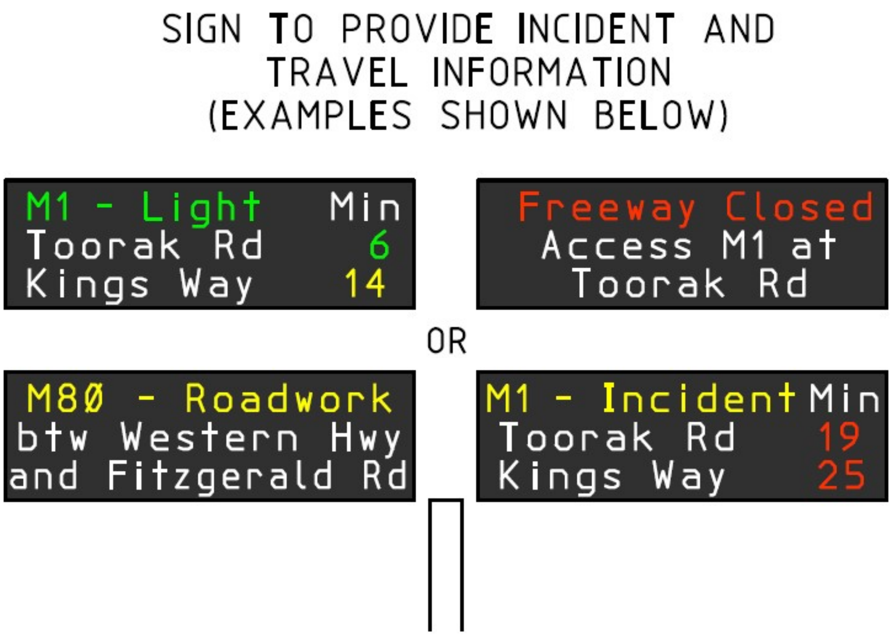


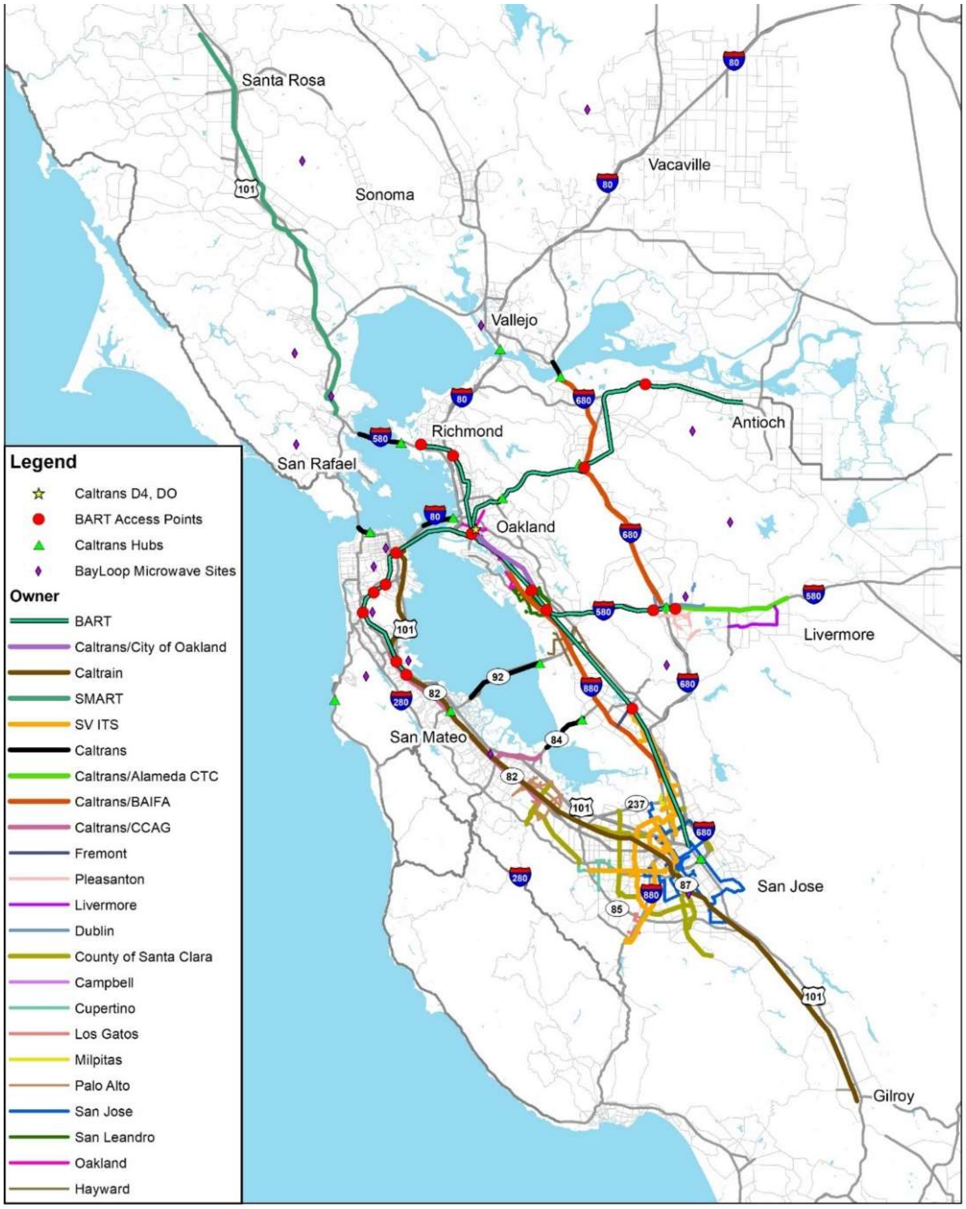
Figure 4-21 is an excerpt from the VicDOT Standard Drawings for Managed Motorways and shows examples of the types of messages can be displayed. The arterial sign can also provide the traveler with both a quantitative (number of minutes to a listed location) and qualitative (Red/Yellow/Green) color coding to support messaging. It should be noted that while this color scheme may not be currently allowed by MUTCD, it is included to showcase the potential opportunity to pilot new technology.

For the purposes of the Phase 1 CARM deployment, a focused area within the City of San Ramon has been recommended for the installation of sixteen arterial signs to pilot the devices. This location was recommended for the testing the signs because the arterial network is configured in a grid, providing redundancy between routes and the ability to demonstrate alternative options during different traffic management situations.

4.2.5 Communications

Managing traffic in real time is data intensive and requires a low latency system with the ability to transfer large volumes of information efficiently and reliably every 20 seconds in order to monitor and respond to the changing dynamics of traffic flows. The CARM communications system will need to have adequate bandwidth to process and control the devices in the field, as well as redundancy to continue to operate should a line be disrupted or broken.

As highlighted in MTC's *Bay Area Regional Communications Strategic Investment Plan*, the I-680 study corridor has an existing fiber trunk line that was installed as part of the I-680 Express Lanes Project (see Figure 4-22). The fiber trunk line is currently owned and maintained by BAIFA. The supporting conduit infrastructure is owned by Caltrans and is in the Caltrans right-of-way. In addition, Caltrans owns 72 strands of fiber along the corridor. This fiber trunk line connects to Caltrans communications hubs to the north (near the CA-24 Interchange) and to the south (near the I-580 interchange), ultimately connecting to the Caltrans District 4 Traffic Management Center (TMC) via BART trunk line fiber on CA-24, I-580 and I-880. Assuming no other major changes to the current ITS infrastructure, it is expected



that the existing network has adequate bandwidth available to support the CARM operations in the I-680 corridor. Additional investment in a communications trunk line would not be required. However, if there is a desire for a redundant network path, the cost of providing redundancy in the fiber network would need to be accounted for.

Figure 4-22 Regional Fiber Communications Network

Should the project seek to utilize the existing I-680 fiber trunk line, it is recommended that BAIFA be engaged early in the Concept of Operations development process to confirm the network architecture, security needs, and proposed connections to the ATMS and existing Caltrans field devices.

4.2.6 Closed Circuit Television (CCTV)

Having the capability to visually observe traffic flows in the corridor is beneficial for TMC operators to see how traffic is responding and to confirm the cause of any observed flow breakdowns. Given that there is ample coverage in the corridor from existing CCTV sites owned and maintained by Caltrans, additional CCTV cameras on the corridor are not expected to be needed. However, the coverage, health and functionality of the existing devices should be considered as a part of the CARM project, specifically during the development of the Concept of Operations. If gaps exist in CCTV coverage, particularly at ramp locations, additional CCTV may be recommended to ensure full coverage with pan, tilt and zoom (PTZ) capability is available. Like the need for highly reliable and precise mainline detection, having effective eyes on the road is critical to achieving control in a managed freeway system.

It should also be noted that BAIFA owns several CCTV sites along the corridor that are used to monitor the express lanes from the Regional Operations Center at the MTC Headquarters in Oakland. These sites are maintained by the toll system integrator to ensure consistent and continuous express lane operations.

5 Key Findings

This final chapter of the evaluation report synthesizes the findings of the analysis. It reviews the recommended number of lanes and storage at each interchange and juxtaposes that information with the civil improvements that are proposed based on. The chapter also provides cost estimates for the physical improvements described in Chapter 4 at all on-ramps to I-680, together with the estimated costs for the ITS equipment on the ramps and on the mainline. Separate estimates are also provided for the annual cost of operating and maintaining the CARM system. This includes the upkeep and operation of the different ITS components, together with the anticipated annual STREAMS® software and device integration, hosting and support fees, and the annual licensing fee to operate the STREAMS® software.

Given that CCTA intends to implement CARM on a sequential basis in the I-680 corridor, the information described above is presented for the following four segments:

- I-680 Northbound, south of SR-24
- I-680 Northbound, north of SR-24
- I-680 Southbound, north of SR-24
- I-680 Southbound, south of SR-24

Decisions on advancing the implementation of CARM technology in these different segments of the corridor will be made based on their complexity, cost, location, the extent and duration of congestion, and the anticipated effects of CARM on traffic operations. As mentioned earlier, CCTA has opted to begin the implementation of CARM technology on I-680 northbound, south of SR-24 because its initial feasibility review found that this would be the simplest segment in the corridor. In addition, the cost of advancing CARM in this segment aligns with the $25 million in available funding that the California Transportation Commission has made available to Contra Costa County from State Transportation Improvement Program (STIP) funding. The information presented below is intended to inform further decisions on advancing CARM implementation in the I-680 corridor.

5.1 I-680 Northbound South of SR-24

Table 5-1 summarizes the proposed modifications at the 11 interchanges on I-680 northbound south of SR-24 to enable CARM operations. The grey shaded columns provide the existing traffic volumes, number of lanes, and the existing vehicle storage in lane feet, together with the number of lanes proposed by the SHOPP project. The green shaded columns provide the recommended number of lanes, storage, and typical cycle times using the VicDOT standards. Lastly the yellow shaded columns provide the improvements that CCTA proposes, together with the estimated civil and ITS costs for each interchange. Schematic drawings of the proposed civil improvements are provided in Appendix D. The right-hand column in Table 5-1 provides the drawing numbers depicting the civil improvements proposed for each interchange. If the proposed number or lanes, vehicle storage, or cycle times do not meet the VicDOT recommendations, they are shown in orange font in Table 5-1.

Table 5-1 Proposed Improvements – I-680 Northbound, South of SR-24

On Ramp Location *(South to North)*	Volume *(veh/hour)*	Existing Number of Lanes	Existing Storage *(lane feet)*	Lanes Proposed in SHOPP Project	VicDOT Recommended Number of Lanes	VicDOT Recommended Storage *(lane feet)*	VicDOT Typical Cycle Time *(seconds)*	Volume *(veh/hour)*	Proposed Number of Lanes	Proposed Storage *(lane feet)*	Typical Cycle Time *(seconds)*	Cost Estimate *(Civil)*	Cost Estimate *(ITS)*	Total Estimated Cost	Drawing Number
Alcosta Boulevard	889	2	2,500	3	3	1,673	12.0	889	3	2,150	12.0	$20,000	$481,000	$501,000	*L-2*
Bollinger Canyon Road Loop Ramp	418	1	570	2	1	781	8.7	418	1	1,550	8.0	$4,900,000	$481,000	$5,381,000	*L-3, L-4*
Bollinger Canyon Road Direct Ramp	940	2	2,464	3	2	1,168	11.5	940	2	2,700	8.0	*See above*	*See above*	*See above*	*L-3, L-4*
Crow Canyon Road Loop Ramp	880	1	1,550	2	2	1,634	8.2	880	**1**	1,900	**5.8**	$2,700,000	$500,000	$3,200,000	*L-7, L-8*
Crow Canyon Road Direct Ramp	974	2	1,650	3	2	1,207	11.1	974	2	2,300	**5.8**	*See above*	*See above*	*See above*	*L-7, L-8*
Sycamore Valley Road	1,434	1	1,340	2	3	2,661	7.5	1,434	3	**1,640**	7.5	$750,000	$481,000	$1,231,000	*L-11*
Diablo Road Loop Ramp	282	1	700	2	1	558	13.1	282	1	800	13.1	$650,000	$417,000	$1,067,000	*L-13, L-14*
Diablo Road Direct Ramp	289	1	670	2	1	558	12.7	289	1	700	12.7	$650,000	$417,000	$1,067,000	*L-13, L-14*
El Cerro Boulevard	598	1	800	2	2	1,115	12.0	598	2	1,400	12.0	$690,000	$463,000	$1,153,000	*L-15*
El Pintado Road	179	1	420	2	1	371	18.0	179	1	450	18.0	$800,000	$417,000	$1,217,000	*L-17*
Stone Valley Road	700	1	890	2	2	1,299	10.3	700	2	2,000	10.3	$2,400,000	$462,000	$2,862,000	*L-18*
Livorna Road	475	1	440	2	2	932	14.4	475	2	**900**	14.4	$720,000	$462,000	$1,182,000	*L-20*
Rudgear Road / Danville Boulevard	777	1	1,290	2	2	1,451	9.3	777	2	1,500	9.3	$0	$462,000	$462,000	*L-23*
Olympic Boulevard	1,445	2	1,675	2	3	2,692	7.5	1,445	3	**1,900**	7.5	$1,100,000	$481,000	$1,581,000	*L-27*
								Totals				***$15,380,000***	***$5,524,000***	***$20,904,000***	

Proposed number of lanes shown in **ORANGE** to not meet the VicDOT recommended number.
Proposed vehicle storage numbers shown in **ORANGE** do not meet the VicDOT recommended amount.
Proposaed cycle time numbers shown in **ORANGE** would only be appropriate when the mainline analysis indicates ramp demands are accommodated with spare capacity for several downstream interchanges.

As shown in Table 5-1 and described previously in Section 4.1.2, with a combined peak hour volume of 1,854 at the Crow Canyon Road interchange, the VicDOT guidance recommends four lanes at the stop bar at this location. However, due to the presence of an overcrossing in the vicinity of the stop bar, it will only be possible to provide three lanes without substantial civil and structural construction impacts. As a result, the typical cycle time is estimated to be 5.8 seconds during the peak hour. This may be mitigated if there is spare capacity at several downstream interchanges.

There are three interchanges on I-680 northbound south of SR-24 where the proposed linear feet of vehicle storage space does not meet the VicDOT guidance recommendation. They include Sycamore Valley Road, which is immediately downstream from Crow Canyon Road and will have a deficit of 1,021 linear feet of storage. That length would be expected to provide the capacity to accommodate approximately 37 vehicles. To compensate for the storage deficit, the CARM system would need to allow these 37 vehicles to enter the mainline more quickly than they would otherwise to avoid traffic backing up onto the arterial street network from the ramp.

The Livorna Road ramp, which is the fifth interchange downstream of Sycamore Valley Road, would have a small deficit of 32 linear feet; equating to approximately one vehicle. In addition, the Olympic Boulevard interchange, which is located at the northern end of the segment, would have a deficit of 792 linear feet, equating to 29 vehicles. The short fall in vehicle storage will require faster cycle times during peak operations to avoid having vehicle queues from the ramps spilling onto the local street network.

As shown in Table 5-1, the estimated cost of preparing the interchanges on this analysis segment for CARM operations is $20.9 million. This includes roughly $15.4 million for civil improvements and $5.5 million for ITS installations. Civil costs range from a low of $20,000 at Alcosta Boulevard, which will not be widened, to a high of $4,900,000 at Bollinger Canyon Road. Other interchanges with civil costs exceeding $1,000,000 include Crown Canyon Road, Stone Valley Road, and Olympic Boulevard.

5.2 I-680 Northbound North of SR-24

Table 5-2 summarizes the proposed modifications at 10 interchanges on I-680 northbound north of SR-24 to enable CARM operations. As discussed in Section 4.1.3, CCTA does not propose ramp metering on the SR-24 direct connector ramps due to safety concerns and driver expectations, or at the truck scales due to low traffic volumes. The CARM system would be deployed on the remaining 10 interchanges in this segment and would have to manage any potential delays due to the 4,400 peak-hour vehicles accessing I-680 northbound from SR-24. As shown in Table 5-2, the recommended number of lanes can be provided at eight of the 10 interchanges. However, at Monument Boulevard, widening to three lanes would impact 13 homes, so it is recommended the ramp would only be widened to two lanes to accommodate 1,180 vehicles per hour. This would necessitate a cycle time of 6.1 seconds.

Table 5-2 Proposed Improvements – I-680 Northbound, North of SR-24

On Ramp Location *(South to North)*	Volume *(veh/hour)*	Existing Number of Lanes	Existing Storage *(lane feet)*	Lanes Proposed in SHOPP Project	VicDOT Number of Lanes	VicDOT Storage *(lane feet)*	Average Cycle Time *(seconds)*	Volume *(veh/hour)*	Proposed Number of Lanes	Proposed Storage *(lane feet)*	Proposed Cycle Time *(seconds)*	Cost Estimate *(Civil)*	Cost Estimate *(ITS)*	Total Estimated Cost	Drawing Number
SR-24	4,400	3	NA	3	NA	NA	NA	4,400	NA	NA	NA	$0	$0	$0	*none*
Lawrence Way / Penniman Way / North Main	1,660	2	1,140	2	4	3,089	8.7	1,660	4	3,560	9.1	$8,250,000	$500,000	$8,750,000	*L-30*
Truck Scales	40	1	NA	NA	NA	NA	NA	40	NA	NA	NA	$0	$0	$0	*none*
Buskirk Avneue / Treat Boulevard	1,330	1	177	2	3	2,474	8.1	1,330	4	4,060	10.9	$24,310,000	$481,000	$24,791,000	*L-32*
Oak Road / Elena Court / Coggins Drive	850	1	414	2	2	1,581	8.5	850	2	1,350	8.5	$2,660,000	$462,000	$3,122,000	*L-33*
Monument Boulevard	1,180	1	400	2	3	2,234	9.2	1,180	2	1,850	6.1	$120,000	$462,000	$582,000	*L-36*
Willow Pass Road	1,040	2	930	3	3	1,935	10.4	1,040	3	3,200	10.4	$4,590,000	$481,000	$5,071,000	*L-38*
Burnett Avenue	670	1	309	2	2	1,244	10.8	670	2	1,100	10.8	$2,600,000	$462,000	*$3,062,000*	*L-39*
Concord Avenue	710	1	674	2	2	1,318	10.2	710	2	1,350	10.2	$2,860,000	$462,000	$3,322,000	*L-41*
SR-4 Interchange	1,330	1	3,551	2	3	2,474	8.1	1,330	3	4,360	8.1	$10,250,000	$500,000	$10,750,000	*L-42, L-43*
Arthur Road	420	1	428	2	1	781	8.6	420	1	550	8.6	$1,260,000	$417,000	$1,677,000	*L-44*
Marina Vista / Waterfront Road	590	1	300	2	2	2,194	12.2	590	1	1,100	6.1	$20,000	$417,000	$437,000	*L-50*
								Totals				***$56,920,000***	***$4,644,000***	***$61,564,000***	

Proposed number of lanes shown in **ORANGE** to not meet the VicDOT recommended number.
Proposed vehicle storage numbers shown in **ORANGE** do not meet the VicDOT recommended amount.
Proposaed cycle time numbers shown in **ORANGE** would only be appropriate when the mainline analysis indicates ramp demands are accommodated with spare capacity for several downstream interchanges.

An additional storage deficit is also anticipated at Monument Boulevard. While the amount of storage is proposed to be increased from 400 to 1,850 linear feet, this is 434 feet below the recommended VicDOT guidance. This would require the CARM system to feed an additional 16 vehicles onto the mainline during the peak hour. This situation is further complicated by the fact that the Oak Road / Elena Court / Coggins Avenue, which is located immediately upstream of Monument Boulevard and is constrained, would have a storage deficit of 231 feet equating to nine vehicles in the peak hour. In addition, the Burnett Avenue on-ramp, which is two interchanges downstream from Monument Boulevard, would have a small deficit of 144 linear feet, equating to five vehicles in the peak hour. An additional storage deficit of 231 linear feet is anticipated at Arthur Road, which is three interchanges downstream of Burnett Avenue.

At the Marina Vista / Waterfront Road location a widening would require costly modifications to the elevated ramp structure that rises to meet the mainline as it approaches the Benicia-Martinez Bridge. As a result, one lane will be provided instead of two, resulting in a suboptimal cycle time of 6.1 seconds. This would be further complicated by the fact that the interchange will also have a storage deficit of 1,094 linear feet, in spite of the fact that additional storage is proposed on Waterfront Road. This would require a further reduction in the cycle time to allow 41 additional vehicles on to the mainline in order to avoid backups on local streets. However, given that the CARM system will not be deployed to the north of the Marina Vista interchange, the effects on the operation of the CARM system is not expected to be severe.

As shown in Table 5-2, the estimated capital cost of reconfiguring the ramps and deploying the necessary ITS equipment for CARM operations on I-680 northbound north of SR-24 is approximately $61.6 million. This would include nearly $57 million in civil costs and $4.6 million in ITS costs. Capital costs would range from a low of $20,000 at Marina Vista / Waterfront Road to a high of $24.3 million at Buskirk Avenue / Treat Boulevard. The estimated civil cost at the SR-4 interchange is also significant at $10.25 million. Construction costs would range between $1.0 and 5.0million at all other interchanges, with the exception of Monument Boulevard which is less than $1 million.

5.3 I-680 Southbound North of SR-24

Table 5-1 summarizes the proposed modifications at the 12 interchanges on I-680 southbound north of SR-24 where CARM operations are proposed. The table also provides limited information on the ramp to the SR-24 director connector from Hillside Avenue. CCTA may consider installing CARM on this ramp to avoid having potential congestion on the direct connector caused by the ramp from backing up onto I-680 southbound.

CCTA proposes to install CARM on all mainline ramps in this segment of I-680, with the exception of SR-242 due to driver expectation of uninterrupted full highway speed travel in a straight line between the two facilities. As shown in Table 5-3, due to high peak period volumes at SR-4 interchange, the cycle time would need to be lowered to 6.2 seconds. This is expected to be sustainable given that there would be excess storage capacity at the three downstream interchanges. The CARM system would need to have the capacity to manage possible congestion resulting from the 3,640 vehicles accessing I-680 southbound from SR-242, which is four interchanges downstream of SR-4

Table 5-3 Proposed Improvements – I-680 Southbound, North of SR-24

On Ramp Location *(North to South)*	Volume *(veh/hour)*	Existing Number of Lanes	Existing Storage *(lane feet)*	Lanes Proposed in SHOPP Project	VicDOT Number of Lanes	VicDOT Storage *(lane feet)*	Average Cycle Time *(seconds)*	Volume *(veh/hour)*	Proposed Number of Lanes	Proposed Storage *(lane feet)*	Proposed Cycle Time *(seconds)*	Cost Estimate *(Civil)*	Cost Estimate *(ITS)*	Total Estimated Cost	Drawing Number
Marina Vista Avenue / Waterfront Road	580	1	1,250	2	2	1,079	12.8	580	2	2,550	12.5	$4,130,000	$462,000	$4,592,000	*L-49*
Pacheco Boulevard	850	1	1,170	2	2	1,581	8.5	850	2	2,400	8.5	$2,490,000	$462,000	$2,952,000	*L-47, L-48*
SR-4	2,320	1	4,667	2	4	4,315	6.2	2,320	4	4,600	**6.2**	$9,660,000	$500,000	$10,160,000	*L-45, L-46*
Contra Costa Boulevard	730	1	312	2	2	1,356	9.9	730	2	1,450	9.9	$4,520,000	$462,000	$4,982,000	*L-40*
Concord Avenue / Chilpancingo Pwy	360	1	514	2	1	670	10.2	360	1	660	10.2	$1,260,000	$417,000	$1,677,000	*L-39 L-40*
Willow Pass Road / Sunvalley Boulevard Loop Ramp	500	1	543	2	2	932	14.4	500	2	1,350	14.4	$4,180,000	$462,000	$4,642,000	*L-37*
Willow Pass Road / Sunvalley Boulevard Directional Ramp	620	1	715	4	2	1,152	11.7	620	2	1,600	11.7	$3,120,000	$462,000	$3,582,000	*L-37*
SR-242	3,640	2	NA	NA	NA	NA	NA	3,640	NA	NA	NA	$0	*$0*	$0	*none*
Monument Boulevard	870	1	835	2	2	1,618	8.3	870	2	1,700	8.3	$1,970,000	$462,000	$2,432,000	*L-35*
Boyd Road / Contra Costa Boulevard	820	1	608	2	2	1,526	8.8	820	2	**1,300**	8.8	$2,710,000	$462,000	$3,172,000	*L-34*
North Main Street / Sunnyvale Avenue / Truck Scale	1,020	1	152	2	3	1,898	5.0	1,020	**1**	**152**	**NA**	$0	$417,000	$417,000	*none*
Geary Road / Treat Boulevard	270	1	296	2	1	502	13.8	270	1	550	13.8	$2,980,000	$417,000	$3,397,000	*L-31*
San Luis Road / North Main Street	1,060	2	1,300	2	3	1,972	10.2	1,060	3	2,100	10.2	$5,740,000	$481,000	$6,221,000	L-29
Hillside Avneue / Ygnacio Valley Road	1,350	1	1,332	2	3	2,510	5.0	1,350	**2**	**1,450**	**NA**	$0	$462,000	$462,000	*L-28*
Hillside Avenue to SR-24 Connector	NA	1	225	NA	NA	NA	NA	NA	1	850	NA	$0	$417,000	$417,000	*L-28*
								Totals				***$42,760,000***	***$6,345,000***	***$49,105,000***	

Proposed number of lanes shown in **ORANGE** to not meet the VicDOT recommended number.
Proposed vehicle storage numbers shown in **ORANGE** do not meet the VicDOT recommended amount.
Proposaed cycle time numbers shown in **ORANGE** would only be appropriate when the mainline analysis indicates ramp demands are accommodated with spare capacity for several downstream interchanges.

As shown in Table 5-3, there is a vehicle storage deficit of 226 linear feet equating to approximately eight vehicles at Boyd Road / Contra Costa Boulevard interchange, located two interchanges downstream of SR 242. More importantly, the following interchange at North Main Street / Sunnyvale Avenue / Truck Scale is extremely constrained. The VicDOT guidance calls for three lanes, but any widening in this location would require the acquisition of a shopping center. Therefore, it will only be possible to provide one lane with 152 linear feet of storage at this interchange, creating a deficit of 1,746 linear feet. As a result; the CARM system would need to allow an additional 65 vehicles to access the mainline during the peak hour. It is expected that volumes would be too high to meter effectively at other times of the day. Nonetheless, CARM equipment would be installed to manage traffic flows at the interchange when demand allows.

The VicDOT guidance also calls for three lanes at Hillside Avenue / Ygnacio Valley Road, which is located three interchanges south of North Main Street and is the southernmost access point in the segment. The two-lane interchange is constrained by adjacent highway structures and cannot be widened. It is anticipated that a cycle time in the vicinity of 5 seconds would be necessary to avoid congestion extending onto adjacent arterial streets. This could be accommodated if the CARM system were extended to the south and the downstream access points were to have spare capacity.

The cost of implementing CARM on this segment of I-680 is estimated at $49.1 million, which includes $42.8 million in civil costs and $6.3 million in ITS installations. Civil costs would range from a low of $1.26 million at Concord Avenue / Chilpancingo Parkway and a high of $9.66 million at SR-4 (although the improvements at SR-4 are expected to be completed as part of the I-680/SR-4 Interchange Project). Civil costs are estimated to exceed $1.0 million at all interchanges.

5.4 I-680 Southbound South of SR-24

Table 5-1 summarizes the proposed modifications at the 12 interchanges on I-680 southbound south of SR-24 to enable CARM operations. As shown in Table 5.-4, CCTA will be able to provide the recommended number of lanes at all interchanges in this segment, with the exception of Crow Canyon Road, which will have three lanes rather than the recommended four. The interchange is expected to function adequately assuming that traffic volumes remain relatively stable. However, if demand grows in the future, the interchange could become constrained at times. One interchange to the south, the reconfigured Bollinger Canyon Road ramps will provide the recommended amount of vehicle storage. However, the Bollinger Canyon direct ramp will have a slight deficit of 42 linear feet of storage. This is not expected to have a major effect on operations. All other interchanges will have excess storage capacity. Therefore, they should be able to compensate for vehicles accessing the mainline in shorter cycle times at Hillside Avenue, as discussed above in Section 5.3.

As shown in Table 5-4, the estimated cost of implementing CARM on I-680 southbound south of SR-24 is $36.2 million. This includes $30.6 million in civil costs and close to $5.7 million in ITS installations. Notably there are four interchanges that will not require any additional ramp capacity, including South Main Street and Rudgear Road / Danville

Boulevard, which were both widened to two lanes in 2021. Civil costs at the remaining interchanges range from a low of $600,000 at El Cerro to a high of $10.0 million at Bollinger Canyon Road. The Alcosta / San Ramone Valley interchange has an estimated civil cost of $8.4 million, while civil costs will total $5.6 million at Crow Canyon Road. Civil costs estimates at the remaining interchanges are between $1.1 and 3.4 million.

Table 5-4 Proposed Improvements – I-680 Southbound, South of SR-24

On Ramp Location *(North to South)*	Volume *(veh/hour)*	Existing Number of Lanes	Existing Storage *(lane feet)*	Lanes Proposed in SHOPP Project	VicDOT Number of Lanes	VicDOT Required Storage *(lane feet)*	Average Cycle Time *(seconds)*	Volume *(veh/hour)*	Proposed Number of Lanes	Proposed Storage *(lane feet)*	Proposed Cycle Time *(seconds)*	Cost Estimate *(Civil)*	Cost Estimate *(ITS)*	Total Estimated Cost	Drawing Number
SR-24	1,563	2	7,440	3	3	2,943	6.9	1,563	4	10,400	9.2	$2,020,000	$500,000	$2,520,000	*L-27*
Olympic Boulevard	530	2	2,630	2	2	987	13.7	530	2	2,800	13.7	$0	$462,000	$462,000	*none*
South Main Street	280	2	1,680	2	1	558	13.2	280	2	1,400	13.2	$0	$462,000	$462,000	*L-24, L-24*
Rudgear Road / Danville Boulevard	796	2	1,255	2	2	1,490	9.1	796	2	1,900	9.1	$0	$462,000	$462,000	*L-22, L-23*
Livorna Road	581	1	780	2	2	1,115	12.5	581	2	1,700	12.5	$1,150,000	$462,000	$1,612,000	*L-21*
Stone Valley Road	826	1	780	2	2	1,545	8.7	826	2	1,800	8.7	$1,900,000	$462,000	$2,362,000	*L-19*
El Cerro Boulevard	590	2	730	2	2	1,115	12.2	590	2	1,150	12.2	$600,000	$462,000	$1,062,000	*L-16*
Diablo Road	763	1	670	2	2	1,451	9.4	763	2	1,700	9.5	$3,400,000	$462,000	$3,862,000	*L-13*
Sycamore Valley Road	753	2	980	2	2	1,413	9.6	753	2	1,520	9.6	$1,580,000	$462,000	$2,042,000	*L-12*
Crow Canyon Road Loop Ramp	833	1	1,220	2	2	1,551	8.7	833	1	2,150	7.1	$5,600,000	$481,000	$6,081,000	*L-10*
Crow Canyon Road Direct Ramp	683	1	830	2	2	1,299	10.6	683	2	2,300	7.1	*See above*	*See above*	*See above*	*L-9, L-10*
Bollinger Canyon Road Loop Ramp	1,371	1	510	2	2	1,703	7.9	1,371	2	1,800	7.5	$14,300,000	$500,000	$14,800,000	*L-5, L-6*
Bollinger Canyon Road Direct Ramp	560	1	400	2	2	1,042	14.2	560	2	1,000	7.5	*See above*	*See above*	*See above*	*L-5, L-6*
Alcosta / San Ramone Valley	1,660	3	1,560	3	4	4,113	8.7	1,660	4	7,270	8.7	*See Bollinger*	$500,000	$500,000	*L1, L2*
								Totals				***$30,550,000***	***$5,677,000***	***$36,227,000***	

Proposed number of lanes shown in **ORANGE** to not meet the VicDOT recommended number.
Proposed vehicle storage numbers shown in **ORANGE** do not meet the VicDOT recommended amount.

5.5 Estimated Cost

As shown in Table 5-5, the cost of implementing CARM along I-680 in Contra Costa County varies substantially between the different analysis segments. Implementing CARM on I-680 northbound south of SR-24 has an estimated capital cost of $15.3 million for interchange improvements, which is the lowest of the four segments, with an average per interchange cost of $1.9 million. CCTA will also install 53 TIRTL devices on I-680 northbound south of SR-24 at a cost of $7.8 million, as well as a $3.1 million dynamic message sign pilot at 16 locations on parallel routes to the I-680 Corridor for a total CARM implementation cost of $31.8 million.

Table 5-5 Capital Costs for CARM on I-680 in Contra Costa County

I-680 Segment	Number of Interchanges with CARM Operations	Cost Estimate *(Civil)*	Cost Estimate *(ITS Interchanges)*	Interchanges *(Civil and ITS)*	Average Interchnage Cost	Mainline Detection Costs	Arterial DMS Cost	Total CARM Implementation Cost
NB South of SR-24	11	$15,380,000	$5,524,000	$20,904,000	$1,900,000	$7,800,000	$3,100,000	$31,804,000
NB North of SR-24	10	$56,920,000	$4,644,000	$61,564,000	$6,157,000	$5,700,000	$0	$67,264,000
SB North of SR-24	12	$42,760,000	$6,345,000	$49,105,000	$4,092,000	$5,900,000	$0	$55,005,000
SB South of SR-24	12	$30,550,000	$5,677,000	$36,227,000	$3,019,000	$7,000,000	$0	$43,227,000
Totals / Average	***45***	***$145,610,000***	***$22,190,000***	***$167,800,000***	***$3,867,000***	***$26,400,000***	***$3,100,000***	***$197,300,000***

The cost of implementing CARM on 10 interchanges on I-680 northbound north of SR-24 is nearly $67.3 million, or $6.2 million per interchange. This is more than twice the cost of the northbound interchanges to the south of SR-24. This reflects the complex nature of I-680 north of SR-24, the fact that interchanges are spaced more frequently, and the denser development patterns found in this portion of the alignment. With a cost of $24.3 million, reconfiguring the Buskirk Avenue / Treat Boulevard interchange for CARM operations would be more expensive than all civil work proposed on the entire length of I-680 northbound south of SR-24. Mainline detection will require 39 TIRTL devices and related equipment at a cost of $5.7 million, bringing the total CARM implementation cost to $67.3 million.

The cost of implementing CARM on the 12 interchanges on I-680 southbound north of SR-24 is $49.1 million, with an average implantation cost of $4.1 million per interchange. This cost would be greater if widening the North Main Street / Sunnyvale Avenue / Truck Scale interchange were feasible. However, this would require the acquisition of a shopping center. Similarly, no civil works are proposed at Hillside Avenue due to adjacent highway structures. A total of 40 TIRTL devices will be required for mainline detection at a cost of $5.9 million, resulting in a total CARM implementation cost of $55.0 million.

The cost of implementing CARM on the 12 interchanges on I-680 southbound south of SR-24 is $36.2 million, with an average cost of $3.0 million. These lower costs reflect the fact that additional capacity is not necessary at four of the interchanges in this segment, including two that were widened in 2021. 48 TIRTL detection devices will be required on this segment at a cost of $7.0 million, bringing the total CARM implementation cost to $43.2 million.

5.6 Anticipated Performance

Table 5-6 identifies the instances in which individual interchanges in the four analysis segments are not anticipated to meet the recommended VicDOT CARM performance standards for lane requirements, storage requirements, or cycle times. While these situations may be mitigated to a certain extent by excess capacity at other nearby interchanges, they are indicative of the anticipated performance of the CARM system in the four analysis segments. Each metric has a distinct effect on the ability of the CARM system to manage congestion.

- ***Lane Requirements***: As traffic volumes increase at interchanges equipped with CARM, additional storage capacity is needed. In addition, as volumes approach certain thresholds, additional lanes are also needed at the stop bar to provide the CARM system with the flexibility to respond to changes in real time traffic conditions. As highway facilities become more congested, groups of vehicles often encounter constraints to free-speed travel that create vehicle platoons. While there are clusters of congestion, they are often interspersed with less constrained areas. The CARM system detects these patterns and feeds vehicles onto the mainline more rapidly when it detects less congested pockets. However, in order to do so, the system needs to have an adequate number of lanes at the stop bar. If it does not, the system will not be able to utilize all capacity on the mainline.

- ***Storage Requirements***: When equipped with CARM, interchanges must have the capacity to store vehicles while they queue and wait to be allowed onto the mainline. If there is not enough storage on a ramp, traffic waiting to enter the mainline can back up onto the arterial street network and cause congestion in local communities. In order to avoid this, the CARM system must allow vehicles to enter the mainline more quickly than is desirable. This can exacerbate congestion on the mainline, but such conditions can also be mitigated if downstream interchanges have the capacity to hold vehicles slightly longer to balance and stabilize traffic flows.

- ***Cycle Times***: If the number of lanes or the amount of storage at an interchange equipped with CARM become constrained due to high traffic volumes, then the system will reduce the cycle time between green signals and allow traffic on to the mainline more quickly. Assuming a four-minute storage standard, cycle times become suboptimal at approximately 7.2 seconds or lower for one- or two-lane interchanges. Three- or four-lane interchanges begin to over burden the mainline when cycle time fall below 6.4 seconds.

Table 5-6 Potential Performance Constraints

I-680 Segment	Interchanges Not Meeting VicDOT Lane Requirements	Interchanges Not Meeting VicDOT Storage Requirements	Interchanges Not Meeting VicDOT Cycle Times
NB South of SR-24	1	3	1
NB North of SR-24	2	5	2
SB North of SR-24	2	3	2
SB South of SR-24	1	1	0

As shown in Table 5-6, among the four analysis segments, ***I-680 southbound south of SR-24*** has the fewest performance constraints and would be likely to result in the strongest operational performance. This segment has one interchange where it does not provide the recommended number of lanes and one instance where there is a 40 linear foot shortfall in vehicle shortfall. However, as described in Section 5.4, the constraints are minor and as a result cycle times do not fall below the desired thresholds and the CARM should be able to manage flows on the mainline while avoiding congestion on local streets.

I-680 northbound south of SR-24 is anticipated to have the next strongest performance of the analysis segments. As discussed in Section 5.1, it has three interchanges with capacity shortfalls and one interchange where three lanes are provided rather than the recommended four. This results in a suboptimal cycle time of 5.8 seconds. This will be further complicated by the fact that the interchange immediately downstream has a storage shortfall of approximately 1,000 feet.

The two segments north of SR-24 are expected to have poorer operational performance due to the more dense and complex development patterns in this area. As discussed in Section 5.2, ***I-680 northbound north of SR-24*** has two interchanges where the optimal number of lanes cannot be provided. In addition, neither of these interchanges has adequate ramp capacity, with significant shortfalls of 500 and 1,100 linear feet. This will result in cycle time of less than 6 seconds during peak periods. These constraints are complicated by storage shortfalls at three additional interchanges, two of which are immediately upstream of the ramps with lane constraints.

As described in Section 5.3, it will not be possible to meter the interchange with the highest peak hour volumes on ***I-680 southbound north of SR 24*** due to safety reasons. In addition, it will not be possible to widen two interchanges due to constraints posed by existing structure. Peak hour traffic volumes are high enough that the VicDOT guidance has no cycle times for these conditions. In addition, the interchange immediately upstream of the first constrained ramp has a storage shortfall of over 200 linear feet.

5.6.1 Next Steps

The information in this Evaluation Report is intended to facilitate several discussions and decisions that will allow CCTA to plot a path forward and advance the implementation of CARM in the I-680 corridor.

CCTA has determined to commence the implementation of CARM in the corridor on I-680 northbound south of SR-24 (now being referred to as Segment 1). The California Transportation Commission has made $25 million in STIP funding available for the project and CCTA is preparing a PA/ED to gain the necessary approvals to implement the project. At the same time, Caltrans is advancing its SHOPP project to implement standard ramp metering improvements at various ramps along the full length of I-680 in Contra Costa County. Both projects are going through separate environmental approvals processes, but it is anticipated that the two projects will be implemented under a combined construction contract.

Therefore, as these two analyses are underway, Caltrans and CCTA will need to coordinate closely to ensure that the design of the SHOPP project will be consistent with the requirements for CARM operation. While more refined CARM design and cost information will be development for Segment 1 (I-680 northbound south of SR-24) as part of the ongoing PA/ED process, the Evaluation Report provides important information on the anticipated CARM requirements in all four operational segments and should be particularly helpful in informing further discussions on the two southbound segments and on I-680 northbound north of SR-24.

There are several next steps for CCTA and Caltrans as plans for CARM in the I-680 corridor advance. They include:

- Reviewing the recommended designs and investments identified in the Evaluation Report
- Comparing the civil ramp capacity enhancements required for CARM operations to those proposed for the Caltrans SHOPP ramp metering project
- Reviewing and gaining concurrence on the feasibility of civil improvements on ramps with site constraints
- Consider possible modifications to the Caltrans SHOPP ramp metering project to align with the requirements for CARM operations
- Reviewing and gaining concurrence on the operational parameters for CARM implementation, including the need to allow GP traffic in all ramp lanes
- Refining these recommendations and gaining concurrence on civil design elements at all interchanges
- Reviewing and gaining concurrence on phasing of the different elements of both the CARM and SHOPP projects
- Reviewing the costs of the improvements and gaining concurrence on how they will be shared between Caltrans and CCTA

Appendix A. Freeway Mainline Maximum Sustainable Flow Rates

The sixth edition of the Transportation Research Board's *Highway Capacity Manual (HCM 6)*[3] defines capacity of highway segments as "the maximum sustainable hourly flow rate at which persons or vehicles reasonably can be expected to traverse a point or a uniform section of a lane or roadway during a given time period under prevailing roadway, environmental, traffic, and control conditions." *HCM 6* further defines service flow rate as "the maximum direct rate of flow that can be sustained in a given segment under prevailing roadway, traffic, and control conditions without violating the criteria for a given [level of service] LOS." *HCM 6* subsequently establishes maximum service flow rates for target LOS as a basis for planning, designing and evaluating highway segments, and presents HCM-based tools for conducting operations-level analysis. However, *HCM 6* acknowledges the limitations of these methods, indicating that "alternative applications may be appropriate for evaluating [Active Travel and Demand Management] ATDM measures requiring finer temporal sensitivity to dynamic changes in the system than can be provided by typical 15-min[ute] HCM analysis period. This may occur in evaluating traffic-responsive signal timing, traffic adaptive control, dynamic ramp metering, dynamic congestion pricing, or strategies affecting the prevalence or duration of incidents with less than 10 min[ute] durations."

Recognizing the limitations of HCM methods, VicDOT developed a methodology for determining maximum sustainable flow rate (MSFR) of freeway segments as a basis for planning and designing managed freeways. VicDOT's method for determining and applying MSFR is presented in their *Managed Motorway Design Guide*, Volume 1, Part 3[4]. According to VicDOT's guidance, MSFR represents the maximum flow rate a freeway facility or segment can sustain while avoiding traffic flow breakdown. This measure provides a basis for planning and designing managed freeways to achieve maximum reliability and optimal productivity.

MSFR values are based on measured flow rates representing a 1% probability of traffic flow breakdown per 15-minutes, and are adjusted recognizing a range of static and dynamic factors that cause spatial and temporal fluctuations in sustainable flows. These factors include vertical grade, horizontal curvature, the prevalence of heavy vehicle, changes in lane count or geometry, such as lane additions or reductions as well as areas with heavy weaving volumes, managed lanes, and the level at which the traffic flow is managed.

As shown in Tables A.1 through A.3, the WSP team has developed a series of adjustment factors based on VicDOT's guidance and adapted for the evaluation of MSFR on I-680 corridor.

[3] National Research Council, Transportation Research Board. *Highway Capacity Manual, Sixth Edition: A Guide for Multimodal Mobility Analysis*. Transportation Research Board, Washington, D.C., 2016.
[4] Victoria State Government, Department of Transport, VicDOT. *Managed Motorway Design Guide* Volume 1: Role, Traffic Theory & Science for Optimization Part 3: Motorway Capacity Guide. VicDOT, Melbourne, VIC., Australia, June 2019.

Table A.1 Maximum Sustainable Flow Rate Adjustment Factors

Variable		Value	Notes
Base Capacity		2,087.5 vphpl	This is the recommended maximum flow rate based on VicDOT's research
Adjustment Factors ($\leq 100\%$)	Number of Lanes (Excluding Aux. Lane)	Varies (See Table A.2)	More lanes results in an increase in friction amongst the lanes due to the effects of lane changing and therefore results in a reduction in flow rate
	Grade (%)		Large uphill and downhill grades affect vehicle performance leading to reductions in flow rate
	Heavy Vehicle (%)		High percentages of heavy vehicles results in reductions in flow rate
	Mid-block Lane Drop	90%	A mid-block lane drop results in an unmanaged merge that reduces flow rate
	Heavy Weaving	90%	This factor is applied to segments that experience heavy weaving (weaving in excess of a single lanes flow rate) to account for the additional friction that impacts flow rates; in this study corridor the segment between the Creekside Dr off-ramp and CA-24 off-ramp
	Exclusive Exit Lane (EEL)	Capacity for EEL is the exit volume	An EEL is usually not utilized to the level of a full lane and therefore flow rate is reduced to account for the reduced utilization
	Auxiliary Lane	30%	An auxiliary lane is usually not utilized to the level of a full lane and therefore flow rate is reduced to account for the reduced utilization.
	Partly Managed Transition Zone	Varies (See Table A.3)	It takes multiple managed on-ramps to transition from unmanaged segment to fully managed segment and therefore flow rate reductions account for this transition
	Managed Lane (ML)	100% - [5% + 20%/N] N = Number of mainline lanes	The reduction in flow rate associated with managed lanes is calculated in 2 parts; a 5% reduction in flow rate to account for the effects of weaving in and out of the ML; and a 20% reduction for each managed lane to account for the lower utilization of the lanes

Table A.2 Adjustment Factors for Lanes, Grades (%), and Heavy Vehicle (%)

Number of Lanes[1]	Grade (%)	Heavy Vehicle (%)						
		0	5	10	15	20	25	30
2	<2	100.0%	95.2%	91.0%	86.8%	83.2%	79.6%	76.6%
3	<2	96.6%	92.2%	88.2%	83.8%	80.6%	77.4%	73.9%
4	<2	93.4%	89.2%	85.3%	81.1%	77.8%	74.6%	71.6%
5	<2	88.9%	85.0%	81.2%	77.1%	74.3%	72.1%	68.0%
6	<2	82.6%	79.4%	76.0%	72.9%	69.5%	66.3%	62.6%
2	2-3	94.6%	90.4%	86.8%	82.6%	79.0%	76.0%	72.5%
3	2-3	91.8%	87.8%	83.8%	79.8%	76.6%	73.5%	70.3%
4	2-3	88.6%	84.7%	80.8%	76.9%	74.0%	71.0%	68.0%
5	2-3	84.3%	80.7%	77.1%	73.3%	70.4%	67.5%	64.7%
2	3-4	89.8%	86.2%	82.0%	77.8%	74.9%	71.9%	68.9%
3	3-4	87.0%	83.0%	79.4%	75.4%	72.7%	69.5%	66.7%
4	3-4	84.1%	80.2%	76.6%	73.1%	70.1%	67.1%	64.4%
5	3-4	80.0%	76.4%	73.1%	69.5%	66.8%	64.0%	61.1%
2	4-5	82.6%	79.0%	75.4%	71.9%	69.5%	66.5%	63.5%
3	4-5	80.2%	76.6%	73.1%	69.9%	67.1%	64.3%	61.5%
4	4-5	77.5%	74.0%	70.7%	67.4%	64.7%	62.0%	59.3%
5	4-5	73.8%	70.4%	67.3%	64.2%	61.6%	58.9%	56.3%

[1] The VicDOT published table includes mainline segments up to 5 through lanes. For a 6-lane segment with flat terrain, the adjustment values shown were added based on an extrapolation of the trend for other data points.

Table A.3 Adjustment Factors for Partly Managed Transition Zone

Segment Since First Managed On-Ramp	Number of Mainline Lanes			
	2	3	4	5
0	85.0%	85.0%	85.0%	85.0%
1	90.0%	90.0%	90.0%	90.0%
2	92.0%	92.0%	91.4%	91.1%
3	94.0%	94.0%	92.8%	92.2%
4	96.0%	96.0%	94.3%	93.3%
5	98.0%	98.0%	95.7%	94.4%
6	100.0%	100.0%	97.2%	95.6%
7	100.0%	100.0%	98.6%	96.7%
8	100.0%	100.0%	100.0%	97.8%
9	100.0%	100.0%	100.0%	98.9%
>9	100.0%	100.0%	100.0%	100.0%

It should be noted that adjustment factors for auxiliary lanes and managed lanes were modified for the purposes of the I-680 study corridor evaluation. VicDOT's guidance reflects no additional capacity for auxiliary lanes. However, a review of I-680 Performance Measurement System (PeMS) data indicates that auxiliary lane volumes are approximately 40% to 80% those on adjacent general-purpose lanes. This finding is consistent with published guidance, including *HCM 6*, which states: "the capacity of an auxiliary lane is assumed…to be the same as that of a regular lane; however, utilization of the auxiliary lane may be lower than that of a through lane…[therefore, the HCM] assumes that the capacity of an auxiliary shoulder lane is one-half that of a normal freeway through lane." More detailed research on the capacity of auxiliary lanes was completed by the University of Florida and published in a report titled *Investigation of Freeway Capacity: a) Effect of Auxiliary Lanes on Freeway Segment Volume Throughput* [5]. The study reports that auxiliary lanes result in increased segment volumes, with specific rates presented as shown in Table A.4.

Table A.4 Average Percentage Increase in Volume by Adding an Auxiliary Lane

Number of through lanes	Percentage increase in volume
2	48.87%
3	32.03%
4	23.81%
5	18.71%

Table source: University of Florida *Investigation of Freeway Capacity (March 2010)*

Although the findings presented by the University of Florida study do not specifically correlate the increased volumes in freeway segments with auxiliary lanes to the capacity of auxiliary lanes, they do indicate that auxiliary lanes consistently accommodate a substantial increase in volumes which infers that meaningful additional capacity is being provided. Based on the findings of University of Florida research, HCM 6 and field observations in the I-680 corridor, the MSFR was adjusted to reflect the additional capacity provided by the inclusion of auxiliary lanes. For the purposes of the I-680 corridor evaluation, the capacity of the auxiliary lane was conservatively assumed to be 30% of the capacity of adjacent general-purpose lanes.

Similarly, the MSFR for I-680 was determined using adjustment factors for managed lanes capacity that differed from those values proposed by VicDOT. For managed lanes segments, it was assumed the overall MSFR is reduced by an additional 5% due to the added effects of weaving to ingress and egress the managed lane, with the 5% rate being half the adjustment for other heavy weaving segments. Additionally, the MSFR of the managed lane specifically is reduced by 20% to reflect the lower average flow rates observed in the managed lanes compared to adjacent general-purpose lanes. These lower flow rates were confirmed by a review of PeMS data and are consistent with the primary managed lanes objective to achieve higher operating speeds by managing demand.

Using these adjustment factors, the WSP study team developed a spreadsheet model to facilitate the determination of MSFR for segments of the I-680 study corridor. The calculated MSFR values allow for an assessment of the ability of the freeway mainline to accommodate existing traffic flows. The calculated MSFR values are also used as inputs to the R-Model analysis to help determine the optimal metering rates and required storage space at each on-ramp location in the I-680 study area.

A.1 Maximum Sustainable Flow Rates for Northbound I-680 (South of SR-24)

A comparison of the calculated MSFR for the mainline segments on northbound I-680 and the existing peak-hour traffic flows (volumes) observed in the corridor based on balanced

[5] University of Florida, Transportation Research Center, Department of Civil and Coastal Engineering. *Investigation of Freeway Capacity: a) Effect of Auxiliary Lanes on Freeway Segment Volume Throughput, and b) Freeway Segment Capacity Estimation for Florida Freeways*. Transportation Research Center, University of Florida, Gainesville, FL., March 2010.

traffic counts collected during weekdays in November 2019 are summarized in Figure A.1 and Figure A.2. As shown in Figure A.1, 9 out of 28 northbound mainline segments identified to have existing traffic flows in excess of the calculated MSFR during the AM peak hour. As shown in Figure A.2, none of the study segments were found to have existing flows in excess of the MSFR during the PM peak hour.

Figure A.1 Northbound I-680 MSFR and AM Peak Hour Flow Under Existing Conditions

(balanced volumes for 7:00 AM to 8:00 AM weekdays in November 2019)

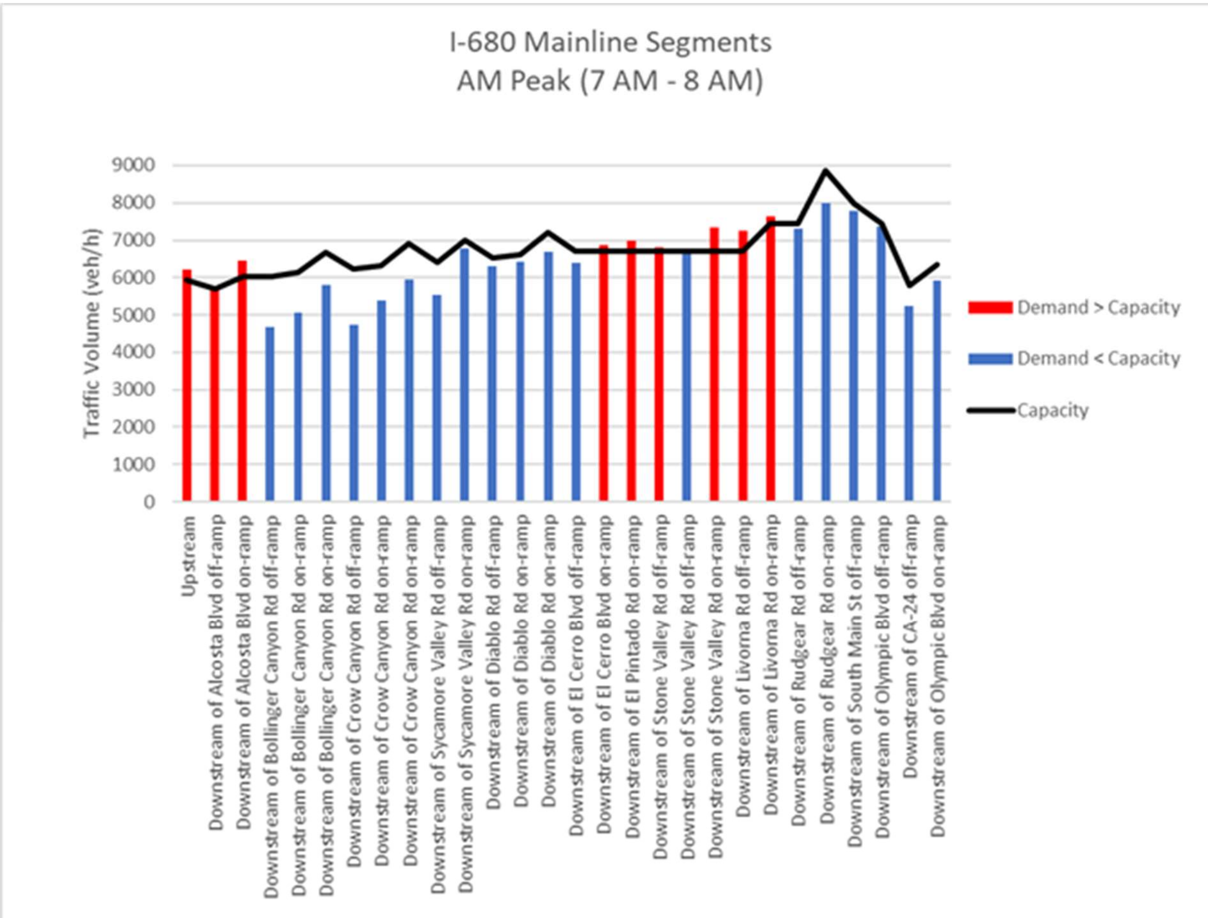
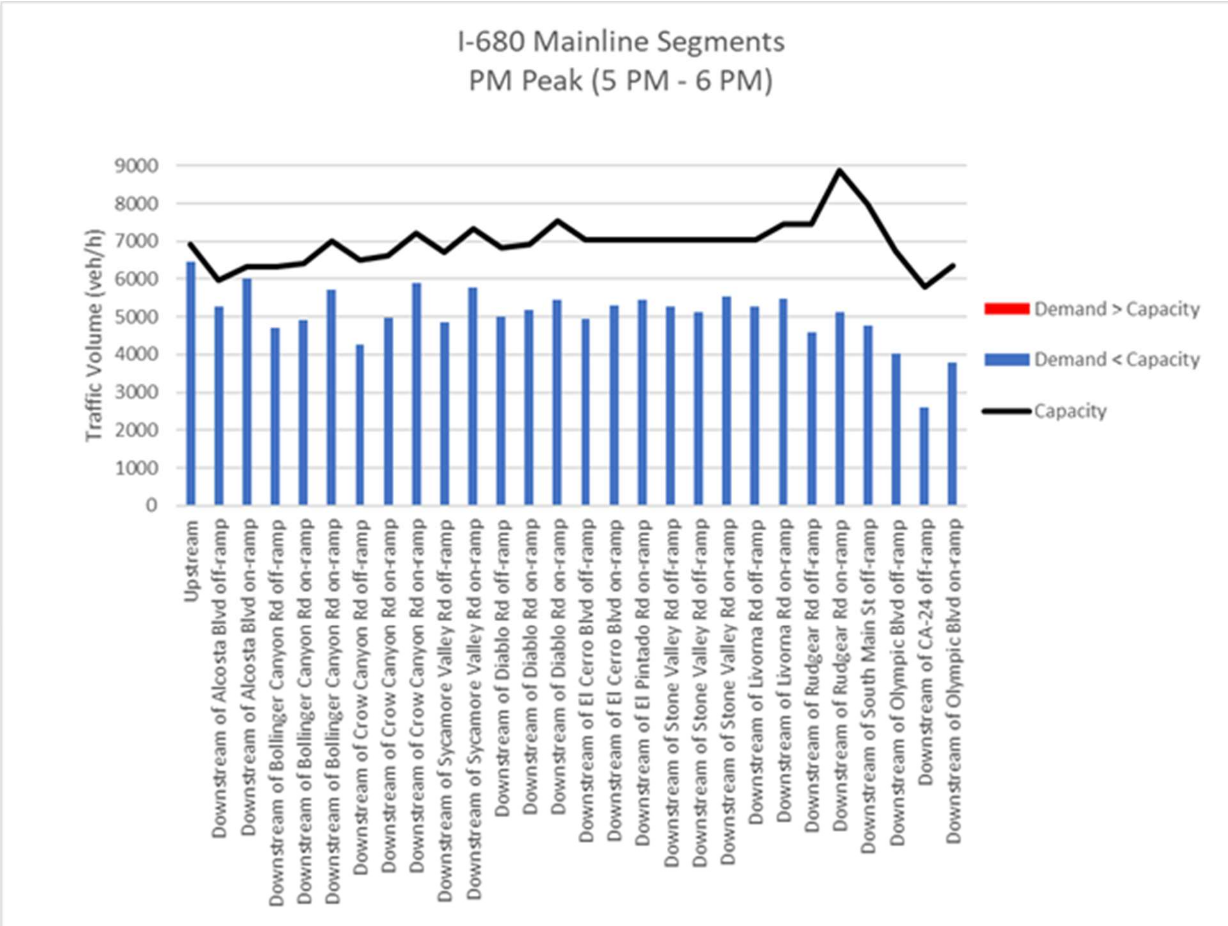


Figure A.2 Northbound I-680 MSFR and PM Peak Hour Flow Under Existing Conditions
(balanced volumes for 5:00 PM to 6:00 PM weekdays in November 2019)



The segments identified in Figure A.1 as having existing AM peak hour flows that exceed the MSFR confirm the findings provided in Chapter 3 on bottlenecks resulting in flow breakdown. These include the following segments:

- Alameda County line to the Bollinger Canyon Road off-ramp
- El Cerro Boulevard on-ramp to the Stone Valley Road off-ramp, and
- Stone Valley Road on-ramp to the Rudgear Road off-ramp.

The segment most severely exceeding the MSFR during the AM Peak hour is the segment downstream of the Stone Valley Road on-ramp, where observed flows are approximately 10% above the calculated MSFR.

A.2 Maximum Sustainable Flow Rates for Southbound I-680 (South of SR-24)

Two Scenarios, plus with ELs completed (Future Geometry)

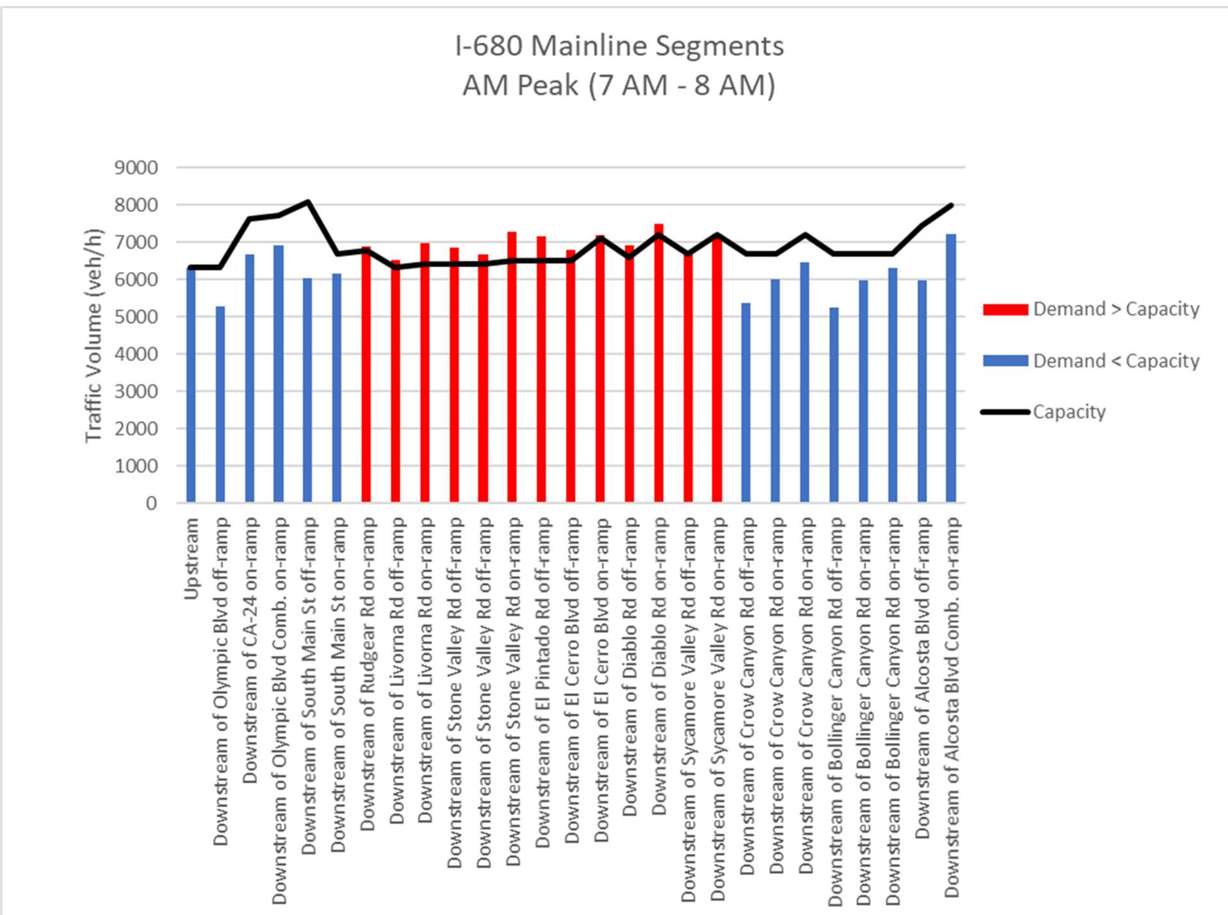
Two scenarios were evaluated for I-680 southbound to determine MSFR based on the existing lane configuration. The first assumes the CA-24 connector on-ramp would be metered as part of a CARM deployments, while the second assumes it would remain unmetered. Whether or not the CA-24 connector is metered will impact the MSFRs for many downstream mainline segments, as the location of the partly managed transition zone would shift (refer to Table A.3 for more information). Figures A.3 through A.6 compare calculated MSFR for the mainline segments and the existing peak-hour volumes in the corridor based on balanced traffic counts from November 2019.

A.2.1 Southbound I-680 Scenario 1 (CA-24 Connector Metered, South of SR-24)

As shown in Figure A.3, 13 out of 27 mainline segments are identified to have existing traffic flows in excess of the MSFR during the AM peak hour, assuming that the CA-24 connector ramp is metered, with significant excessive flow projected between the Livorna Rd and the Diablo Rd on-ramps.

Figure A.3 Southbound I-680 MSFR and AM Peak Hour Flow Under Existing Conditions with CA-24 Connector Metered

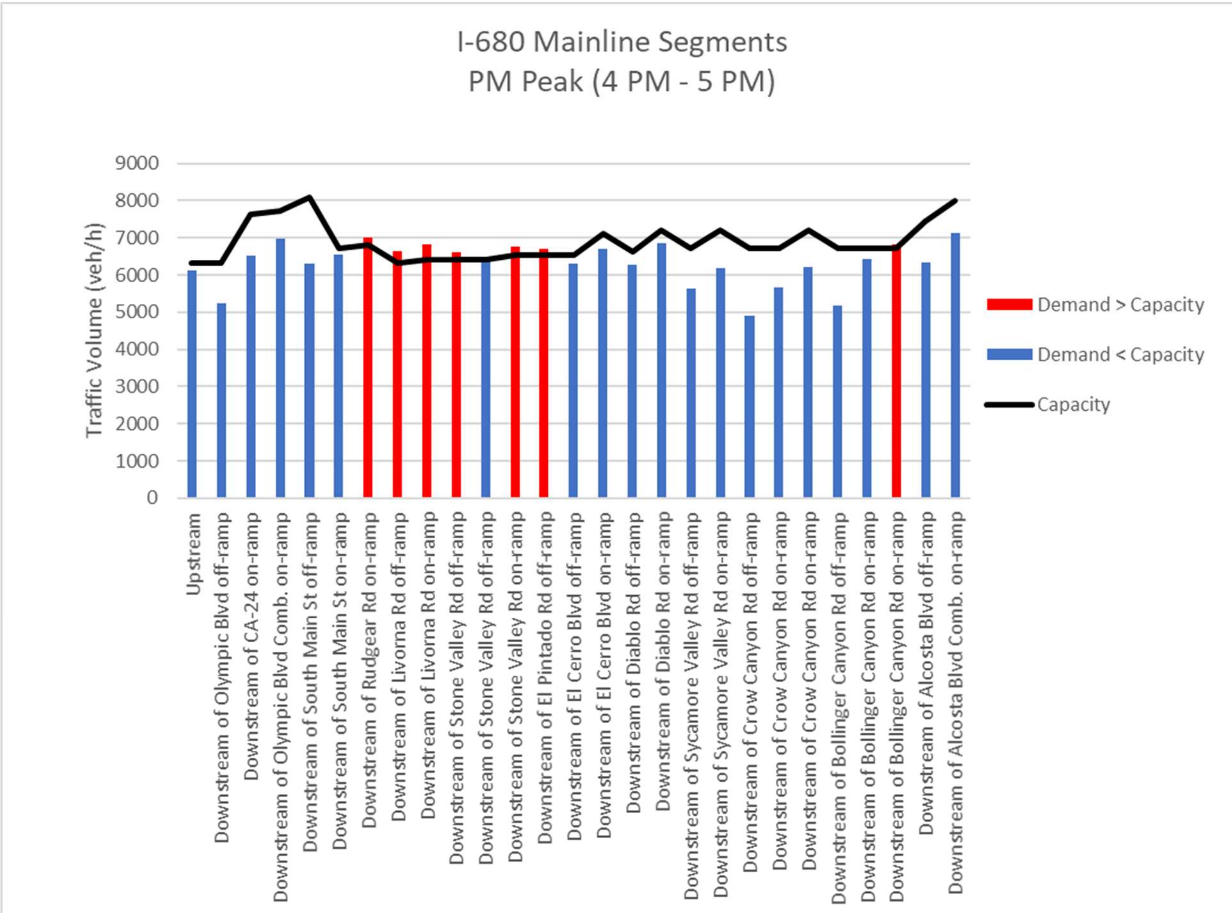
(balanced volumes for 7:00 AM to 8:00 AM weekdays in November 2019)



As shown in Figure A.4, seven southbound mainline segments are found to have existing flows in excess of the MSFR during the PM peak hour, with several additional segments at or near capacity.

Figure A.4 Southbound I-680 MSFR and PM Peak Hour Flow Under Existing Conditions with CA-24 Connector Metered

(balanced volumes for 4:00 PM to 5:00 PM weekdays in November 2019)

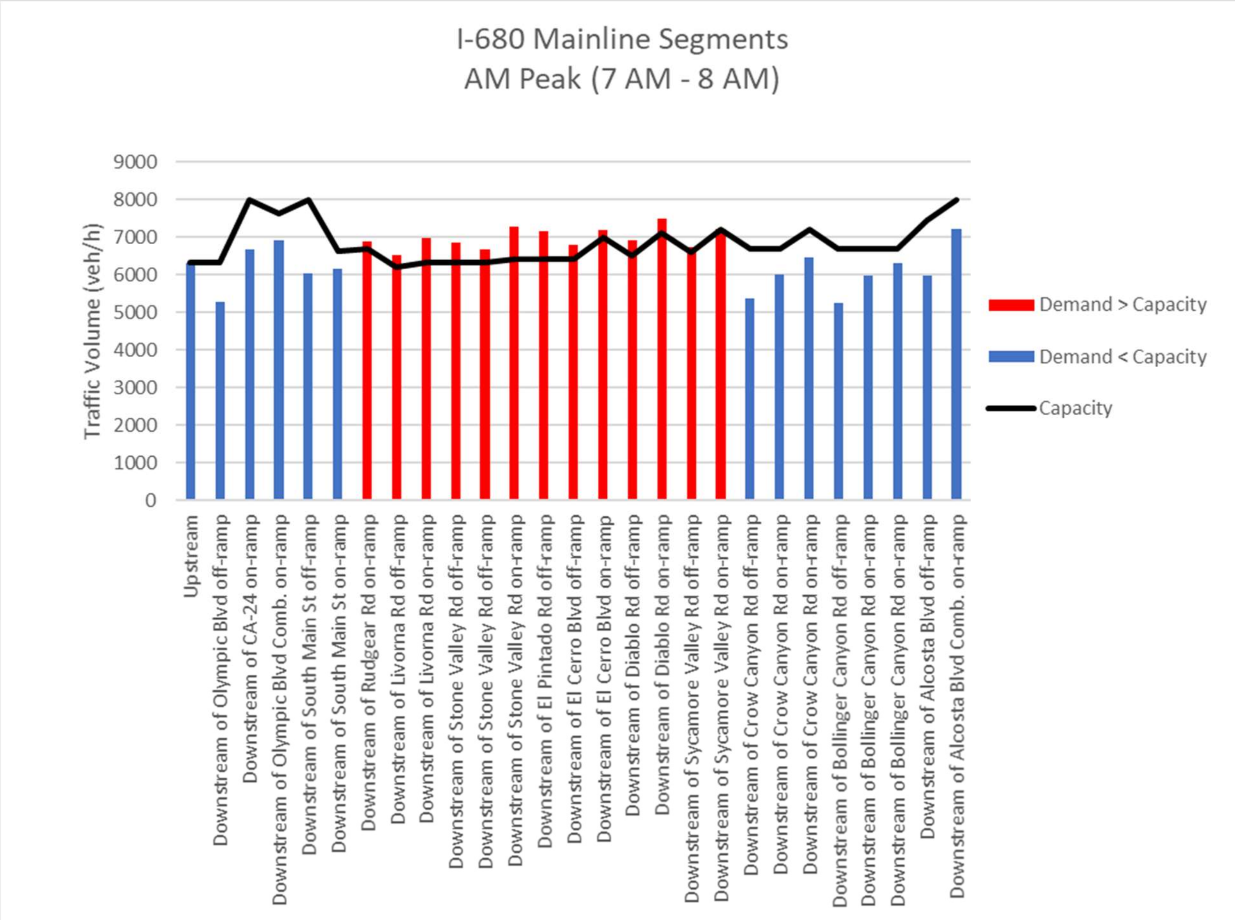


A.2.2 Southbound I-680 Scenario 1 (CA-24 Connector Not Metered, South of SR-24)

Without metering on the CA-24 connector, the MSFR values for most southbound mainline segments are calculated to be lower than with metering on the CA-24 connector. Intuitively, this makes sense because if flow from the CA-24 connector is not managed, it can create more potential for conflict and turbulence in the mainline traffic flow downstream of the convergence. As shown in Figure A.5, 13 mainline segments are identified to have existing traffic flows in excess of the MSFR during the AM peak without metering on the CA-24 connector. This is similar to the metered scenario shown in Figure A.3.

Figure A.5 Southbound I-680 MSFR and AM Peak Hour Flow Under Existing Conditions with CA-24 Connector Not Metered

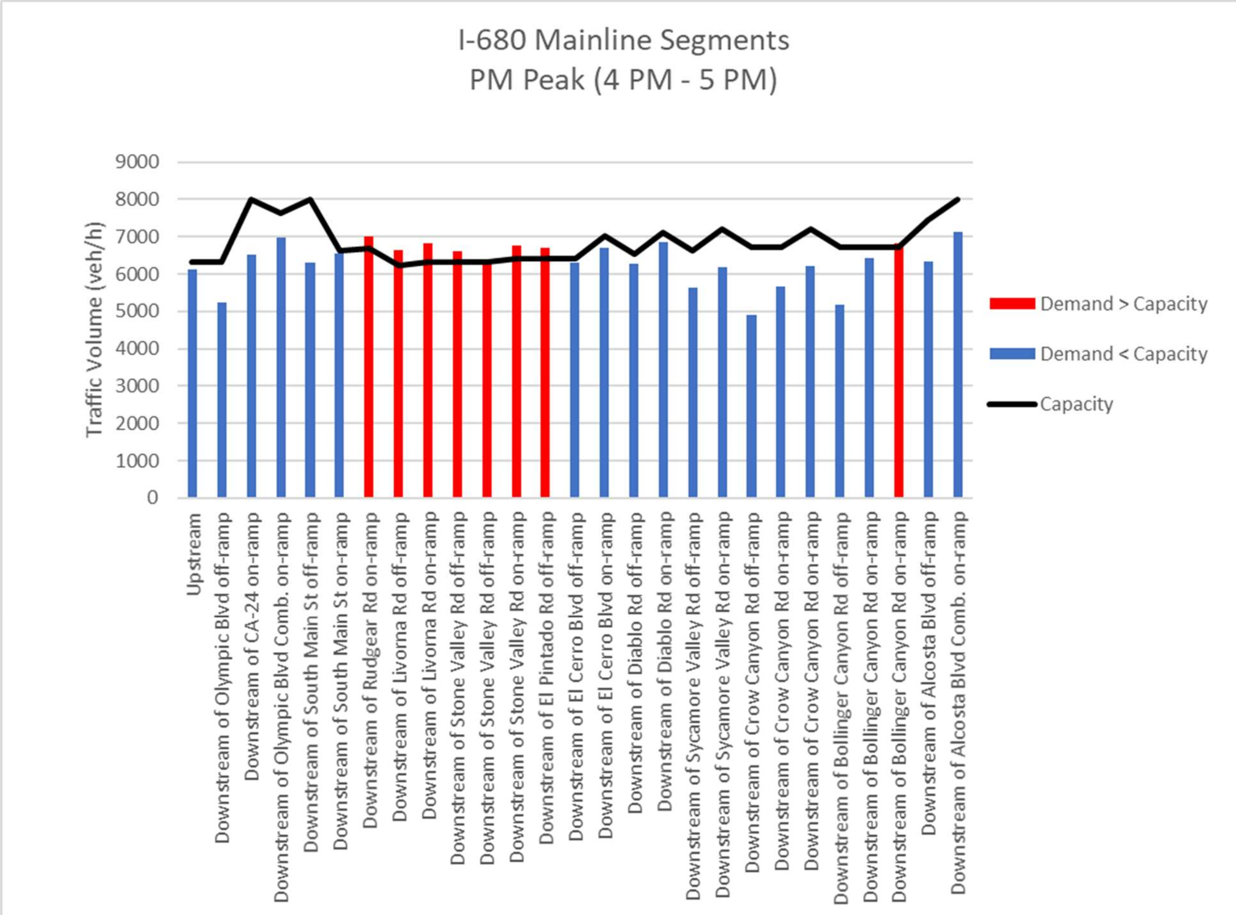
(balanced volumes for 7:00 AM to 8:00 AM weekdays in November 2019)



For the PM peak hour, as shown in Figure A.6, eight mainline segments are found to have existing flows in excess of the MSFR if the CA-24 connector remains unmetered. These segments include seven consecutive segments between the Rudgear Rd on-ramp and the El Cerro Blvd off-ramp, and the segment downstream of the Bollinger Canyon Rd on-ramp.

Figure A.6 Southbound I-680 MSFR and PM Peak Hour Flow Under Existing Conditions with CA-24 Connector Not Metered

(balanced volumes for 4:00 PM to 5:00 PM weekdays in November 2019)



Overall, the segments identified as having existing flows that exceed the MSFR confirm the findings of critical bottlenecks resulting in flow breakdown as discussed in Chapter 3. The one major disparity is the AM peak conditions between the Diablo Road and Sycamore Valley Road interchanges, where the INRIX data showed no congestion but the MSFR calculation suggested otherwise. One likely explanation is that the INRIX plot showed the "observed demand", where the traffic flows at Diablo Road and Sycamore Valley Road interchanges are constrained by the upstream bottlenecks. On the contrary, the MSFR plot focused on the "total demand" (observed plus unmet demand), which leads to higher mainline flow rates at the area of interest. This finding further highlights the importance of tackling the congestion issues from a system perspective, which is sensitive to the corridor-wide impacts of alleviating a single bottleneck.

A.3 Maximum Sustainable Flow Rates for Southbound I-680 (Future Geometry, South of SR-24)

On August 24, 2020, CCTA and its stakeholder partners opened an 11-mile HOV lane addition from Treat Boulevard to the Rudgear Road interchange. The opening of the new HOV lane is the initial phase of an ongoing construction project that will ultimately result in the conversion of the HOV lane to an express lane in late 2020 or early 2021. With the opening of the HOV lane coinciding with the preparation of this report, the study team also evaluated MSFR values with the new managed lane in place. Figure A.7 and Figure A.8 compares the resultant capacity with the existing balanced peak hour flows. For this exercise, it is assumed that the CA-24 connector will be metered.

Figure A.7 Southbound I-680 MSFR and AM Peak Hour Flow with Express Lanes Completed

(balanced volumes for 7:00 AM to 8:00 AM weekdays in November 2019)

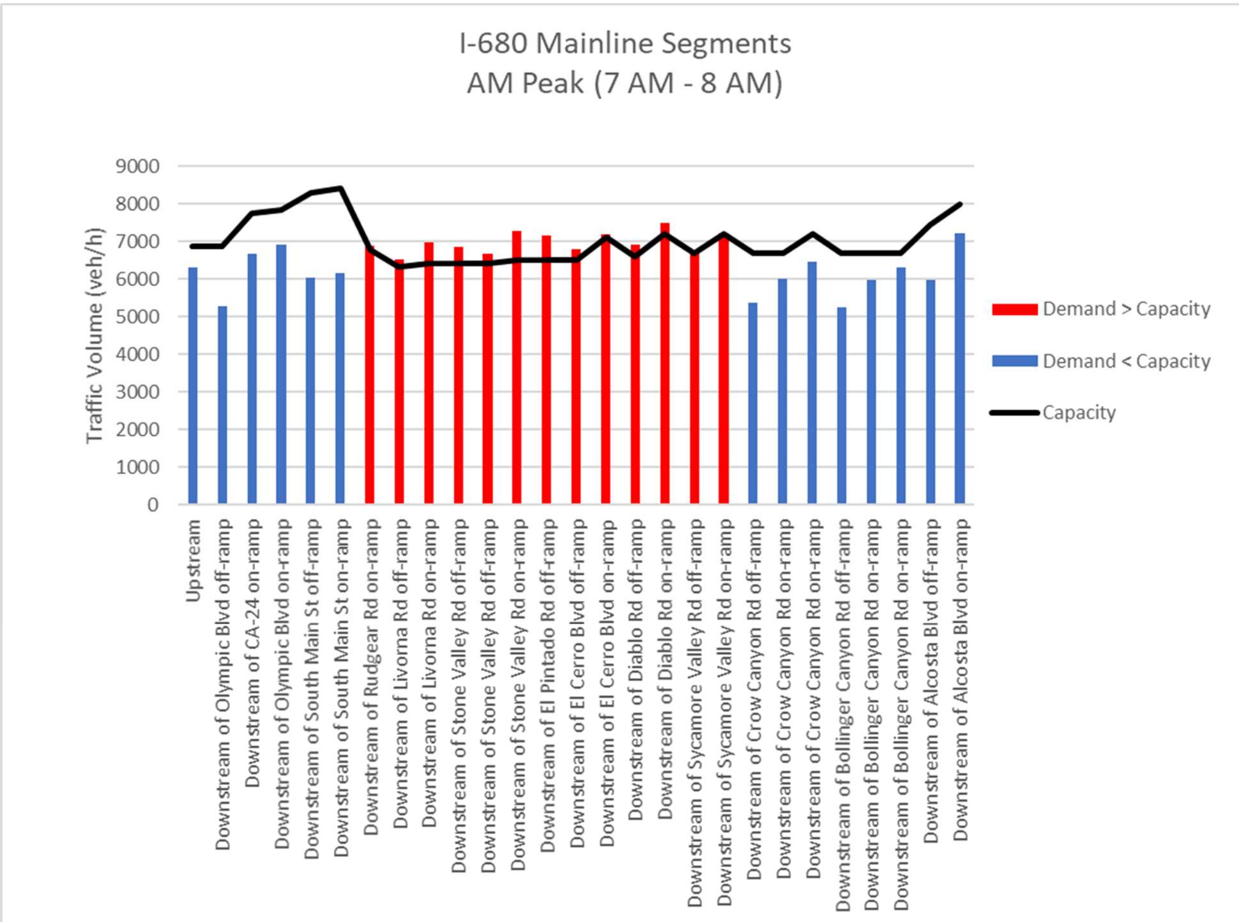
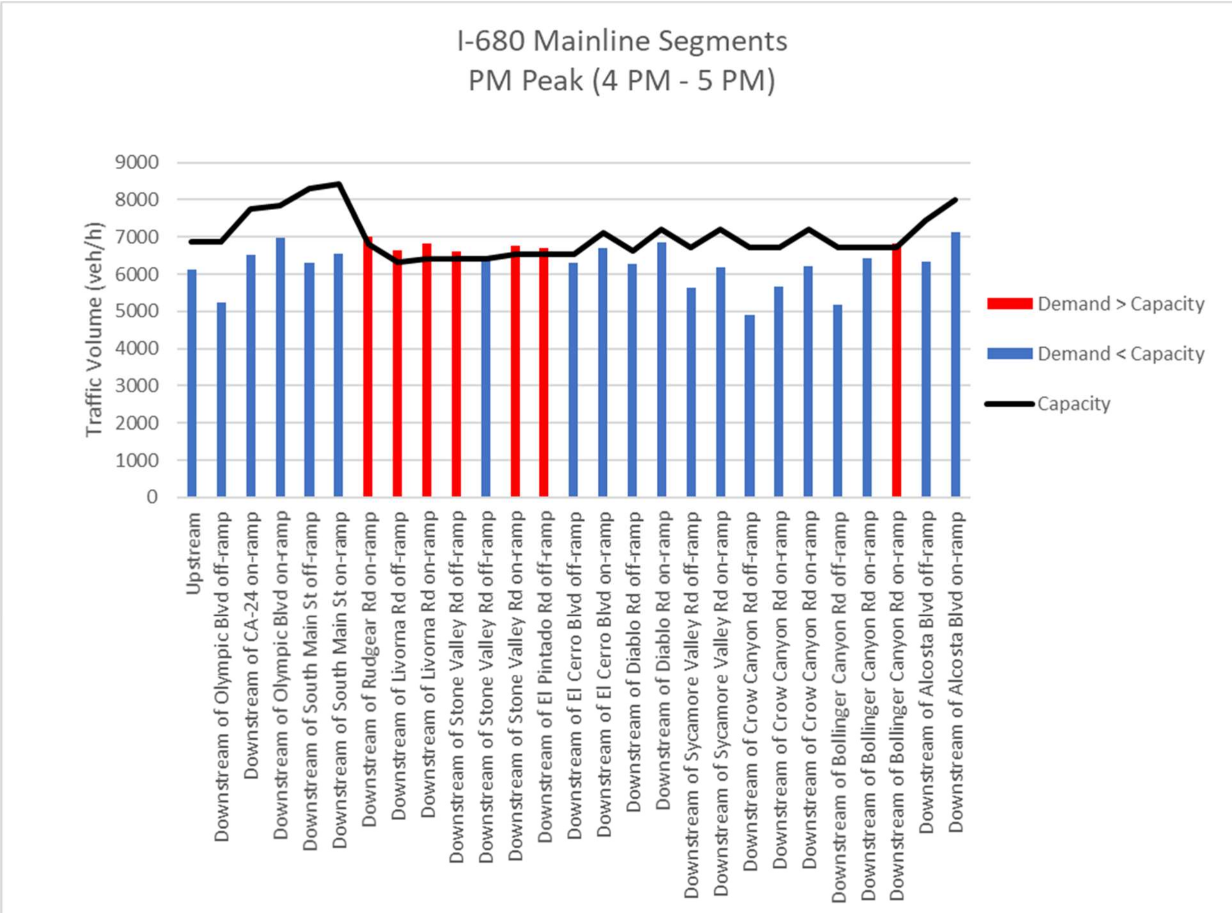


Figure A.8 Southbound I-680 MSFR and PM Peak Hour Flow with Express Lanes Completed (balanced volumes for 4:00 PM to 5:00 PM weekdays in November 2019)



The express lane extension project impacts the MSFRs in the first few northern mainline segments in the southbound direction, where the new highway capacity is added. In these segments, existing traffic flows were already found to be below the existing MSFR; this condition does not change with the addition of the new express lane. The MSFRs downstream of the Rudgear Road interchange (where an express lane already exists) are identical to those described in Section A.1.2.1.

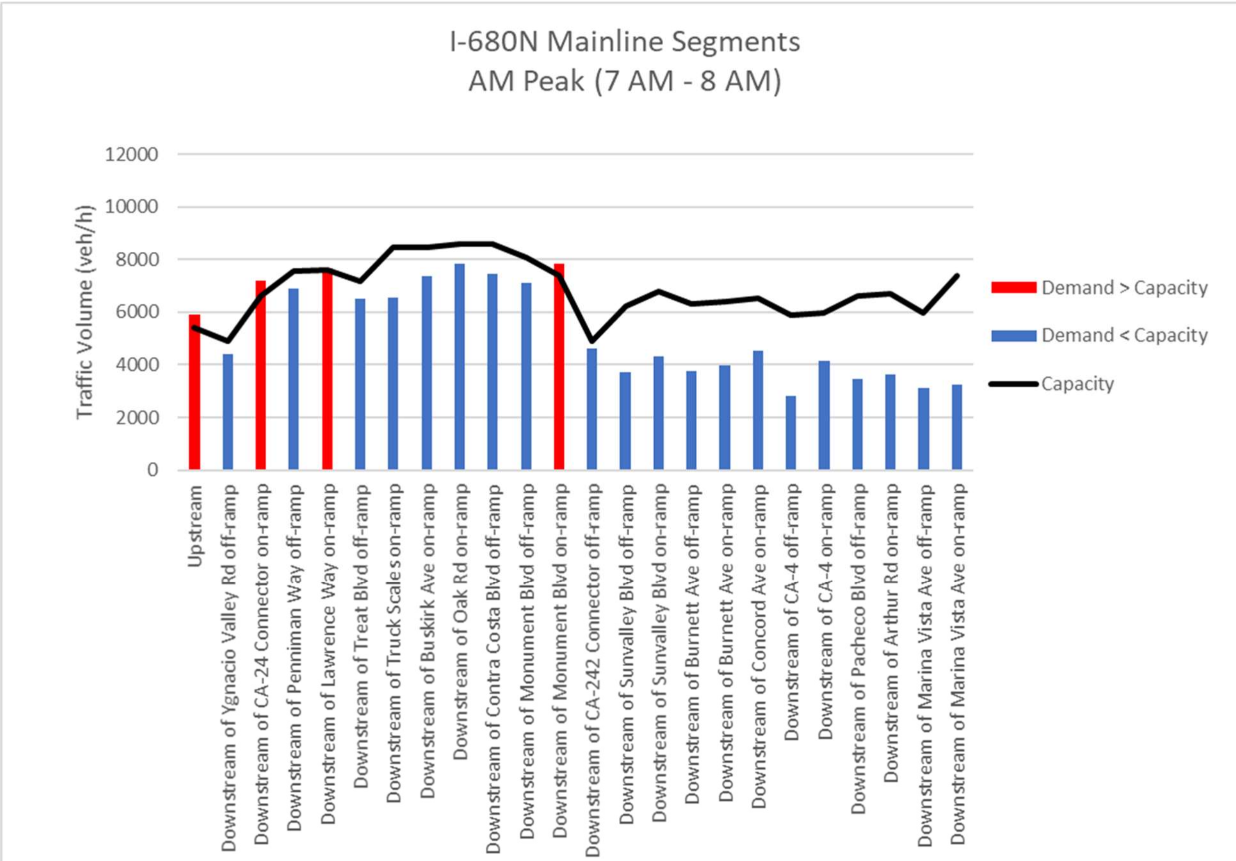
A.4 Maximum Sustainable Flow Rates for Northbound I-680 (North of SR-24)

A comparison of the calculated MSFR for the mainline segments on northbound I-680 and the existing peak-hour traffic flows (volumes) observed in the corridor based on balanced traffic counts are summarized in Figure A.9 and Figure A.10. To be consistent with the volume data, which were collected during weekdays in November 2019, MSFR values were calculated based on 2019 lane configurations.

For the northbound I-680 study corridor, all on-ramps except for the CA-24 connector and the truck scale entrance are assumed to be metered. The CA-24 connector is not metered due to geometry (left-hand side freeway entrance) and driver expectancy concerns. The truck scale entrance will remain un-metered to allow for adequate acceleration time/distance for heavy trucks. As shown in Figure A.9, four out of 24 northbound mainline segments were identified to have existing traffic flows in excess of the calculated MSFR during the AM peak hour. Overall, the AM peak hour demand is over or near capacity between the upstream mainline segment and the Sunvalley Blvd off-ramp.

Figure A.9 Northbound I-680 MSFR and AM Peak Hour Flow Under Existing Conditions

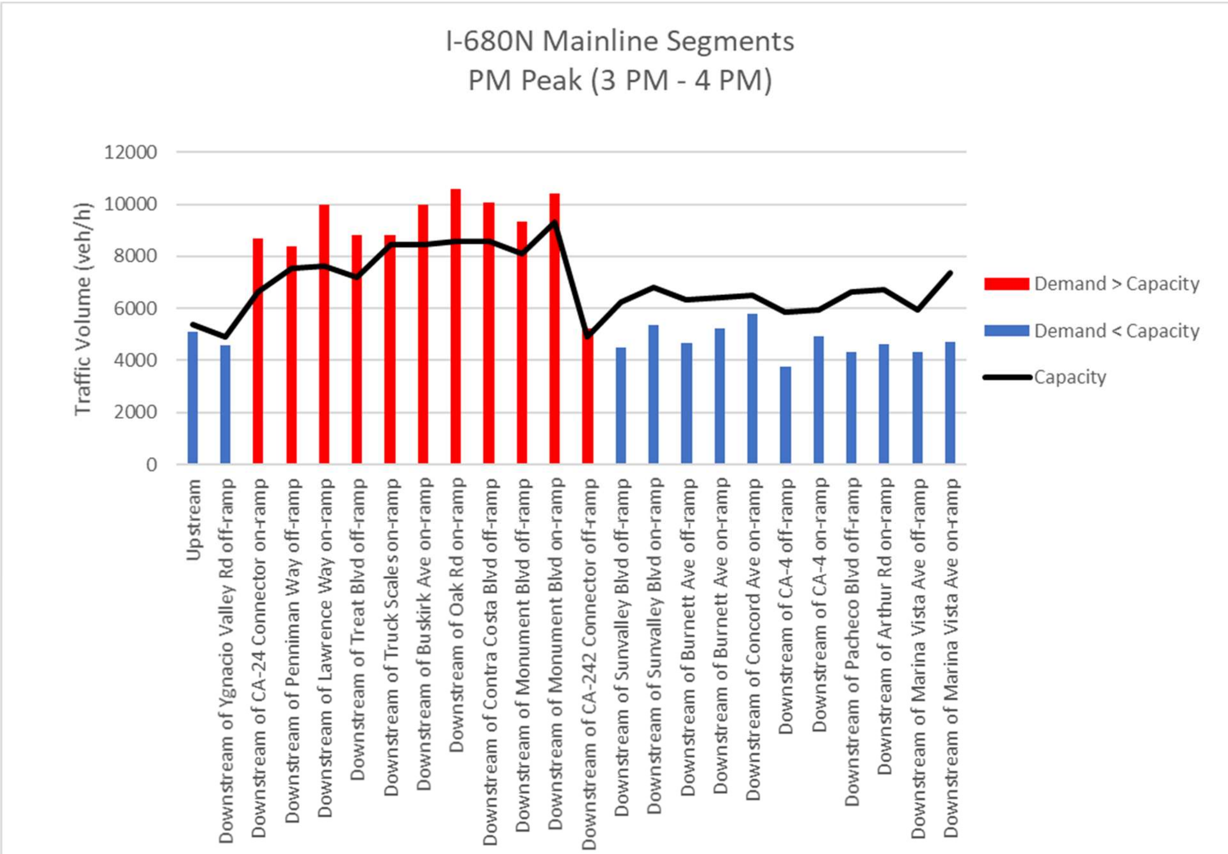
(balanced volumes for 7:00 AM to 8:00 AM weekdays in November 2019)



The PM peak hour comparison is shown in Figure A.10. Eleven study segments were projected to have existing flows in excess of the MSFR during the PM peak hour. In addition, significant gaps were identified at multiple mainline segments between the CA-24 connector on-ramp and CA-242 connector off-ramp.

Figure A.10 Northbound I-680 MSFR and PM Peak Hour Flow Under Existing Conditions

(balanced volumes for 3:00 PM to 4:00 PM weekdays in November 2019)



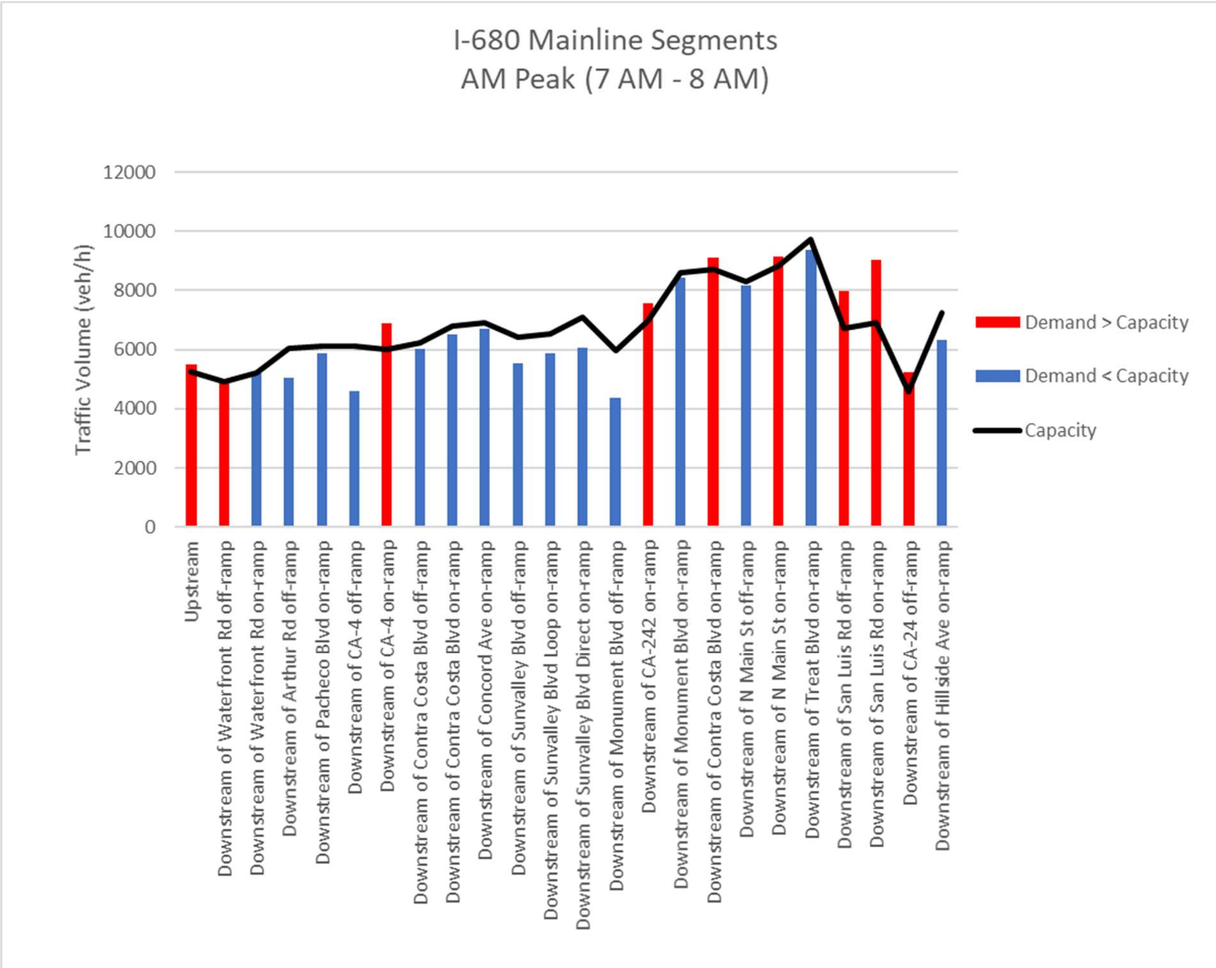
A.5 Maximum Sustainable Flow Rates for Southbound I-680 (North of SR-24)

A similar comparison was carried out in the southbound direction, and summarized in Figure A.11 and Figure A.12. For this study, all on-ramps except for the CA-242 connector are assumed to be metered. The CA-242 connector is not metered due to driver expectancy (high-speed straight-line entrance) concerns.

As shown in Figure A.11, nine of the 24 southbound mainline segments were identified to have existing traffic flows in excess of the calculated MSFR during the AM peak hour. Of the nine problematic segments, significant gaps were projected downstream of the CA-4 on-ramp and the San Luis Rd on-ramp.

Figure A.11 Southbound I-680 MSFR and AM Peak Hour Flow

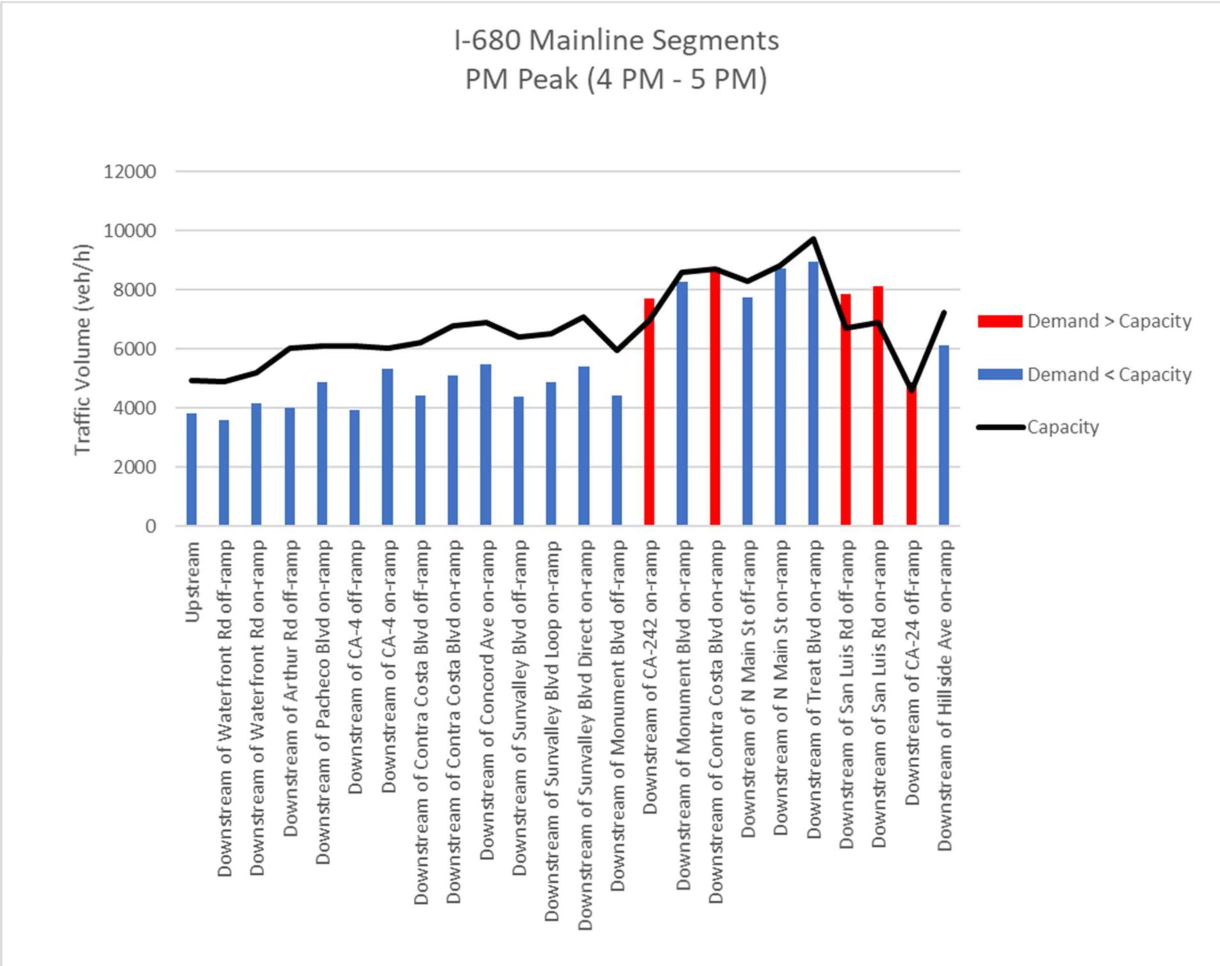
(balanced volumes for 7:00 AM to 8:00 AM weekdays in November 2019)



As shown in Figure A.12, five southbound mainline segments were found to have existing flows in excess of the MSFR during the PM peak hour, with several additional segments at or near capacity downstream of the CA-242 connector on-ramp.

Figure A.12 Southbound I-680 MSFR and PM Peak Hour Flow

(balanced volumes for 4:00 PM to 5:00 PM weekdays in November 2019)



Appendix B. R-Model Results South of SR-24

B.1 Northbound I-680 R-Model Analysis

The R-model was used to evaluate the feasibility and effectiveness of CARM strategy to accommodate existing northbound traffic volumes south of SR-24, assuming that CARM operations would not be in place in the segment of I-680 north of SR-2A. Both AM period (6:00 AM to 10:00 AM) and PM period (3:00 PM – 7:00 PM) were analyzed. The results are summarized in the following sections.

B.1.1 Northbound I-680 Analysis Under Existing Conditions

The R-model was first used to investigate the ability of CARM to manage the northbound traffic flow under the existing corridor configurations. As expected, the initial R-Model analysis was unable to find a viable solution due to multiple mainline capacity constraints discussed previously.

As described in Chapter 2 of the Evaluation Report, nine of the 28 study segments analyzed were found to have existing AM peak hour traffic flows that exceed the calculated MSFR. Of these nine segments, the two southernmost segments (upstream and downstream of the Alcosta Boulevard off-ramp) cannot be mitigated through the CARM strategy, as it is not possible to manage the flows at these two segments without additional ramp metering at locations further upstream. This would include the need to meter system connectors from I-580 to northbound I-680, as well as the service interchange at Village Parkway, both located in Alameda County. Other segments with identified flows in excess of MSFR include downstream of the Alcosta Boulevard on-ramp, and between the El Cerro Boulevard on-ramp and the Rudgear Road off-ramp. These locations are mainline capacity bottlenecks that are prone to recurring flow breakdown. Sensitivity testing was subsequently conducted as the basis for finding a viable R-Model solution and recommending specific improvements and operational management strategies.

B.1.2 Sensitivity Analysis

As described in Chapter 2, the existing study corridor experiences operational capacity constraints at multiple mainline segments during AM peak, and as a result, the initial R-Model analysis could not provide a viable solution without adjusting the balance between MSFR and existing flows. This section describes various alternative improvements and assumptions analyzed to evaluate the sensitivity of existing traffic flows to the mainline capacity deficit, and to assess the extent to which traffic flow management and mainline capacity improvements can result in a feasible CARM strategy. The sensitivity analysis also provides results that can guide on ramp requirements (i.e. number of lanes, storage) under a successful CARM implementation. The various alternative strategies analyzed are summarized in Table B.1.

Table B.1 R-Model Sensitivity Test Alternative Strategies and Feasibility Findings

Alternative Strategy	R-Model CARM Feasibility Finding	Comments
Increase maximum wait time to 5 minutes	✘	Maximum wait-time would exceed 5 minutes at some locations
Add general-purpose lane capacity in segments where existing flow exceeds MSFR	✓	Adding general-purpose capacity is likely to be required long-term to fully address future travel demand, but is not considered feasible for initial CARM demonstration
Add auxiliary lane capacity in segments where existing flow exceeds MSFR	✘	Specific segments downstream of an off-ramp still have peak flow rates exceeding MSFR
Increase MSFR by 10% in segments where existing flow exceeds MSFR	✓	The application of CARM and related management strategies could be expected to stabilize flow rates reducing the risk of flow breakdown as flows approach MSFR

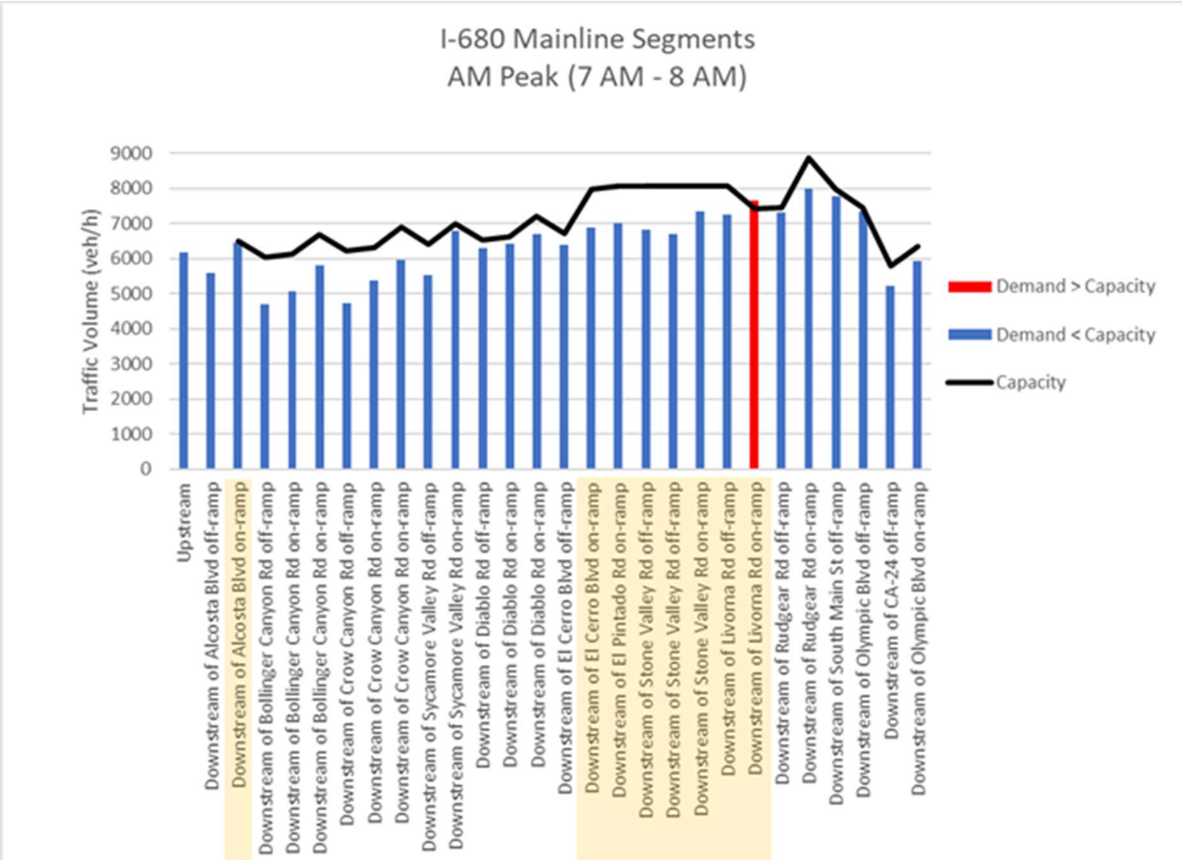
The sensitivity analysis assessed the performance of the northbound I-680 focus area between the Alcosta Boulevard on-ramp and the Olympic Blvd on-ramp. For this reason, the operational conditions at the two mainline segments upstream and downstream of the Alcosta Boulevard off-ramp remain unresolved due to influences outside of Contra Costa County.

Added General-Purpose Lane, El Cerro Boulevard to Rudgear Road

To address the freeway operational capacity constraint identified by the MSFR analysis, an alternative adding a fourth general-purpose lane was evaluated. The yellow highlight in Figure B.1 indicates the segments where the fourth general-purpose lane was added. These locations include the segments from the El Cerro Boulevard on-ramp to the Rudgear Road off-ramp (it should be noted that the added lane from the Livorna Road on-ramp to the Rudgear Road off-ramp effectively forms an exclusive exit lane, therefore, providing a lower MSFR compared to upstream segments). This alternative also included the addition of an auxiliary lane from the Alcosta Boulevard on-ramp to the Bollinger Canyon Road off-ramp. As shown in Figure B.1, this resolves the operational capacity constraints in all segments except the segment downstream of the Livorna Road on-ramp. However, the R-Model was able to determine a feasible solution despite the capacity constraints downstream of the Livorna Road on-ramp.

Figure B.1 Northbound I-680 MSFR and AM Peak Hour Flow with Added General-Purpose Lane

(balanced volumes for 7:00 AM to 8:00 AM weekdays in November 2019)



Figures B.2 and B.3 present the R-Model results for the added general-purpose lane alternative. Figure B.1 shows the average wait times at the various ramp locations, while Figure B.2 shows the average queue lengths.

The blue bands in Figures B.2 and B.3 represent a range of results covering the 50th percentile (median) and 95th percentile values, consistent with Table B.1. Wait times at locations upstream of Livorna Road range between about 2:45 minutes and 4:00 minutes. In addition, the on-ramps at Livorna Road, Stone Valley Road, El Cerro Boulevard and Sycamore Valley Road will operate near their existing storage capacity. These results indicate that the metering system coordinating across the corridor to manage the operational capacity constraint in the segment of downstream of the Livorna Road on-ramp. Despite this constraint, the system can successfully manage traffic flows in the corridor without exceeding the maximum 4-minute average wait time threshold or the existing ramp storage.

Figure B.2 Northbound I-680 AM Peak Hour R-Model Average Wait Time Results for Added General-Purpose Lane Alternative

(balanced volumes for 7:00 AM to 8:00 PM weekdays in November 2019)

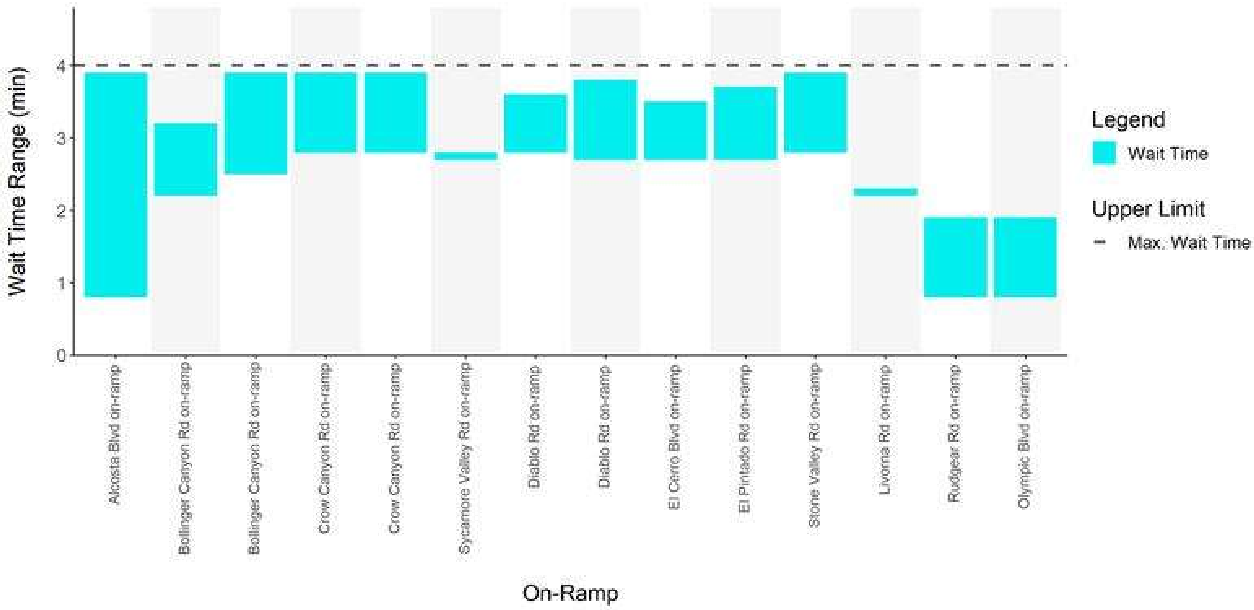
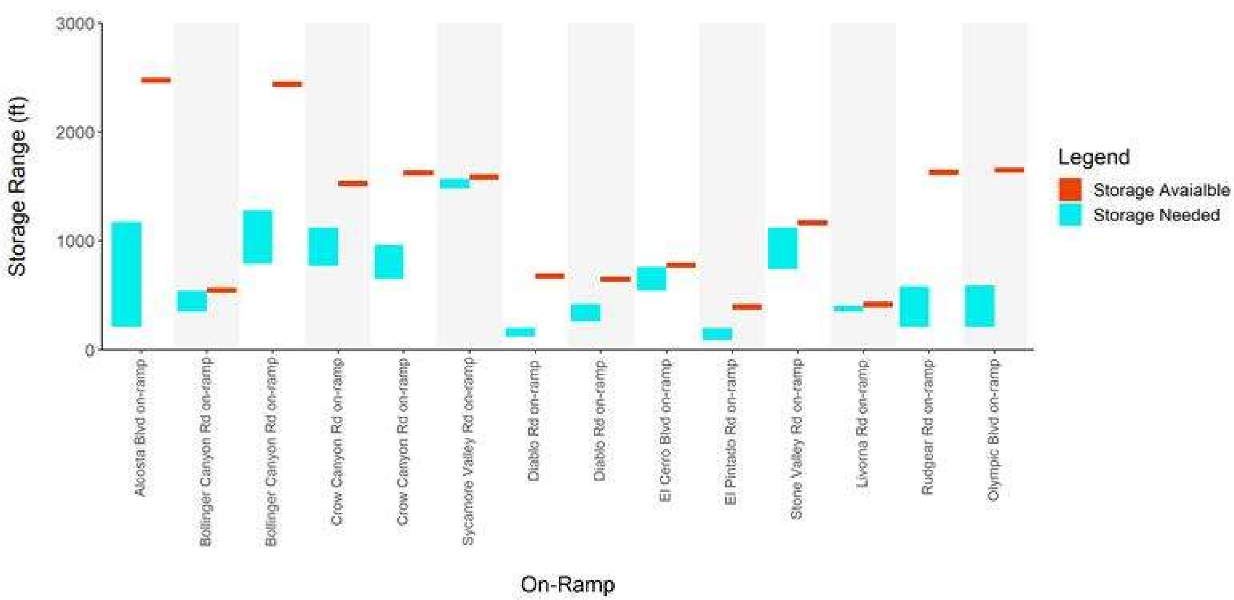


Figure B.3 Northbound I-680 AM Peak Hour R-Model Average Queue Length Results for Added General-Purpose Lane Alternative

(balanced volumes for 7:00 AM to 8:00 PM weekdays in November 2019)



These findings show CARM can be applied successfully in the corridor, although the existing traffic flows in some segments are near or slightly above the calculated MSFR, indicating an increased risk of flow breakdown. Increasing the capacity of segments that exceed the MSFR by adding lanes has been demonstrated to resolve the operational capacity constraints and allow effective CARM operations. However, the added capacity would not be fully utilized in several segments (particularly in the short-term), making the addition of a fourth general-purpose lane more suitable (and likely necessary) as a longer-term mitigation strategy.

Adjusted MSFR, El Cerro Boulevard to Rudgear Road

Based on the findings of the added general-purpose lane alternative, the sensitivity of existing traffic flows in segments that exceeded their calculated MSFR were evaluated assuming MSFR values 10% above the calculated values. This adjustment was made for the segments from the Alcosta Boulevard on-ramp to the Bollinger Canyon Road off-ramp, and the El Cerro Boulevard on-ramp to the Rudgear Road off-ramp. The intent of evaluating this alternative is to determine how close the R-Model is to finding a feasible solution for existing conditions, recognizing the conservative nature of the MSFR calculation assumptions and the ability for CARM to optimize traffic flows. The resultant MSFR and AM peak hour flows are compared in Figure B.4, with the segments with adjusted MSFR values highlighted in yellow.

The R-Model results for this alternative are presented in Figures B.5 and B.6. The results indicate that the traffic flows in the corridor are very sensitive to only minor changes in MSFR assumptions. Therefore, it is probable that existing traffic flows can be managed effectively with CARM, although the existing operational capacity constraints create a potential risk of isolated flow disruption during AM peak periods. The results indicate that CARM can function effectively with the average wait times remaining below 2-minutes and queues remaining well below existing capacity.

Figure B.4 Northbound I-680 MSFR and AM Peak Hour Flow with Adjusted MSFR

(balanced volumes for 7:00 AM to 8:00 AM weekdays in November 2019)

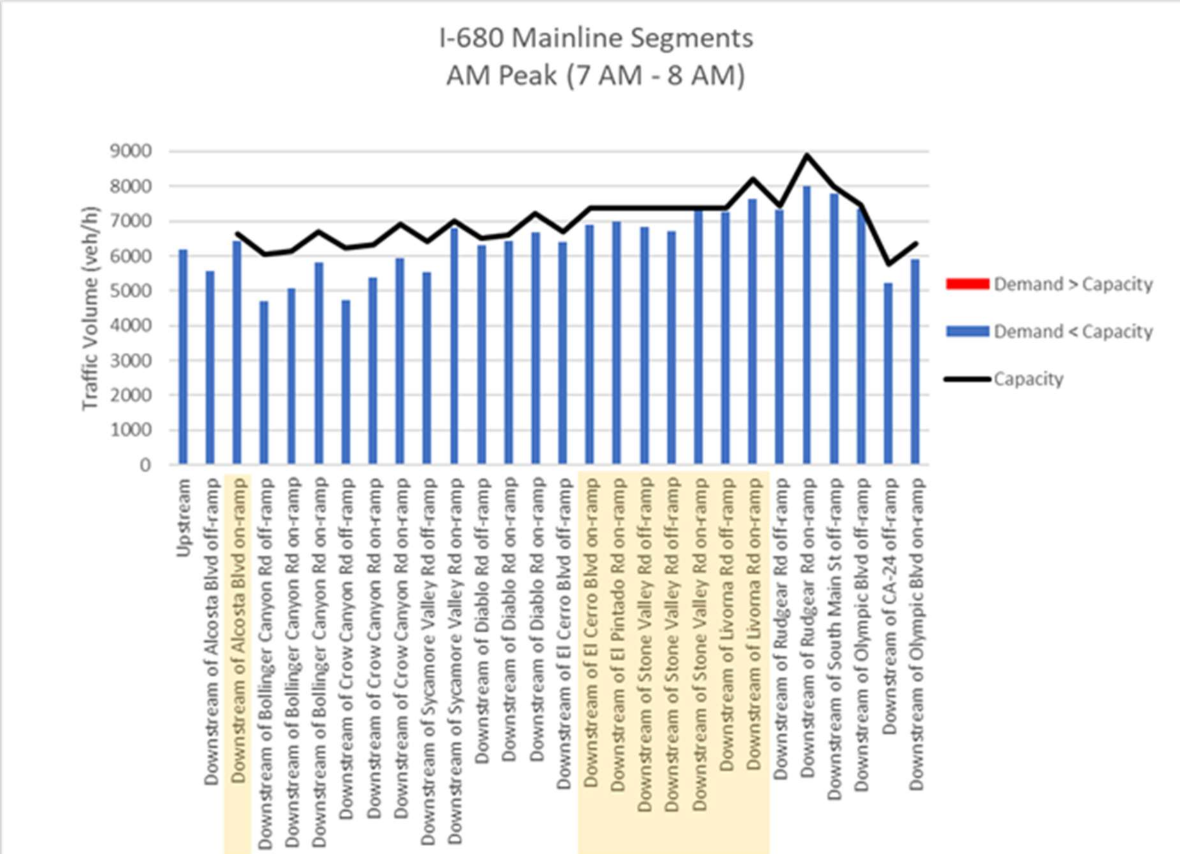


Figure B.5 Northbound I-680 AM Peak Hour R-Model Average Wait Time Results for Adjusted MSFR Alternative

(balanced volumes for 7:00 AM to 8:00 PM weekdays in November 2019)

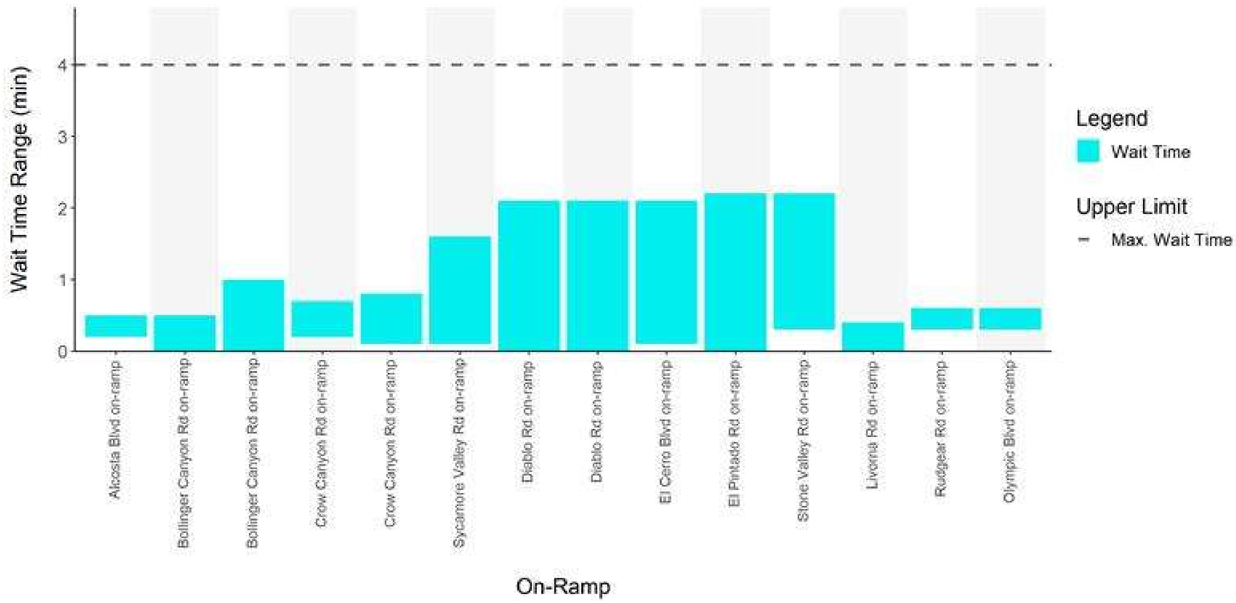
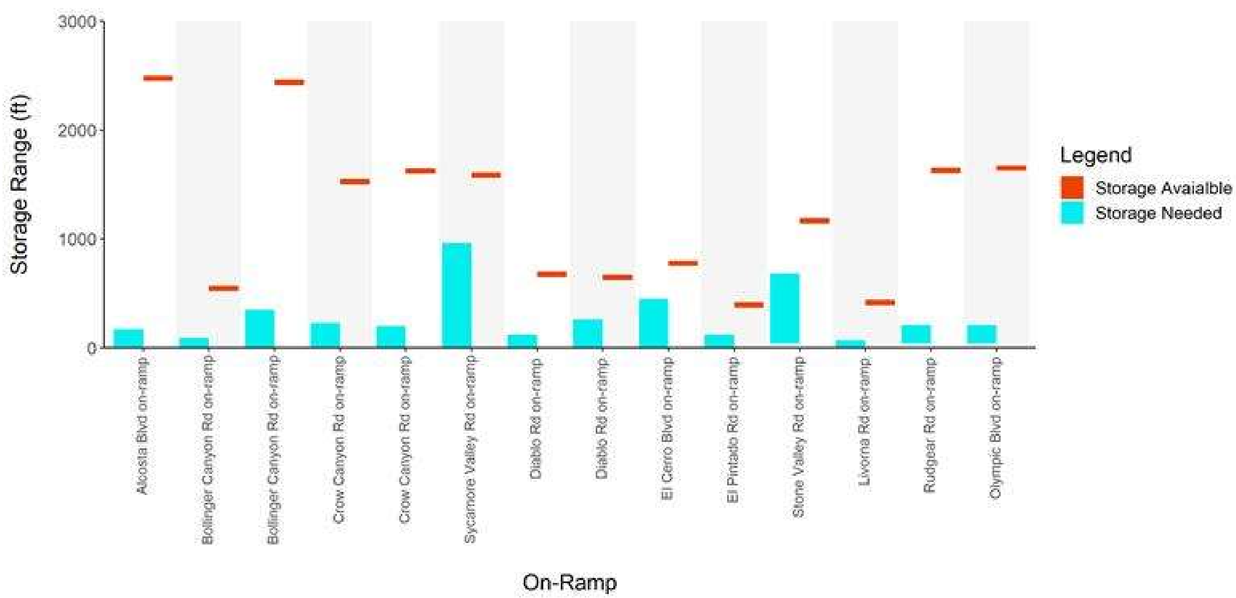


Figure B.6 Northbound I-680 AM Peak Hour R-Model Average Queue Length Results for Adjusted MSFR Alternative

(balanced volumes for 7:00 AM to 8:00 PM weekdays in November 2019)



These findings indicate there remains a risk of isolated flow disruption under existing conditions with AM peak hour flows exceeding MSFR in some segments. However, CARM implementation would be expected to reduce this potential demonstrating the effectiveness of the concept. Furthermore, CARM deployment would provide more refined traffic flow data enabling evaluation of the effect of the system on traffic flows and providing a more definitive recommendation on the need for additional general-purpose lane capacity.

As shown in Table B.2, the R-Model evaluation for the adjusted MSFR alternative indicates the overall on-ramp storage requirements across the simulation period (4-hour AM peak period and 4-hour PM peak period) are sufficient. However, certain on-ramps including Sycamore Valley Road, El Cerro Boulevard, Stone Valley Road, and Livorna Road, would operate near their current capacity and would benefit from storage improvements to meet future demands.

Table B.2 Northbound I-680 On-Ramp Storage Requirements for CARM Deployment

On-Ramp Location (South to North)	95th Percentile Storage Needs (ft)	Existing Storage (ft)	Existing Storage Sufficient?
Alcosta Blvd	510	2,500	✓
Bollinger Canyon Rd	260	570	✓
Bollinger Canyon Rd	1,040	2,464	✓
Crow Canyon Rd	970	1,550	✓
Crow Canyon Rd	770	1,650	✓
Sycamore Valley Rd	1,550	1,610	✓
Diablo Rd	200	700	✓
Diablo Rd	280	670	✓
El Cerro Blvd	790	800	✓
El Pintado Rd	190	420	✓
Stone Valley Rd	970	1,190	✓
Livorna Rd	280	440	✓
Rudgear Rd	310	1,655	✓
Olympic Blvd	390	1,675	✓

Given that the sensitivity analysis found existing corridor conditions exceeding MSFR at several locations, and the potential of the CARM system to be stressed when managing northbound AM peak period traffic flows, the availability of additional discharge capacity is recommended at several ramp locations to allow vehicles to access the mainline more quickly when capacity is available. The VicDOT *Managed Motorway Design Guide* [6] generally recommends one lane of discharge capacity for each 500 vehicles of flow on a given ramp during the peak hour. Based on this guidance, several ramp locations would require additional ramp discharge capacity at the metering threshold to accommodate existing and

[6] Victoria State Government, Department of Transport, VicDOT. *Managed Motorway Design Guide* Volume 2: Design Practice Part 3: Motorway Planning and Design, Section 6.2 Ramp Discharge Capacity for Design. VicDOT, Melbourne, VIC., Australia, June 2019.

future ramp volumes. Table B.3 summarizes the ramp discharge recommendations and other key findings for the 4-hour AM peak period and 4-hour PM peak simulation period.

Table B.3 Northbound I-680 On-Ramp Discharge Requirements for CARM Deployment

On-Ramp Location	Existing Number of Discharge Lanes	95th Percentile Ramp Volume (veh/hr)	95th Percentile Wait Time (minutes)	Recommended Number of Discharge Lanes
Alcosta Blvd	2	889	1.4	2
Bollinger Canyon Rd	1	418	1.6	2
Bollinger Canyon Rd	2	940	3.0	3
Crow Canyon Rd	2	880	2.6	2
Crow Canyon Rd	2	974	2.8	3
Sycamore Valley Rd	2	1,434	2.5	3
Diablo Rd	1	282	3.2	1
Diablo Rd	1	289	3.2	1
El Cerro Blvd	1	598	3.0	2
El Pintado Rd	1	179	3.3	1
Stone Valley Rd	1	700	3.2	2
Livorna Rd	1	475	1.4	2
Rudgear Rd	2	777	0.9	2
Olympic Blvd	2	1,445	1.0	3

As indicated in Table B.3, additional discharge capacity is required at Sycamore Valley Road, El Cerro Boulevard, Stone Valley Road and Olympic Boulevard to meet existing peak ramp volumes. Additional ramp discharge capacity is also recommended at both Bollinger Canyon Road ramps, the Crow Canyon Road direct ramp, and Livorna Road to meet increased future demands.

As discussed in the *I-680 Northbound Coordinated Adaptive Ramp Metering Demonstration Field Review – Alameda County Line to CA-24* technical memorandum, the existing parclo interchange design at Bollinger Canyon Road and Crow Canyon Road both include a short weave distance of approximately 250 feet on the eastbound to northbound loop ramp. The short weave distance combined with the relatively high peak hour combined ramp volumes at these locations is likely contributing to traffic flow disruption observed in this vicinity during the AM peak period on several of the heat plots exhibited in Figure 3.1. Although these disruptions do not always result in traffic flow breakdown under existing conditions, they do appear to elevate the rate of crashes in this vicinity, as evidenced on Figure 3.5, and specifically as depicted in the heat plots diagrams in Figure 3.1 at 9:00 AM on October 22, 2018 and 8:00 PM on October 30, 2018.

Implementing a short collector-distributor system that combines the two northbound on-ramps at each of these locations into a single extended merge area is recommended to consolidate and expand storage and improve discharge capacity on the ramps to facilitate CARM implementation. At Bollinger Canyon Road, the combined ramp peak hour volume would be 1,358, requiring 3 lanes of capacity a consolidated threshold, while Crow Canyon

Road would have a combined ramp peak hour volume of 1,854 requiring 4 lanes of capacity to be provided at a consolidated threshold. Additionally, the presence of existing auxiliary lanes downstream of the respective direct on-ramps at Bollinger Canyon Road and Crow Canyon Road can accommodate the peak ramp volumes and provide an extended merge distances to facilitate weaving with the mainline lanes.

B.2 Southbound I-680 R-Model Analysis

The R-model was also used to evaluate the feasibility and effectiveness of implementing CARM strategy to manage existing southbound traffic volumes in the I-680 study corridor in the morning (6:00 AM to 9:00 AM) and evening (3:00 PM – 7:00 PM) peak periods. The results are summarized in the sections that follow.

B.2.1 Southbound I-680 Analysis Under Existing Conditions

The R-model was first used to investigate the ability for CARM to manage the southbound traffic flows under the existing corridor configurations. Similar to the northbound analysis, the initial R-Model analysis could not yield a viable solution due to multiple mainline capacity constraints identified previously.

B.2.2 Sensitivity Analysis

As with the northbound analysis, sensitivity testing was then conducted as the basis for achieving a viable R-Model solution and recommending specific improvements and operational management strategies for southbound I-680. This section describes the alternative improvements and assumptions considered to assess the sensitivity of existing traffic flows to mainline capacity deficits and evaluates the extent that traffic flow management and/or mainline capacity improvements can produce a feasible CARM strategy. The sensitivity analysis results also provide guidance on ramp requirements (i.e. number of lanes, storage) for a successful CARM implementation. Consistent with the MSFR evaluation discussed previously, the study team performed analyses on two alternatives comparing different strategies for managing the flows from the eastbound CA-24 connector to southbound I-680.

Southbound I-680 Scenario 1 (CA-24 Connector Metered)

This scenario assumes that the CA-24 connector on-ramp will be metered to manage the traffic entering the southbound I-680 study corridor between CA-24 and the Alameda County line. Using the same approach described in the introduction to Appendix A, adjusted MSFR values were analyzed for select mainline segments to evaluate how close the R-Model is to finding a feasible solution for managing existing conditions. MSFR adjustments were made for the segments shown in Table B.4. The resultant MSFR and peak hour flows are compared in Figures B.7 and B.8. The adjusted MSFR values were assumed for the segments highlighted in yellow.

Table B.4 Southbound I-680 MSFR Adjustments for Sensitivity Analysis with CA-24 Connector Metered

Mainline Segment Downstream of	6 – 7 AM	7 – 8 AM	4 – 5 PM
Rudgear Rd On-ramp	+5%	+5%	+5%
Livorna Rd Off-ramp	+10%	+5%	+5%
Livorna Rd On-ramp	+10%	+10%	+10%

Mainline Segment Downstream of	6 – 7 AM	7 – 8 AM	4 – 5 PM
Stone Valley Rd Off-ramp	+5%	+10%	+5%
Stone Valley Rd Off-ramp	+5%	+10%	+5%
Stone Valley Rd On-ramp	+5%	+15%	+5%
El Pintado Rd Off-ramp	+5%	+10%	+5%
El Cerro Blvd Off-ramp	No Change	+5%	+5%
El Cerro Blvd On-ramp	No Change	+5%	+5%
Diablo Rd Off-ramp	No Change	+5%	+5%
Diablo Rd On-ramp	No Change	+5%	+5%
Bollinger Canyon Rd On-ramp	No Change	No Change	+5%

Figure B.7 Southbound I-680 MSFR and AM Peak Hour Flow with Adjusted MSFR and CA-24 Connector Metered

(balanced volumes for 7:00 AM to 8:00 AM weekdays in November 2019)

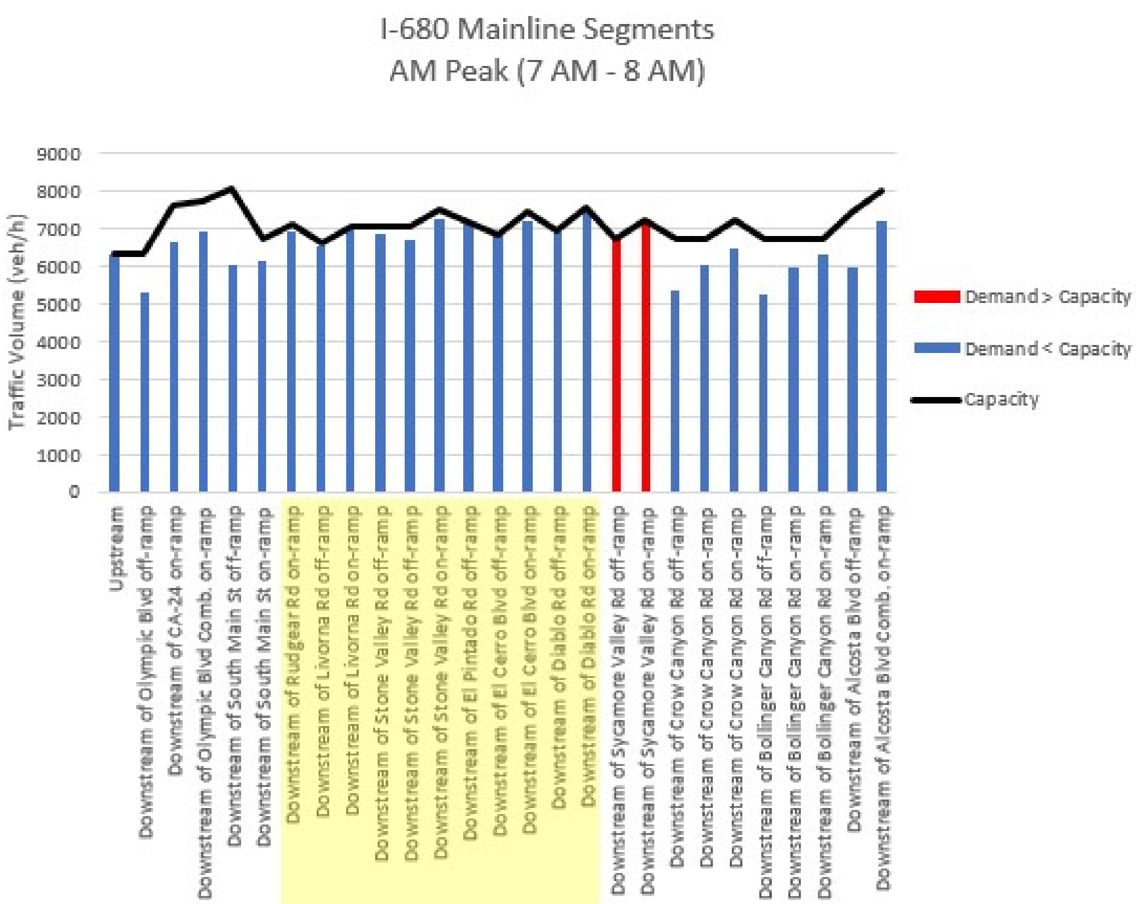
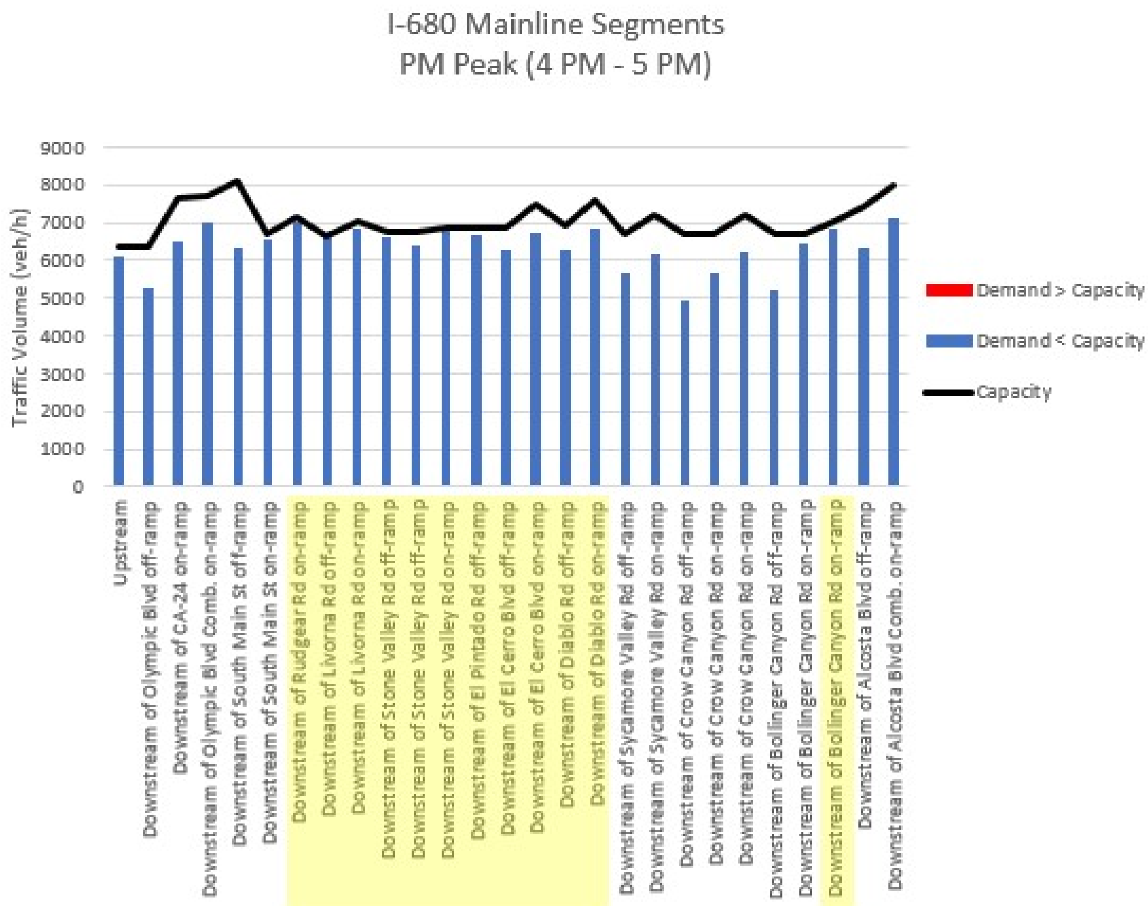


Figure B.8 Southbound I-680 MSFR and PM Peak Hour Flow with Adjusted MSFR and CA-24 Connector Metered

(balanced volumes for 4:00 AM to 5:00 AM weekdays in November 2019)



As shown in Figures B.3 and B.2, the MSFR adjustment resolves the operational capacity constraints in all segments except the segments downstream of the Sycamore Valley Road off- and on-ramps during AM peak. Despite the remaining capacity constraints after the MSFR adjustment, the R-Model was able to determine a feasible solution. The R-Model results for this alternative are presented in Figures B.9 through B.12.

Figure B.9 Southbound I-680 AM Peak Hour R-Model Average Wait Time Results with Adjusted MSFR and CA-24 Connector Metered

(balanced volumes for 7:00 AM to 8:00 PM weekdays in November 2019)

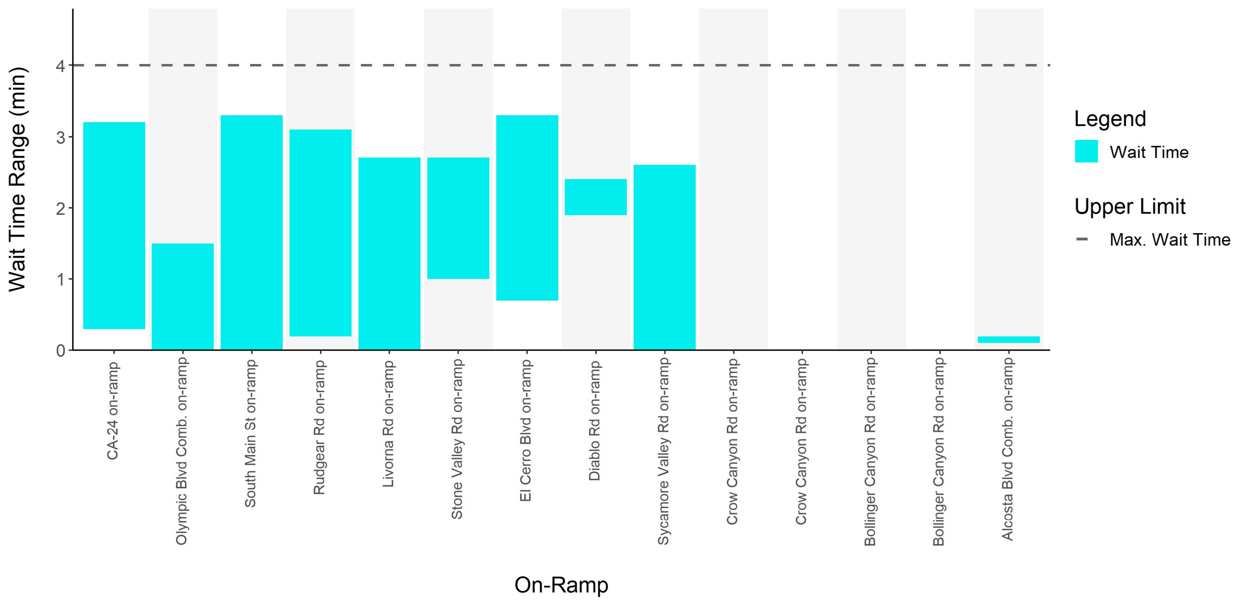


Figure B.10 Southbound I-680 AM Peak Hour R-Model Average Queue Length Results with Adjusted MSFR and CA-24 Connector Metered

(balanced volumes for 7:00 AM to 8:00 PM weekdays in November 2019)

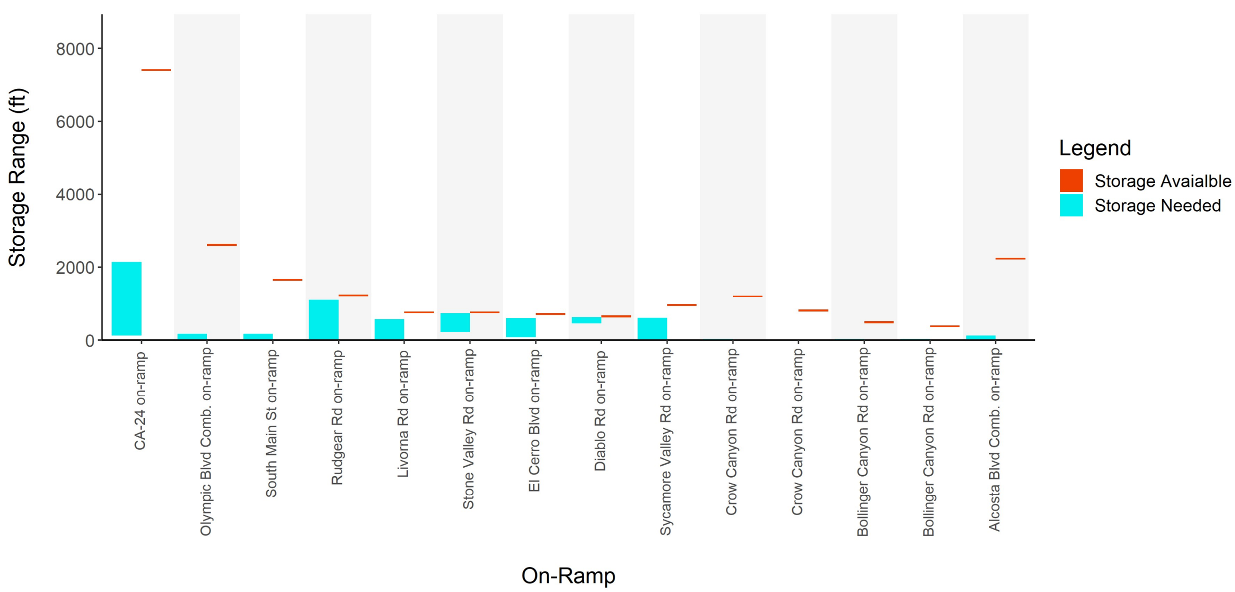


Figure B.11 Southbound I-680 PM Peak Hour R-Model Average Wait Time Results with Adjusted MSFR and CA-24 Connector Metered

(balanced volumes for 4:00 AM to 5:00 PM weekdays in November 2019)

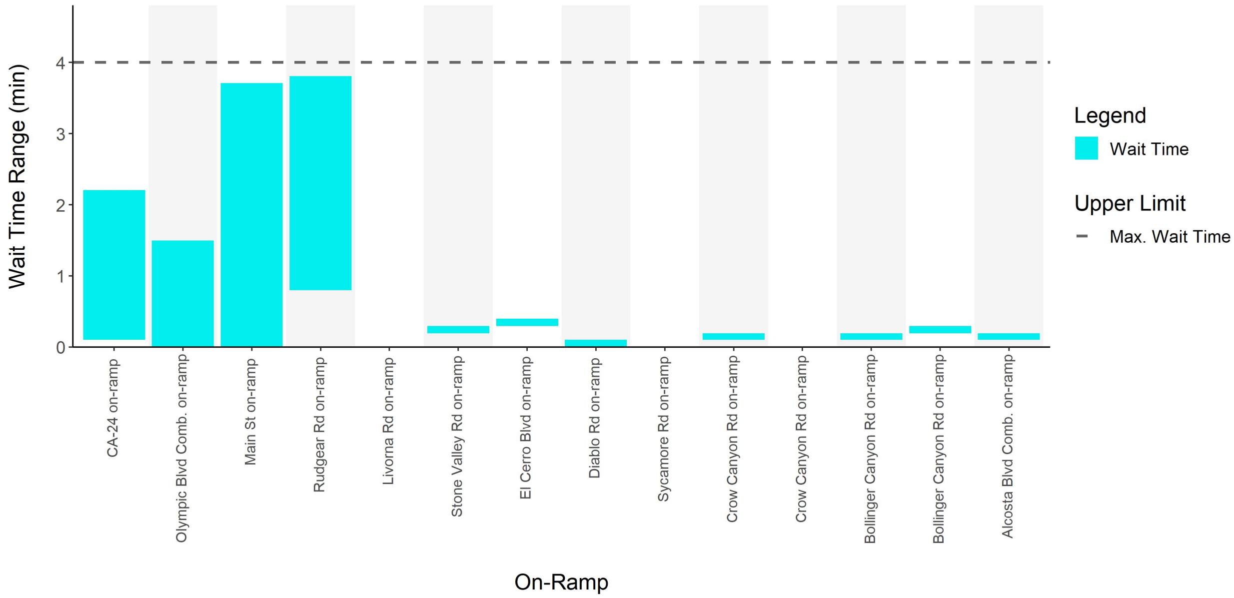
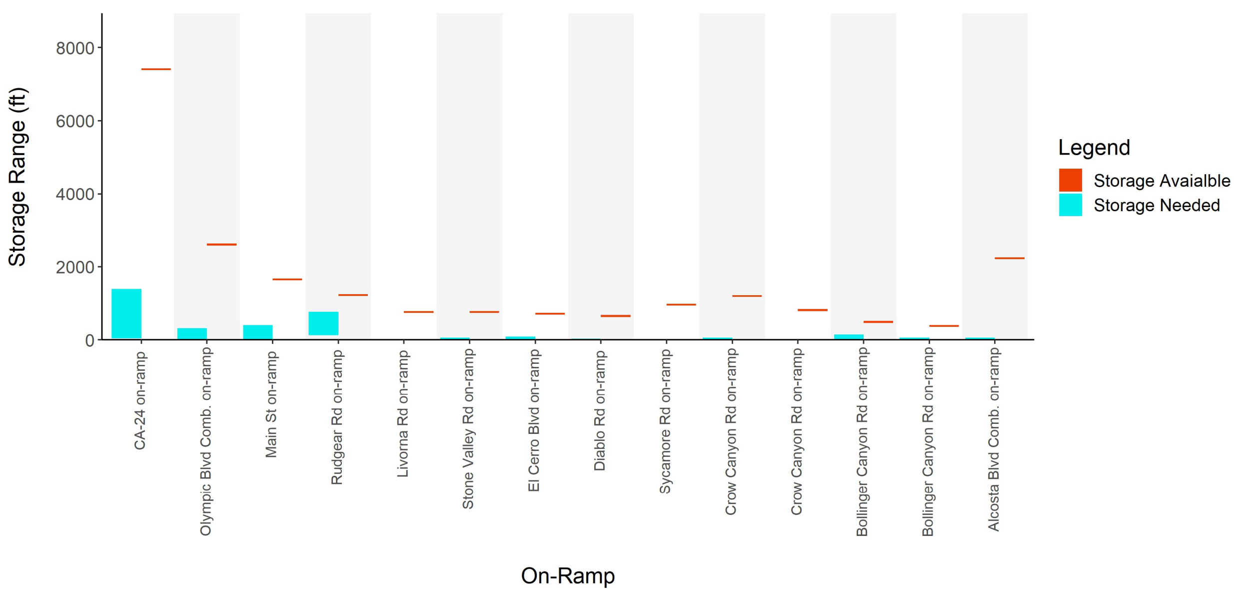


Figure B.12 Southbound I-680 PM Peak Hour R-Model Average Queue Length Results with Adjusted MSFR and CA-24 Connector Metered

(balanced volumes for 4:00 AM to 5:00 PM weekdays in November 2019)



For the AM peak hour, the MSFR deficit at the Sycamore Valley Road off-ramp and on-ramp results in high 95th percentile wait time and queue length on the upstream segments, as the CARM strategy works to distribute the excess demand along the corridor to meet the operational objectives shown in Table B.5. During the PM peak hour, significant wait times are projected at the Rudgear Road on-ramp and the South Main Street on-ramp, due to capacity constraints on the downstream mainline segment after the Livorna Road off-ramp, where the auxiliary lane terminates.

The analysis indicates that the adjustments required to arrive at a feasible solution for I-680 southbound are more substantial than those for the northbound direction. This is consistent with the more significant operational constraints found in the southbound freeway mainline, particularly in the vicinity of Stone Valley Road and El Pintado Road. While it is expected that the implementation of CARM would improve the management of southbound traffic flows, reduce the probability of traffic flow breakdowns, and reduce the frequency and magnitude of recurrent congestion, the implementation of CARM would not fully resolve the identified MSFR deficiency. Therefore, it is recommended that options to provide additional strategic mainline capacity and/or travel demand reduction measures be considered as part of any permanent CARM deployment on I-680 southbound.

Based on the results of the R-Model evaluation of the adjusted MSFR alternative, the overall on-ramp storage requirements across the simulation period (3-hour AM peak period and 4-hour PM peak period) are summarized in Table B.10. While the results indicate that existing storage is sufficient based on current traffic flows, it must be recognized that moderate adjustments to the MSFR values were necessary to find a feasible solution. For this reason, on-ramps, such as Rudgear Road, Livorna Road, Stone Valley Road, El Cerro Boulevard and Diablo Road would likely require additional storage and discharge capacity to meet existing (and future) demands and allow the CARM system to effectively balance ramp queues to manage traffic flows through the segments with MSFR deficiencies.

Table B.5 Southbound I-680 On-Ramp Storage Requirements for CARM Deployment with CA-24 Connector Metered

On-Ramp Location (North to South)	95th Percentile Storage Needs (ft)	Existing Storage (ft)	Existing Storage Sufficient?
CA-24	2,140	7,440	✓
Olympic Blvd Combined	260	2,630	✓
South Main St	370	1,680	✓
Rudgear Rd	1,100	1,255	✓
Livorna Rd	570	780	✓
Stone Valley Rd	730	780	✓
El Cerro Blvd	600	730	✓
Diablo Rd	630	670	✓
Sycamore Valley Rd	610	980	✓
Crow Canyon Rd	120	1,220	✓
Crow Canyon Rd	30	830	✓
Bollinger Canyon Rd	140	510	✓
Bollinger Canyon Rd	90	400	✓

On-Ramp Location (North to South)	95th Percentile Storage Needs (ft)	Existing Storage (ft)	Existing Storage Sufficient?
Alcosta Blvd Combined	260	2,255	✓

Assuming the VicDOT standard of one lane of discharge capacity for each 500 vehicles of flow on the ramp during the peak hour, most ramp locations will require additional ramp discharge capacity at the metering threshold. Ramp discharge recommendations and other key findings are summarized in Table B.6.

Table B.6 Southbound I-680 On-Ramp Discharge Requirements for CARM Deployment with CA-24 Connector Metered

On-Ramp Location (North to South)	Existing Number of Discharge Lanes	95th Percentile Ramp Volume (veh/hr)	95th Percentile Wait Time (minutes)	Recommended Number of Discharge Lanes
CA-24	2	1,563	3.2	4
Olympic Blvd Combined	1	530	1.5	2
South Main St	1	280	3.5	1
Rudgear Rd	1	796	3.1	2
Livorna Rd	1	581	2.7	2
Stone Valley Rd	1	826	2.7	2
El Cerro Blvd	1	590	3.3	2
Diablo Rd	1	763	2.4	2
Sycamore Valley Rd	1	753	2.6	2
Crow Canyon Rd	1	833	0.6	2
Crow Canyon Rd	1	683	0.1	2
Bollinger Canyon Rd	1	1,371	0.4	3
Bollinger Canyon Rd	1	560	0.4	2
Alcosta Blvd Combined	2	1,660	0.6	4

Southbound I-680 Scenario 2 (CA-24 Connector Not Metered)

The second southbound scenario corresponds to the condition in which the CA-24 connector on-ramp remains unmetered. While high-volume, system-to-system ramps are typically unmetered in the US, managing flows at all access points (i.e. all on-ramps and off-ramps) is recommended to maximize the ability to control freeway traffic flows under the CARM strategy. As shown in previous sections, the MSFR values for most southbound mainline segments decrease when the CA-24 connector is not metered. As a result, certain mainline segments will have flow rates that exceed MSFR by greater amounts hence requiring greater MSFR adjustments to resolve the existing southbound flow deficiencies within the study corridor.

MSFR adjustments are required at numerous mainline segments (as shown in Table B.7) to find a feasible R-Model solution. As expected, both the number of adjusted mainline segments and the magnitude of adjustments increase in this scenario when compared to the adjustments under the scenario where the CA-24 connector is metered. In general, larger

MSFR adjustments suggest critical capacity constraints, and greater potential risk for flow breakdown to occur at bottleneck locations.

Table B.7 Southbound I-680 MSFR Adjustments for Sensitivity Analysis with CA-24 Connector Not Metered

Mainline Segment Downstream of	6 – 7 AM	7 – 8 AM	4 – 5 PM	5 - 6 PM
South Main St On-ramp	No Change	+5%	No Change	No Change
Rudgear Rd On-ramp	+5%	+5%	+10%	No Change
Livorna Rd Off-ramp	+10%	+10%	+10%	No Change
Livorna Rd On-ramp	+10%	+15%	+10%	+5%
Stone Valley Rd Off-ramp	+10%	+10%	+10%	No Change
Stone Valley Rd Off-ramp	+5%	+10%	+5%	No Change
Stone Valley Rd On-ramp	+10%	+15%	+10%	No Change
El Pintado Rd Off-ramp	+5%	+15%	+5%	No Change
El Cerro Blvd Off-ramp	+5%	+10%	No Change	No Change
El Cerro Blvd On-ramp	No Change	+5%	No Change	No Change
Diablo Rd Off-ramp	No Change	+10%	No Change	No Change
Diablo Rd On-ramp	No Change	+10%	No Change	No Change
Sycamore Valley Rd Off-ramp	No Change	+5%	No Change	No Change
Sycamore Valley Rd On-Ramp	No Change	+5%	No Change	No Change
Bollinger Canyon Rd On-ramp	No Change	No Change	+5%	No Change

The resultant MSFR and peak hour flows are compared in Figure B.13 and Figure B.14 (yellow highlights indicate the segments where adjusted MSFR values are used).

Figure B.13 Southbound I-680 MSFR and AM Peak Hour Flow with Adjusted MSFR and CA-24 Connector Not Metered

(balanced volumes for 4:00 AM to 5:00 AM weekdays in November 2019)

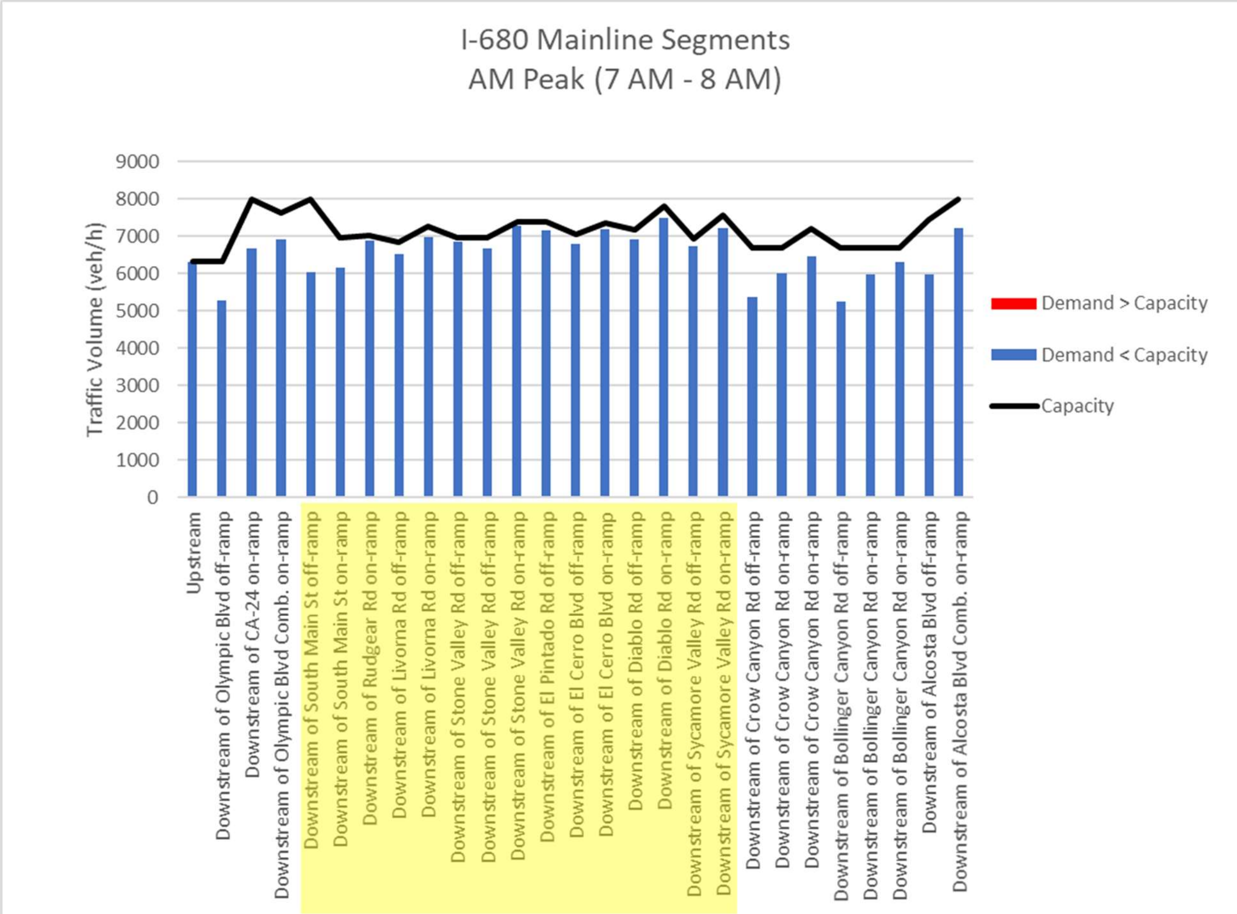
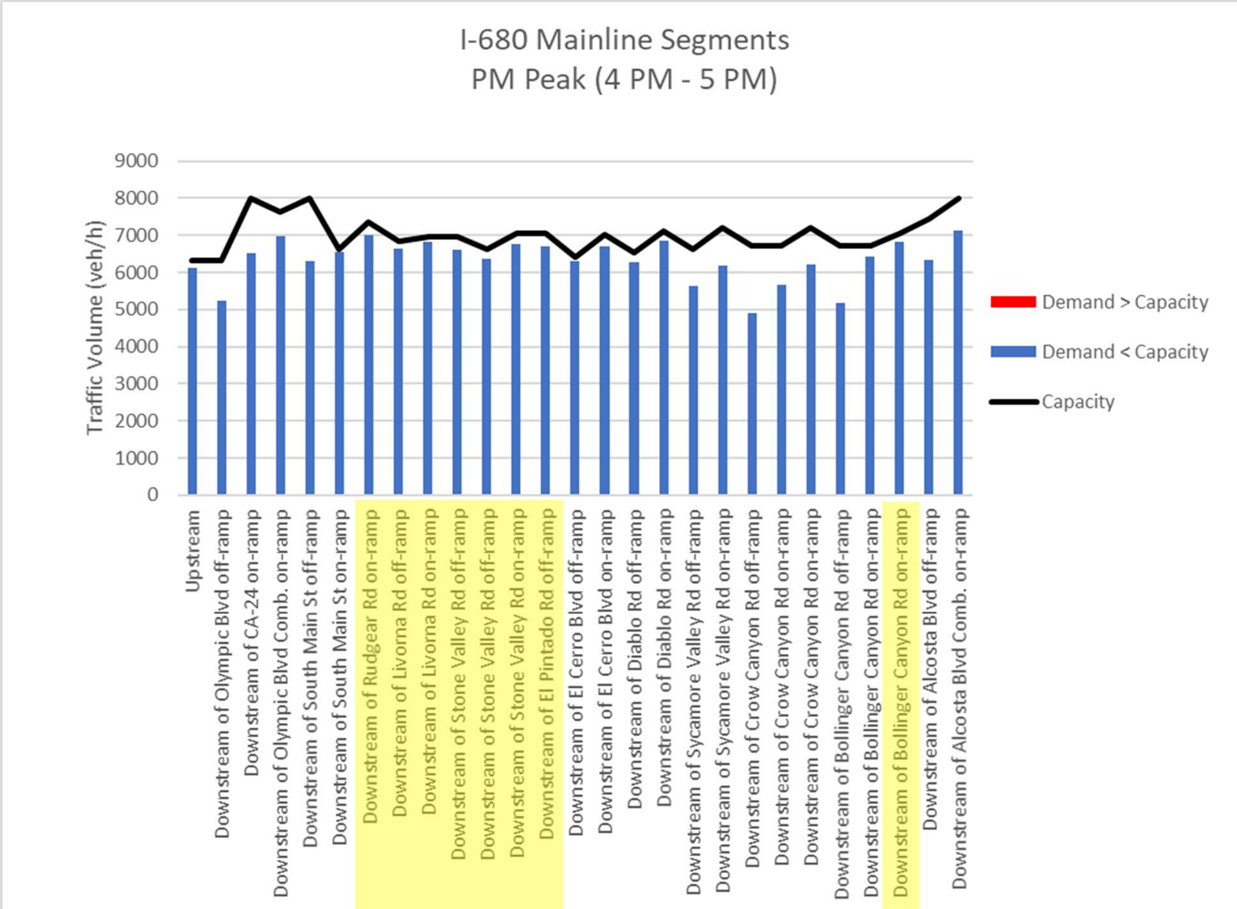


Figure B.14 Southbound I-680 MSFR and PM Peak Hour Flow with Adjusted MSFR and CA-24 Connector Not Metered

(balanced volumes for 4:00 AM to 5:00 AM weekdays in November 2019)



These MSFR adjustments resolve the operational capacity constraints in all segments allowing the R-Model to achieve a feasible solution, although the results for this alternative indicated minimal average wait times and minimal average queue lengths reflecting the assumed availability of sufficient capacity along the freeway mainline to manage traffic flows. However, without metering the CA-24 connector or implementing strategic capacity improvements to the freeway mainline this is not the case under existing conditions, with multiple segments requiring considerable adjustments in MSFR to achieve a simulated CARM solution. Given the MSFR adjustments necessary to achieve a feasible simulation result, the existing traffic flows can be expected to be more effectively managed with CARM, although the existing operational capacity constraints create an elevated risk of flow disruption and breakdown during both the AM and PM peak periods. Metering the CA-24 connector provides greater ability for CARM to managed existing traffic flows within the study corridor potentially deferring the need for strategic capacity expansion or sustained reduced travel demands along southbound I-680 to fully resolve the recurrent bottlenecks.

Appendix C. R-Model Results North of SR-24

C.1 Northbound I-680 R-Model Analysis

The R-model was used to evaluate the feasibility and effectiveness of the CARM strategy to accommodate existing northbound traffic volumes. Both AM period (6:00 AM to 10:00 AM) and PM period (2:00 PM – 7:00 PM) were analyzed. The results are summarized in the following sections.

The analysis of CARM on I-680 north of SR-24 was conducted independently of the analysis of the I-680 south of SR-24 presented in Appendix B and assumes that CARM would be implemented on a stand-alone basis north of SR-24. Therefore, the analysis assumes that traffic traveling north on the I-680 corridor will not be metered as it crosses the junction with SR-24.

If a decision were made to install CARM in the southern section of the corridor in advance of the segment between SR-24 and the Benicia-Martinez Bridge, then the figures presented in this section of the Corridor Evaluation Report would need to be recalculated in order to account for the lower volume of traffic entering I-680 northbound north of SR-2B.

C.1.1 Northbound I-680 Analysis Under Existing Conditions

The R-model was first used to investigate the ability of CARM to manage the northbound traffic flow under the existing corridor configurations. As expected, the initial R-Model analysis was unable to find a viable solution due to multiple mainline capacity constraints discussed previously.

In addition, some of the first several northbound segments, such as the upstream mainline segment and the mainline segment downstream of the *unmetered* CA-24 connector on-ramp, were projected to have MSFR less than the demand for certain hours throughout the day. The capacity deficit at these segments cannot be mitigated through the CARM strategy, as it is not possible to manage the flows at these segments without additional ramp metering at further upstream locations. A separate analysis for further upstream segments between Alameda County Line and CA-24 was performed and summarized in a separate document in 2020[7].

Throughout the study corridor, there are segments with identified flows in excess of MSFR with mainline capacity bottlenecks that are prone to recurring flow breakdown. Sensitivity testing was subsequently conducted to identify a viable R-Model solution and recommend specific improvements and operational management strategies to address these bottlenecks.

C.1.2 Sensitivity Analysis

For this study, the WSP study team performed the sensitivity analysis for two scenarios – one using the existing (2019) roadway configuration to be consistent with the collected traffic

[7] I-680 ADVANCED TECHNOLOGY PROJECT COORDINATED ADAPTIVE RAMP METERING CONCEPT RECOMMENDATION Corridor Evaluation: I-680 Northbound from Alameda County Line to CA-24

data, and a second assuming a potential future roadway configuration where an additional express lane would be added to I-680 northbound between Rudgear Road and CA-242.

Under Existing (2019) Roadway Conditions

As described previously, the existing study corridor experiences operational capacity constraints at multiple mainline segments during certain hours, and as a result, the initial R-Model analysis could not provide a viable solution without adjusting the balance between the freeway mainline capacity (i.e., supply) and existing traffic flows (i.e., demand). This section evaluates the sensitivity of traffic flows to the existing mainline capacity deficit, and assesses the extent to which traffic flow management and mainline capacity improvements can acheive a feasible CARM strategy. The sensitivity analysis also provides results that can guide on ramp requirements (i.e. number of lanes, storage) to facilitate successful CARM implementation.

The intent of the sensitivity analysis is to determine how close the R-Model is to finding a feasible solution with the existing conditions, recognizing the conservative nature of the MSFR calculation assumptions and the ability for CARM to optimize traffic flows. The recommended MSFR adjustments are summarized in Table C.1.

Table C.1 Northbound I-680 MSFR Adjustments for Sensitivity Analysis

Mainline Segment Downstream of	7-8 AM	8-9 AM	2 – 3 PM	3 – 4 PM	4 – 5 PM	5 – 6 PM
Upstream	10%	5%	5%	NA	NA	NA
CA-24 Connector on-ramp	10%	15%	40%	35%	15%	NA
Penniman Way off-ramp	NA	NA	20%	15%	NA	NA
Lawrence Way on-ramp	5%	5%	35%	35%	15%	NA
Treat Blvd off-ramp	NA	NA	25%	25%	10%	NA
Truck Scales on-ramp	NA	NA	5%	5%	NA	NA
Buskirk Ave on-ramp	NA	NA	20%	20%	10%	NA
Oak Rd on-ramp	NA	NA	25%	25%	15%	5%
Contra Costa Blvd off-ramp	NA	NA	15%	20%	10%	NA
Monument Blvd off-ramp	NA	NA	15%	15%	5%	NA
Monument Blvd on-ramp	5%	5%	15%	15%	10%	10%
CA-242 Connector off-ramp	NA	NA	5%	10%	5%	NA

As expected in the Appendix B discussion, the sensitivity analysis suggested that a greater amount of new capacity would be needed in the PM hours than in the AM hours. It should be noted that the CARM strategy is very sensitive to minor changes in MSFR assumptions.

Given the relatively small adjustment needed for the AM hours, and the conservative estimation of MSFR for this study corridor, it is probable that existing traffic flows can be managed effectively with CARM during the AM period. However, the existing operational capacity constraints create a potential risk of isolated flow disruption during the AM hours.

As for the PM hours, substantial additional capacity (>10%) would be needed at multiple mainline locations. While CARM might not be able to fully mitigate the observed congestion for I-680 NB study corridor during the PM hours, it is still expected to deliver benefits such as reducing the duration of congestion (in hours) on the mainline. Furthermore, CARM deployment would provide more refined traffic flow data enabling evaluation of the effect of the system on traffic flows and providing a more definitive recommendation on the need for additional general-purpose lane capacity.

With these MSFR adjustment assumptions, the R-Model evaluation for the overall on-ramp storage requirements across the simulation period (6 AM – 10 AM and 2 PM – 7 PM) is shown in Table C.2. It suggests that four of the twelve on-ramps along the study corridor would benefit from additional storage space under a potential CARM strategy implementation.

Table C.2 Northbound I-680 On-Ramp Storage Requirements for CARM Deployment

On-Ramp Location (South to North)	95th Percentile Storage Needs (ft)	Existing Storage (ft)	Existing Storage Sufficient?
CA-24 Connector*	NA	NA	NA
Lawrence Way	2,190	1,140	✗
Truck Scales*	NA	NA	NA
Buskirk Ave	2,300	177	✗
Oak Rd	1,270	414	✗
Monument Blvd	1,350	400	✗
Sunvalley Blvd	120	930	✓
Burnett Ave	30	309	✓
Concord Ave	60	674	✓
CA-4	150	3,551	✓
Arthur Rd	60	428	✓
Marina Vista Ave	60	300	✓

* Unmetered on-ramps

Given that the sensitivity analysis found existing corridor conditions exceeding MSFR at several locations, and the potential of the CARM system to be stressed when managing northbound traffic flows, the availability of additional discharge capacity is recommended at several ramp locations to allow vehicles to access the mainline more quickly when capacity is available. VicDOT *Managed Motorway Design Guide*[8] generally recommends one lane of discharge capacity for each 500 vehicles of flow on a given ramp during the peak hour. Based on this guidance, several ramp locations would require additional ramp discharge capacity at the metering threshold to accommodate existing and future ramp volumes. Table C.3 summarizes the ramp discharge recommendations and other key findings for the 4-hour AM peak period and 5-hour PM peak simulation periods. As shown in the table, additional

[8] Victoria State Government, Department of Transport, VicDOT. *Managed Motorway Design Guide* Volume 2: Design Practice Part 3: Motorway Planning and Design, Section 6.2 Ramp Discharge Capacity for Design. VicDOT, Melbourne, VIC., Australia, June 2019.

discharge capacity is desired at all on-ramp locations except for the Arthur Rd on-ramp to meet peak ramp volumes.

Table C.3 Northbound I-680 On-Ramp Discharge Requirements for CARM Deployment

On-Ramp Location	Existing Number of Discharge Lanes	95th Percentile Ramp Volume across All Simulation Hours (veh/hr)	95th Percentile Wait Time across All Simulation Hours (minutes)	Recommended Number of Discharge Lanes
CA-24 Connector	NA	4,450	NA	NA
Lawrence Way	2	1,650	3.1	4
Truck Scales	NA	40	NA	NA
Buskirk Ave	1	1,320	4	3
Oak Rd	1	890	4	2
Monument Blvd	1	1,180	4	3
Sunvalley Blvd	2	1,040	0.4	3
Burnett Ave	1	670	0.2	2
Concord Ave	1	710	0.3	2
CA-4	1	1,330	0.3	3
Arthur Rd	1	420	0.3	1
Marina Vista Ave	1	590	0.3	2

Under Potential Future Roadway Conditions

In addition to the existing (2019) lane configurations, the WSP study team also performed the sensitivity analysis under a possible future I-680 lane configuration, where an additional managed lane would be constructed between the Rudgear Rd Interchange (south of the study area) and the CA-242 connector. This potential managed lane project would tie in with the existing HOV lane / express lane north of CA-242, to create a continuous managed lane system on I-680 in the NB direction.

This section evaluates the sensitivity of traffic flows to the updated mainline capacity (with the potential managed lane project), and to assess the extent to which traffic flow management and additional mainline capacity improvements can result in a feasible CARM strategy. With the potential managed lane project, the recommended MSFR adjustments are summarized in Table C.4. It should be noted that this scenario assumes 2019 demand, and does not account for any induced demand or change in traffic pattern due to mainline capacity improvements.

Table C.4 Northbound I-680 MSFR Adjustments with Potential Managed Lane Project for Sensitivity Analysis

Mainline Segment Downstream of	7-8 AM	8-9 AM	2 – 3 PM	3 – 4 PM	4 – 5 PM	5 – 6 PM
CA-24 Connector on-ramp	10%	10%	35%	30%	10%	NA
Penniman Way off-ramp	NA	NA	15%	10%	NA	NA
Lawrence Way on-ramp	NA	5%	30%	30%	15%	NA

Mainline Segment Downstream of	7-8 AM	8-9 AM	2 – 3 PM	3 – 4 PM	4 – 5 PM	5 – 6 PM
Treat Blvd off-ramp	NA	NA	20%	20%	10%	NA
Truck Scales on-ramp	NA	NA	5%	5%	NA	NA
Buskirk Ave on-ramp	NA	NA	15%	15%	5%	NA
Oak Rd on-ramp	NA	NA	20%	20%	15%	5%
Contra Costa Blvd off-ramp	NA	NA	15%	15%	10%	NA
Monument Blvd off-ramp	NA	NA	10%	15%	5%	NA
Monument Blvd on-ramp	NA	NA	5%	5%	5%	10%

It should be noted that because of the added managed lane, both the extent and the magnitude of the required MSFR adjustments are smaller compared to those in Table C.3. Similar to the finding before, the sensitivity analysis suggested that more additional capacity would be needed in the PM hours than in the AM hours.

Given the relatively small adjustment needs for the AM hours, and the conservative estimation of MSFR for this study corridor, the existing traffic flows can still be managed effectively with CARM during the AM period, although the existing operational capacity constraints create a potential risk of isolated flow disruption during the AM hours.

As for the PM hours, substantial additional capacity (>10%) were still needed at multiple mainline locations. While CARM might not be able to fully mitigate the observed congestion for I-680 NB study corridor during the PM hours, it is expected to still deliver benefits such as reducing the congested time length (in hours) on the freeway mainline. Furthermore, CARM deployment would provide more refined traffic flow data enabling evaluation of the effect of the system on traffic flows and providing a more definitive recommendation on the need for additional general-purpose lane capacity.

With these MSFR adjustment assumptions under the potential future lane configurations with the I-680 NB managed lane project, the R-Model evaluation for the overall on-ramp storage requirements across the simulation period (6 AM – 10 AM and 2 PM – 7 PM) is shown in Table C.5. It shows that four of 12 on-ramps along the study corridor would benefit from additional storage space under a potential CARM strategy implementation.

Table C.5 Northbound I-680 On-Ramp Storage Requirements for CARM Deployment

On-Ramp Location (South to North)	95th Percentile Storage Needs (ft)	Existing Storage (ft)	Existing Storage Sufficient?
CA-24 Connector*	NA	NA	NA
Lawrence Way	2,800	1,140	✗
Truck Scales*	NA	NA	NA
Buskirk Ave	2,330	177	✗
Oak Rd	1,070	414	✗
Monument Blvd	1,270	400	✗
Sunvalley Blvd	120	930	✓
Burnett Ave	30	309	✓

On-Ramp Location (South to North)	95th Percentile Storage Needs (ft)	Existing Storage (ft)	Existing Storage Sufficient?
Concord Ave	60	674	✓
CA-4	150	3,551	✓
Arthur Rd	60	428	✓
Marina Vista Ave	60	300	✓

* Unmetered on-ramps

As mentioned previously, the availability of additional discharge capacity is recommended at several ramp locations to allow vehicles to access the mainline more quickly when capacity is available. Following VicDOT discharge lane capacity assumption (500veh/hr), several ramp locations would require additional ramp discharge capacity at the metering threshold to accommodate existing and future ramp volumes. Table C.6 summarizes the ramp discharge recommendations and other key findings for the 4-hour AM peak period and 5-hour PM peak simulation periods. Similar to the finding in Table C.2, additional discharge capacity is desired at all on-ramp locations except for the Arthur Rd on-ramp to meet peak ramp volumes.

Table C.6 Northbound I-680 On-Ramp Discharge Requirements for CARM Deployment

On-Ramp Location	Existing Number of Discharge Lanes	95th Percentile Ramp Volume across All Simulation Hours (veh/hr)	95th Percentile Wait Time across All Simulation Hours (minutes)	Recommended Number of Discharge Lanes
CA-24 Connector	NA	4,440	NA	NA
Lawrence Way	2	1,660	3.9	4
Truck Scales	NA	40	NA	NA
Buskirk Ave	1	1,330	4	3
Oak Rd	1	850	4	2
Monument Blvd	1	1,180	2.7	3
Sunvalley Blvd	2	1,040	0.4	3
Burnett Ave	1	670	0.2	2
Concord Ave	1	710	0.3	2
CA-4	1	1,330	0.3	3
Arthur Rd	1	420	0.3	1
Marina Vista Ave	1	590	0.3	2

C.2 Southbound I-680 R-Model Analysis

The R-model was also used to evaluate the feasibility and effectiveness of implementing CARM strategy to manage existing southbound traffic volumes in the I-680 study corridor in the morning (6:00 AM to 10:00 AM) and evening (2:00 PM – 7:00 PM) peak periods. The results are summarized in the sections that follow.

C.2.1 Southbound I-680 Analysis Under Existing Conditions

The R-model was first used to investigate the ability for CARM to manage the southbound traffic flows under the existing corridor configurations. Similar to the northbound analysis, the initial R-Model analysis could not yield a viable solution due to multiple mainline capacity constraints identified previously.

Similarly, throughout the study corridor, the southbound segments with identified flows in excess of MSFR are mainline capacity bottlenecks that are prone to recurring flow breakdown. Further sensitivity testing was also conducted as the basis for finding a viable R-Model solution and recommending specific improvements and operational management strategies.

C.2.2 Sensitivity Analysis

For this study, the WSP study team performed the sensitivity analysis for two scenarios – one under the 2019 roadway configurations to be consistent with the collected traffic data, and one under the existing (2021) roadway configurations where the existing express lane was recently extended in the I-680 SB direction between San Luis Rd and past the end of the study corridor at the Hillside Ave on-ramp, in addition to new lane pavement markings.

Under Existing (2019) Roadway Conditions

As with the northbound analysis, sensitivity testing was then conducted as the basis for achieving a viable R-Model solution and recommending specific improvements and operational management strategies for southbound I-680. This section describes the alternative improvements and assumptions considered to assess the sensitivity of existing traffic flows to mainline capacity deficits and evaluates the extent that traffic flow management and/or mainline capacity improvements can produce a feasible CARM strategy. The sensitivity analysis results also provide guidance on ramp requirements (i.e. number of lanes, storage) for a successful CARM implementation. Consistent with the MSFR evaluation discussed previously, the study team performed analyses on two alternatives comparing different strategies for managing the mainline flow from the Benicia Martinez Bridge down to the CA-24 connector.

This scenario assumes that all on-ramps, aside from the CA-242 connector, in the study corridor shall be metered to manage the southbound mainline traffic flow in the I-680 study corridor between the Benicia Martinez Bridge and CA-24. The adjusted MSFR values were analyzed for select mainline segments to evaluate how close the R-Model is to finding a feasible solution for managing existing conditions. MSFR adjustments were made for the segments shown in Table C.7.

Table C.7 Southbound I-680 MSFR Adjustments for Sensitivity Analysis

Mainline Segment Downstream of	6-7 AM	7-8 AM	8-9 AM	9-10 AM	2-3 PM	3-4 PM	4-5 PM	5-6 PM
Benicia Martinez Bridge	NA	+5%	NA	NA	NA	NA	NA	NA
Waterfront Rd off-ramp	NA	+5%	NA	NA	NA	NA	NA	NA
Waterfront Rd on-ramp	NA	+5%	NA	NA	NA	NA	NA	NA
CA-4 on-ramp	NA	+15%	+5%	NA	NA	NA	NA	NA
CA-242 on-ramp	+10%	+10%	NA	+10%	+5%	+5%	+10%	+10%

Mainline Segment Downstream of	6-7 AM	7-8 AM	8-9 AM	9-10 AM	2-3 PM	3-4 PM	4-5 PM	5-6 PM
Contra Costa Blvd on-ramp	NA	+5%	NA	NA	NA	NA	NA	NA
N Main St on-ramp	NA	+5%	NA	NA	NA	NA	NA	NA
San Luis Rd off-ramp	+25%	+20%	+5%	+15%	+10%	+15%	+20%	+10%
San Luis Rd on-ramp	+35%	+35%	+15%	+20%	+15%	+15%	+20%	+15%
CA-24 off-ramp	+10%	+15%	NA	NA	NA	+5%	+10%	NA

As expected, the sensitivity analysis suggested that more additional capacity would be needed for both the AM and PM peak hours. It should be noted once again that the CARM strategy is very sensitive to only minor changes in MSFR assumptions.

In the AM period, substantial adjustments for additional capacity (>10%) were needed at multiple mainline locations. Similarly, although the PM period required relatively smaller adjustments than in the AM period, it should still be noted that they were still substantial in terms of additional capacity While CARM might not be able to fully mitigate the observed congestion for I-680 SB study corridor during both periods, it is expected to still deliver benefits such as reducing the congested time length (in hours) on the freeway mainline. Furthermore, CARM deployment would provide more refined traffic flow data enabling evaluation of the effect of the system on traffic flows and providing a more definitive recommendation on the need for additional general-purpose lane capacity.

With the MSFR adjustments, the R-Model evaluation for the overall on-ramp storage requirements across the simulation period (6 AM – 10 AM and 2 PM – 7 PM) is shown in Table C.8. It suggests that four of the 12 on-ramps along the study corridor would benefit from additional storage space under a potential CARM strategy implementation.

Assuming the VicDOT standard of one lane of discharge capacity for each 500 vehicles of flow on the ramp during the peak hour, mentioned earlier, four of the ramp locations will require additional ramp discharge capacity at the metering threshold. Ramp discharge recommendations and other key findings are summarized in Table C.9. As shown in the table, additional discharge capacity is desired at all on-ramp locations, except for the Concord Ave and Treat Blvd on-ramps, to meet peak ramp volumes.

Table C.8 Southbound I-680 On-Ramp Storage Requirements for CARM Deployment

On-Ramp Location (North to South)	95th Percentile Storage Needs (ft)	Existing Storage (ft)	Existing Storage Sufficient?
Waterfront Rd	140	1,250	✓
Pacheco Blvd	290	1,170	✓
CA-4	820	4,667	✓
Contra Costa Blvd	700	312	✗
Concord Ave	370	514	✓
Sunvalley Blvd Loop	510	543	✓
Sunvalley Blvd Direct	620	715	✓

On-Ramp Location (North to South)	95th Percentile Storage Needs (ft)	Existing Storage (ft)	Existing Storage Sufficient?
CA-242*	NA	NA	NA
Monument Blvd	1,040	835	✗
Contra Costa Blvd	680	608	✗
N Main St	1,260	152	✗
Treat Blvd	280	296	✓
San Luis Rd	60	1300	✓
Hillside Ave	120	1332	✓

* Unmetered on-ramps

Table C.9 Southbound I-680 On-Ramp Discharge Requirements for CARM Deployment

On-Ramp Location (North to South)	Existing Number of Discharge Lanes	95th Percentile Ramp Volume (veh/hr)	95th Percentile Wait Time (minutes)	Recommended Number of Discharge Lanes
Waterfront Rd	1	580	1	2
Pacheco Blvd	1	850	1	2
CA-4	1	2,330	1.3	5
Contra Costa Blvd	1	740	2.3	2
Concord Ave	1	360	2.3	1
Sunvalley Blvd Loop	1	500	2.9	2
Sunvalley Blvd Direct	1	620	2.8	2
CA-242	NA	3,640	NA	NA
Monument Blvd	1	900	3.1	2
Contra Costa Blvd	1	830	3	2
N Main St	1	1,050	3	3
Treat Blvd	1	280	2.3	1
San Luis Rd	2	1,060	0.2	3
Hillside Ave	2	1,350	0.3	3

Under 2021 Roadway Conditions

The WSP team also performed the sensitivity analysis of the more recently implemented I-680 express lane configuration, with the managed lane extended past the Hillside Ave on-ramp with new pavement markings to tie in with the existing HOV lane / express lane north of Treat Blvd and the section south of SR-24 to Alcosta Blvd, creating a continuous managed lane system in the SB direction. This scenario assumes 2019 demand and does not account for the induced demand/change in traffic patterns due to the new managed lane.

This section evaluates the sensitivity of traffic flows to the updated mainline capacity (with the recently implemented managed lane project), and to assess the extent to which traffic flow management and additional mainline capacity improvements can result in a feasible CARM strategy. The sensitivity analysis also provides results that can guide on ramp requirements (i.e. number of lanes, storage) under a successful CARM implementation. With the implemented express lane extension, the recommended MSFR adjustments are summarized in Table C.10.

Table C.10 Southbound I-680 MSFR Adjustments for Sensitivity Analysis

Mainline Segment Downstream of	6-7 AM	7-8 AM	8-9 AM	9-10 AM	2-3 PM	3-4 PM	4-5 PM	5-6 PM
Benicia Martinez Bridge	+5%	+5%	NA	NA	NA	NA	NA	NA
Waterfront Rd off-ramp	NA	+5%	NA	NA	NA	NA	NA	NA
CA-4 on-ramp	NA	+15%	+5%	NA	NA	NA	NA	NA
CA-242 on-ramp	+10%	+10%	NA	+10%	+5%	+5%	+10%	+10%
Contra Costa Blvd on-ramp	NA	+5%	NA	NA	NA	NA	NA	NA
N Main St on-ramp	+5%	+5%	NA	NA	NA	NA	NA	NA
Treat Blvd on-ramp	+5%	+5%	NA	NA	NA	NA	NA	NA
San Luis Rd off-ramp	+10%	+5%	NA	NA	NA	NA	+5%	NA
San Luis Rd on-ramp	+30%	+25%	+10%	+10%	+10%	+10%	+15%	+5%
CA-24 off-ramp	NA	+5%	NA	NA	NA	NA	NA	NA

It should be noted that because of the extended managed lane, both the extent and the magnitude of the required MSFR adjustments are smaller compared to those in Table C.5 As expected from the previous MSFR section, the sensitivity analysis suggested that more additional capacity in the southbound direction would be needed in the AM hours than in the PM hours.

During both periods, substantial additional capacity adjustments (>10%) were still needed at multiple mainline locations. However, with the extension of the southbound express lane, overall capacity adjustments were slightly smaller than needed for the 2019 conditions. This was especially true for the remaining segments south of the San Luis Rd off-ramp. While CARM might not be able to fully mitigate the observed congestion for I-680 SB study corridor during both periods, it is expected to still deliver benefits such as reducing the congested time length (in hours) on the freeway mainline. Furthermore, CARM deployment would provide more refined traffic flow data enabling evaluation of the effect of the system on traffic flows and providing a more definitive recommendation on the need for additional general-purpose (GP) lane capacity.

With the MSFR adjustments under the 2021 lane configurations with the I-680 SB managed lane project, the R-Model evaluation is shown in Table C.11. It suggests that two of 12 on-ramps would benefit from additional storage space under a potential CARM implementation, compared to the four on-ramps previously stated under the existing 2019 conditions.

Table C.11 Southbound I-680 On-Ramp Storage Requirements for CARM Deployment

On-Ramp Location (North to South)	95th Percentile Storage Needs (ft)	Existing Storage (ft)	Existing Storage Sufficient?
Waterfront Rd	290	1,250	✓
Pacheco Blvd	120	1,170	✓
CA-4	200	4,667	✓

On-Ramp Location (North to South)	95th Percentile Storage Needs (ft)	Existing Storage (ft)	Existing Storage Sufficient?
Contra Costa Blvd	730	312	✘
Concord Ave	370	514	✓
Sunvalley Blvd Loop	510	543	✓
Sunvalley Blvd Direct	560	715	✓
CA-242*	NA	NA	NA
Monument Blvd	400	835	✓
Contra Costa Blvd	450	608	✓
N Main St	900	152	✘
Treat Blvd	230	296	✓
San Luis Rd	280	1,300	✓
Hillside Ave	120	1,332	✓

* Unmetered on-ramps

Once again, assuming the VicDOT standard of one lane of discharge capacity for each 500 vehicles of flow on the ramp during the peak hour, two of the ramp locations will require additional ramp discharge capacity at the metering threshold. Ramp discharge recommendations and other key findings are summarized in Table C.12. Similar to the 2019 scenario simulation results, Table C.12 shows that additional discharge capacity is desired at all on-ramp locations, except for the Concord Ave and Treat Blvd on-ramps, to meet peak ramp volumes.

Table C.12 Southbound I-680 On-Ramp Discharge Requirements for CARM Deployment

On-Ramp Location (North to South)	Existing Number of Discharge Lanes	95th Percentile Ramp Volume (veh/hr)	95th Percentile Wait Time (minutes)	Recommended Number of Discharge Lanes
Waterfront Rd	1	580	3.2	2
Pacheco Blvd	1	850	0.3	2
CA-4	1	2,320	0.3	5
Contra Costa Blvd	1	730	2.3	2
Concord Ave	1	360	2.3	1
Sunvalley Blvd Loop	1	500	2.3	2
Sunvalley Blvd Direct	1	620	2.3	2
CA-242	NA	3,640	NA	NA
Monument Blvd	1	870	2	2
Contra Costa Blvd	1	820	2	2
N Main St	1	1,020	2	3
Treat Blvd	1	270	2	1
San Luis Rd	2	1,060	2.1	3
Hillside Ave	2	1,350	0.3	3

Appendix D. Conceptual Design Sheets

This appendix provides conceptual design sheets showing the recommended interchange reconfigurations for all access points to I-680 in Contra Costa County to support CARM operations on the freeway. The drawings provide the following information:

1. The number of lanes needed at the stop bar
2. The location of ramp access signage
3. The location of back-of queue detectors
4. The location of mid-queue detectors
5. The location of the stop bar, together with the demand zone detectors and passage zone detectors
6. The location of CHP enforcement areas
7. Merge zones
8. The limits of the existing Caltrans right-of-way
9. Any required right-of-way acquisitions
10. Any required structure widenings

The drawings begin in at the southern limit of the study corridor and continue north, showing both northbound and southbound directions as they progress. Individual sheets providing drawings for the different interchanges are referenced in Tables 5-1 through 5-4. The drawings also identify all interchange-related civil and ITS improvements that are included in the cost estimates presented in Chapter 5.

SEE SHEET L-2

CONTRA COSTA transportation authority

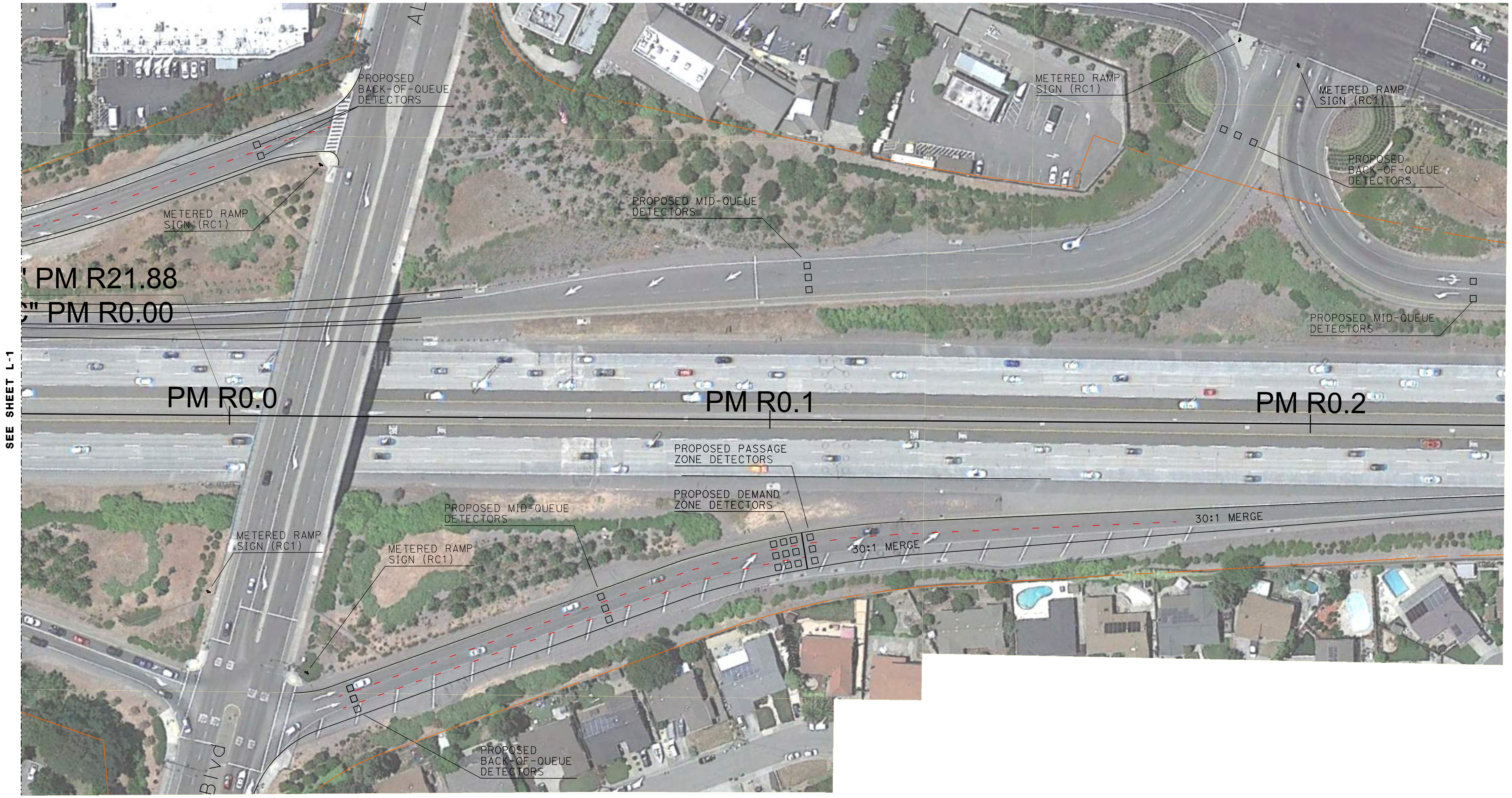
LEGEND

- EXISTING CALTRANS R/W
- R/W ACQUISITION
- STRUCUTRE WIDENING
- NEW RETAINING WALL

INNOVATE 680
FEASIBILITY STUDY
SB ALCOSTA Blvd

SCALE: 1"=100'

L-1



Caltrans

CONTRA COSTA transportation authority

wsp

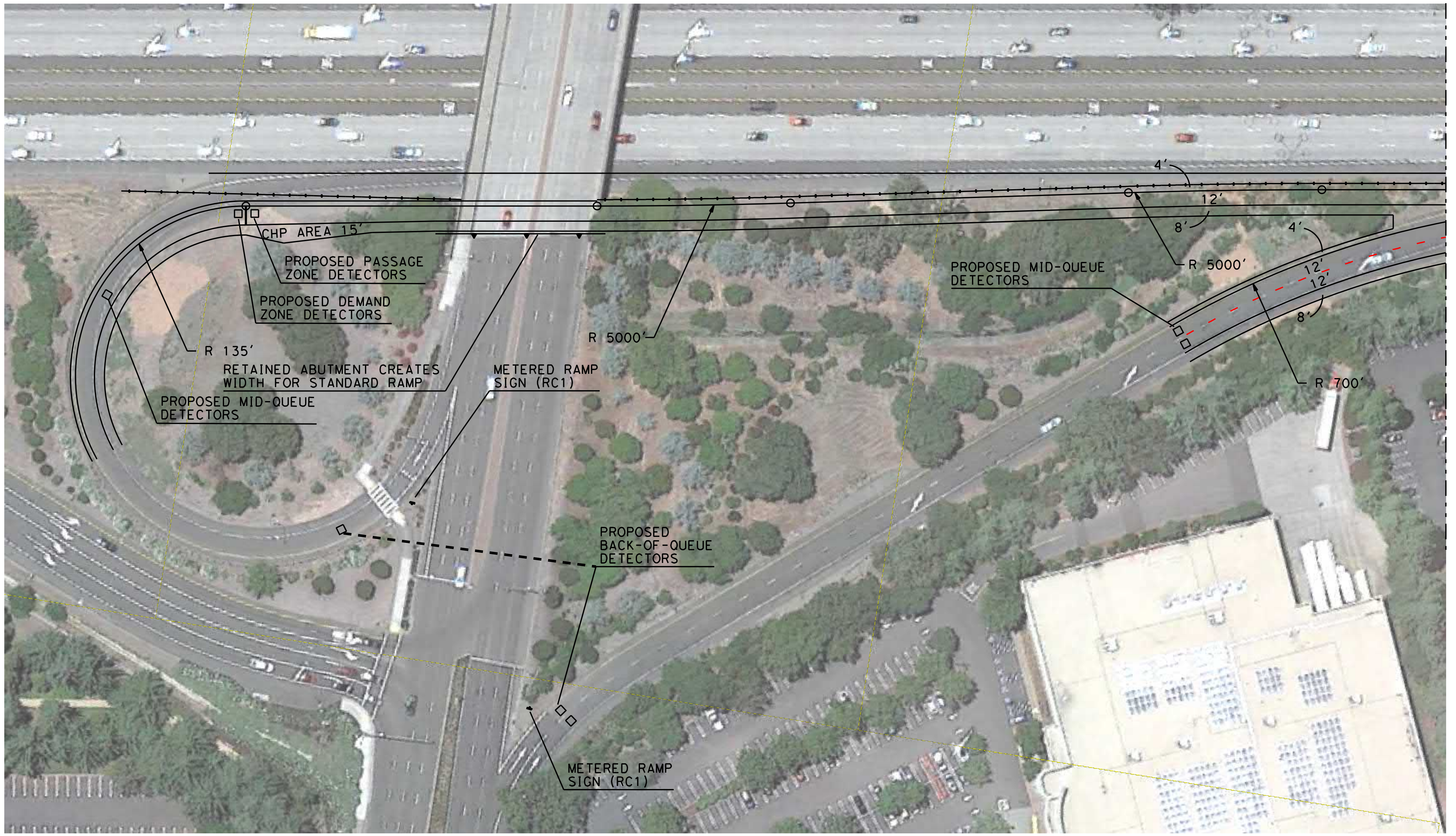
LEGEND

- EXISTING CALTRANS R/W
- R/W ACQUISITION
- STRUCUTRE WIDENING
- NEW RETAINING WALL

INNOVATE 680
FEASIBILITY STUDY
NB & SB ALCOSTA Blvd

SCALE: 1"=100'

L-2



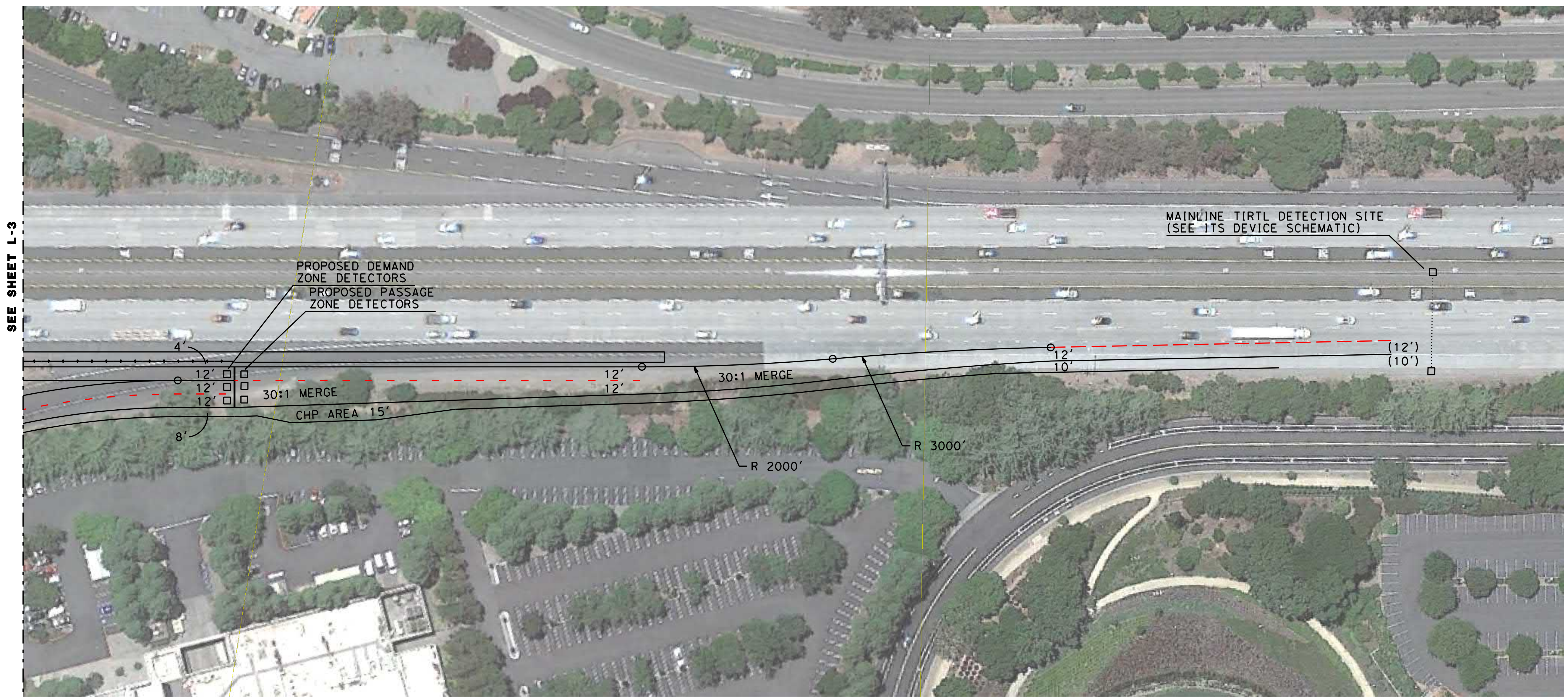
Caltrans

CONTRA COSTA transportation authority

wsp

INNOVATE 680
FEASIBILITY STUDY
NB BOLLINGER CANYON Rd

SCALE: 1"=100'



INNOVATE 680
FEASIBILITY STUDY
NB BOLLINGER CANYON Rd

SCALE: 1"=100'

Caltrans

CONTRA COSTA
transportation
authority

wsp

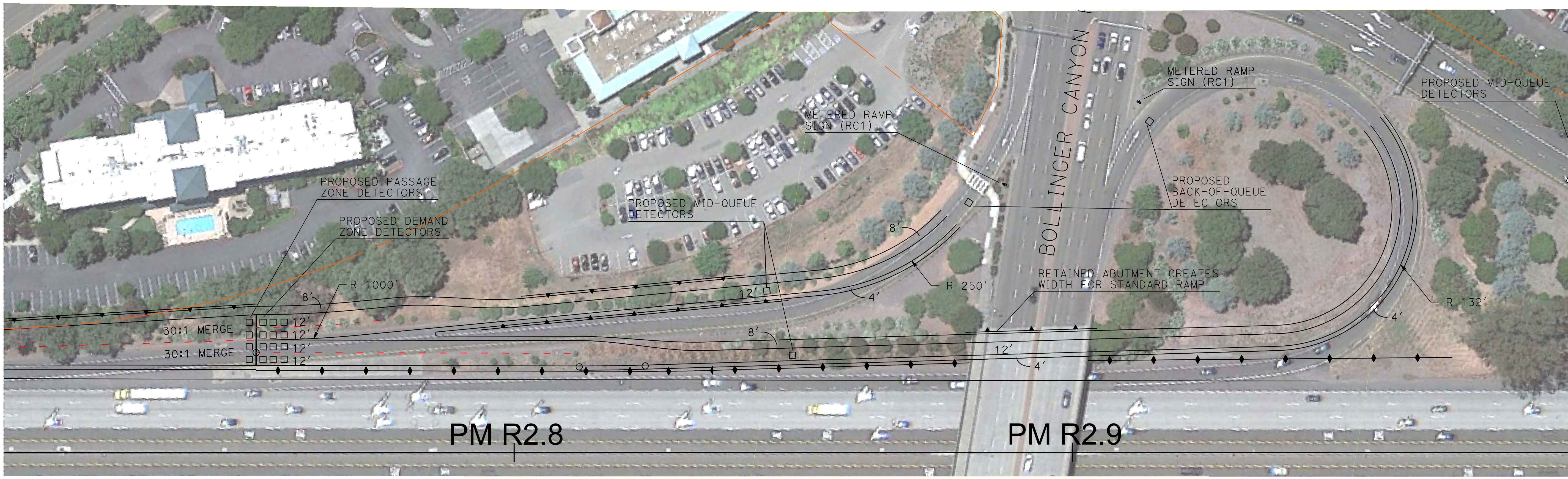
LEGEND

EXISTING CALTRANS R/W
R/W ACQUISITION
STRUCUTRE WIDENING
NEW RETAINING WALL

INNOVATE 680
FEASIBILITY STUDY
SB BOLLINGER CANYON Rd

SCALE: 1"=100'

SEE SHEET L-5



LEGEND

EXISTING CALTRANS R/W
R/W ACQUISITION
STRUCUTRE WIDENING
NEW RETAINING WALL

INNOVATE 680
FEASIBILITY STUDY
SB BOLLINGER CANYON Rd

SCALE: 1"=100'

SEE SHEET L-6

LEGEND

- EXISTING CALTRANS R/W
- R/W ACQUISITION
- STRUCUTRE WIDENING
- NEW RETAINING WALL

CONTRA COSTA transportation authority

INNOVATE 680
FEASIBILITY STUDY
SB BOLLINGER CANYON Rd

SCALE: 1"=100'

LEGEND

- EXISTING CALTRANS R/W
- R/W ACQUISITION
- STRUCUTRE WIDENING
- NEW RETAINING WALL

Caltrans

CONTRA COSTA transportation authority

wsp

INNOVATE 680 FEASIBILITY STUDY SB BOLLINGER CANYON Rd

SCALE: 1"=100'

SEE SHEET L-8

INNOVATE 680
FEASIBILITY STUDY
NB CROW CANYON Rd

SCALE: 1"=100'

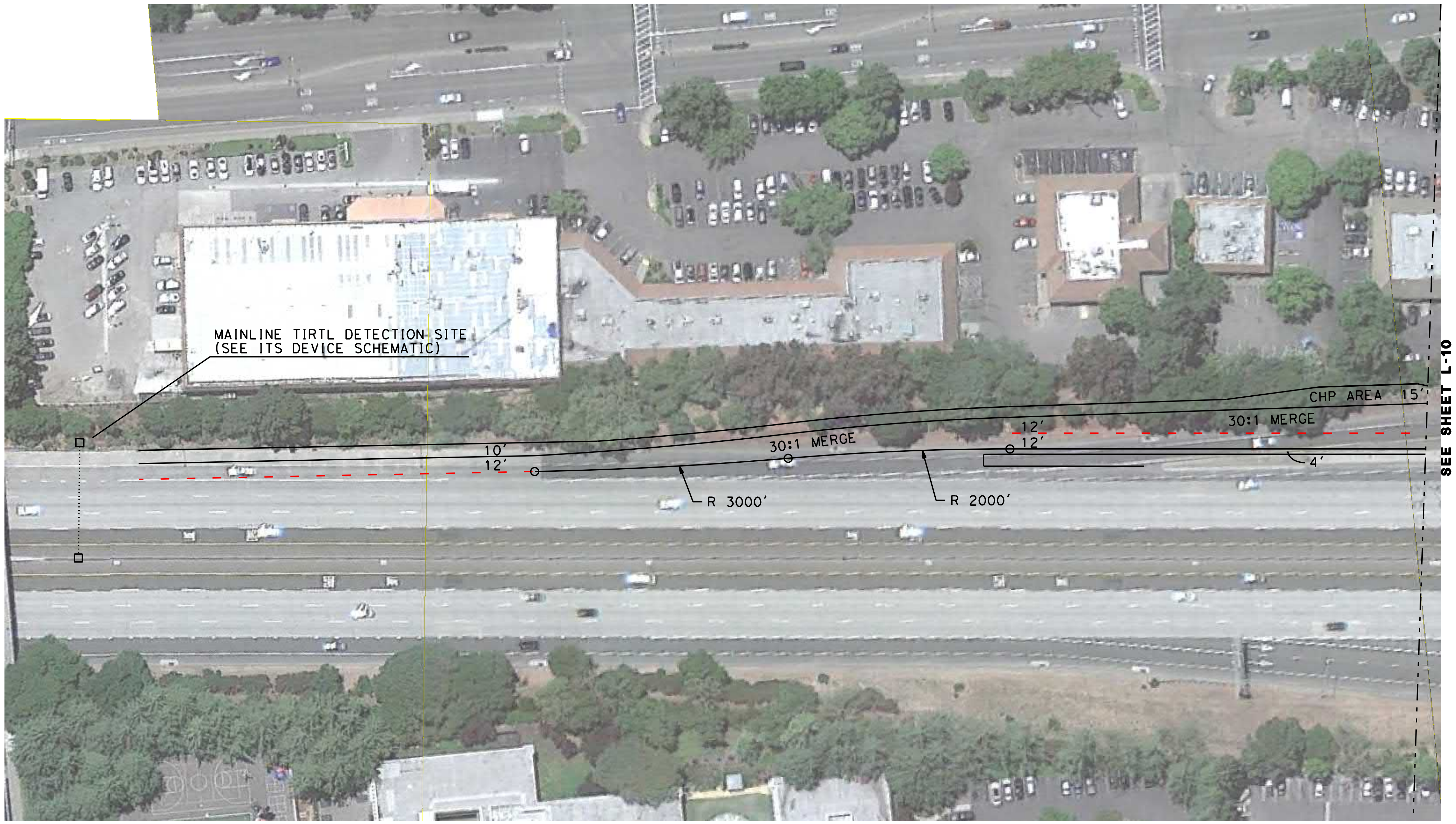
Caltrans

CONTRA COSTA transportation authority

wsp

INNOVATE 680
FEASIBILITY STUDY
NB CROW CANYON Rd

SCALE: 1"=100'



INNOVATE 680
FEASIBILITY STUDY
SB CROW CANYON Rd

SCALE: 1"=100'

SEE SHEET L-9

Caltrans

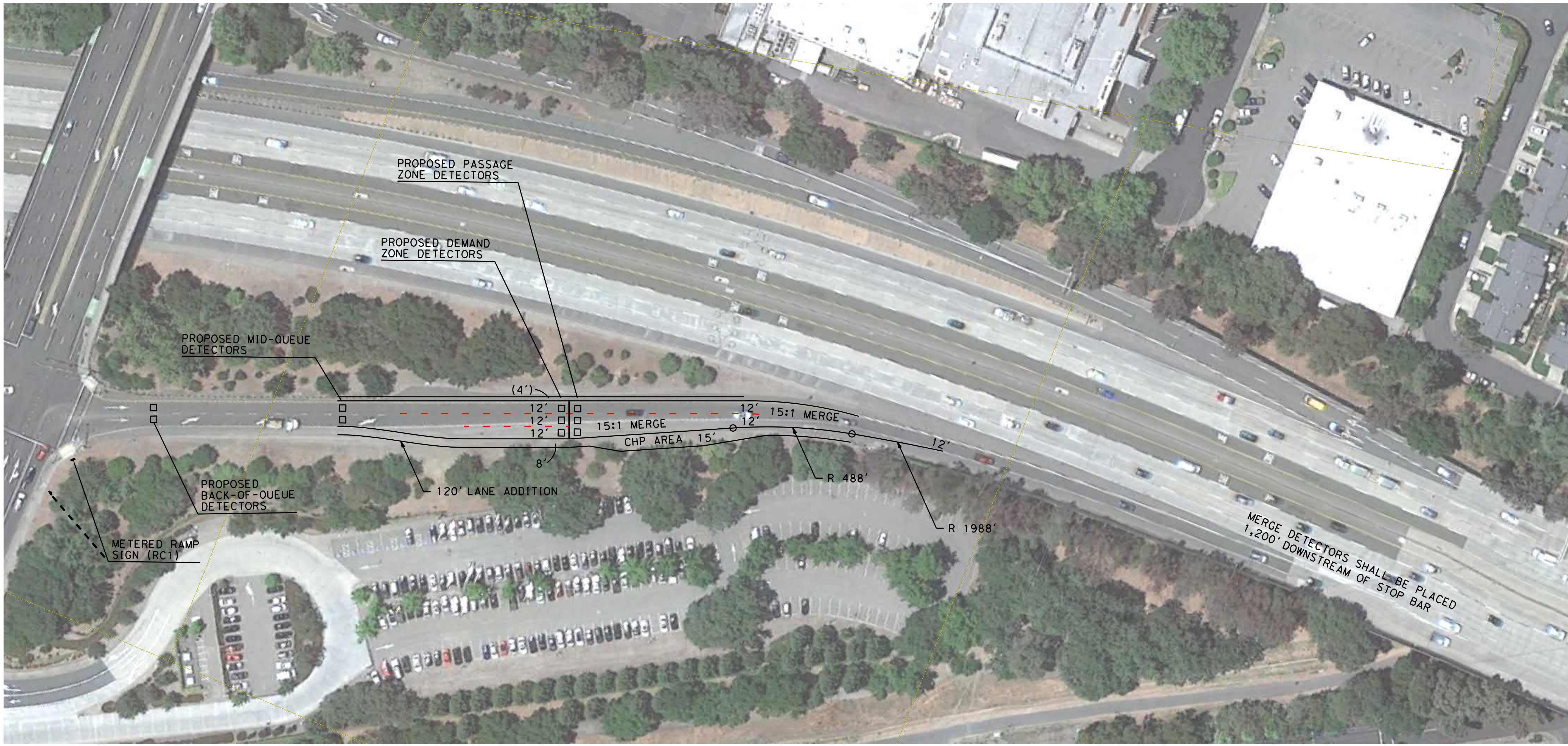
CONTRA COSTA transportation authority

wsp

INNOVATE 680 FEASIBILITY STUDY

SB CROW CANYON Rd

SCALE: 1"=100'



Caltrans®

CONTRA COSTA
transportation
authority

wsp

INNOVATE 680
FEASIBILITY STUDY
NB SYCAMORE VALLEY Rd

SCALE: 1"=100'

Caltrans

CONTRA COSTA transportation authority

wsp

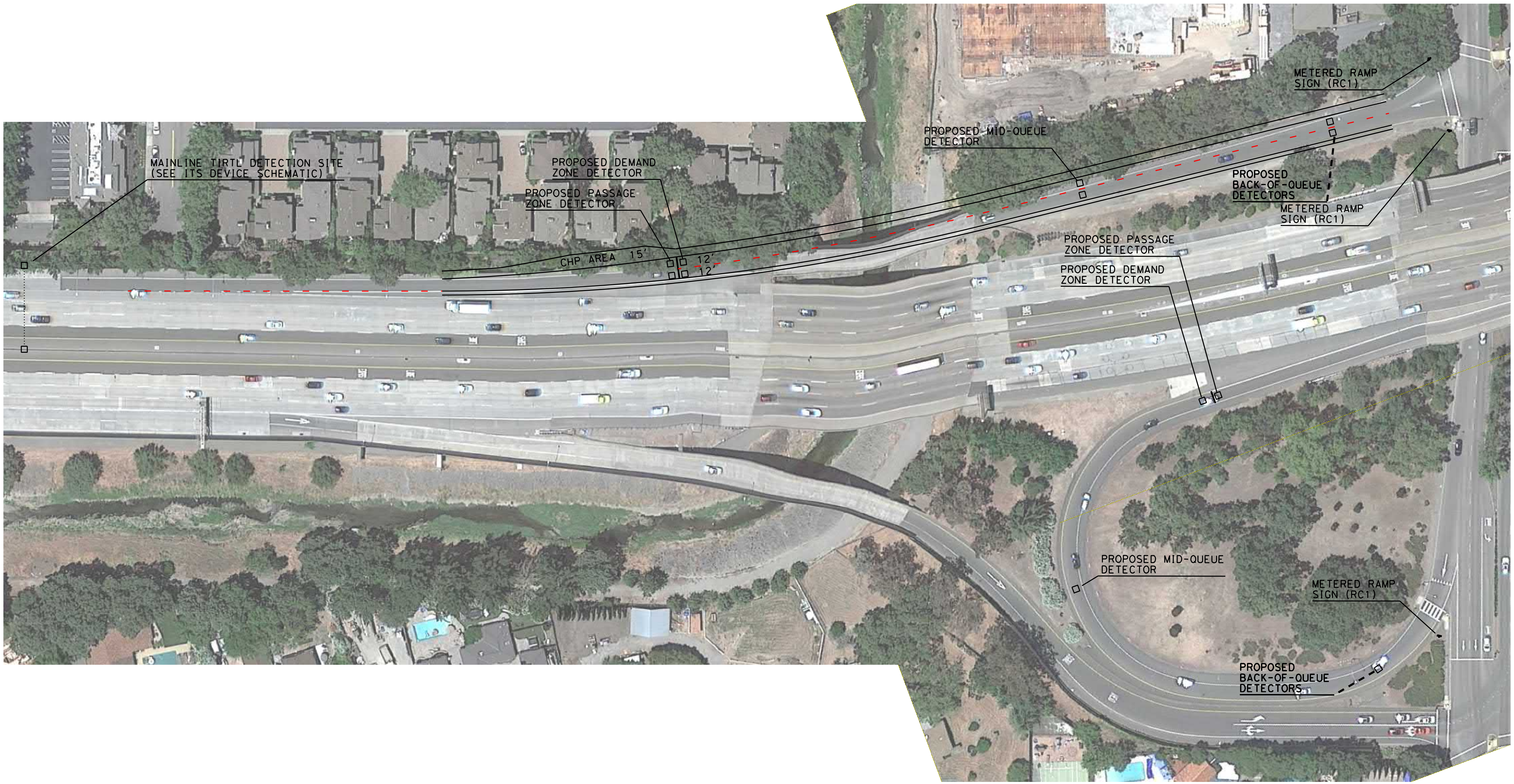
LEGEND

- EXISTING CALTRANS R/W
- R/W ACQUISITION
- STRUCUTRE WIDENING
- NEW RETAINING WALL

INNOVATE 680
FEASIBILITY STUDY
SB SYCAMORE VALLEY Rd

SCALE: 1"=100'

L-12

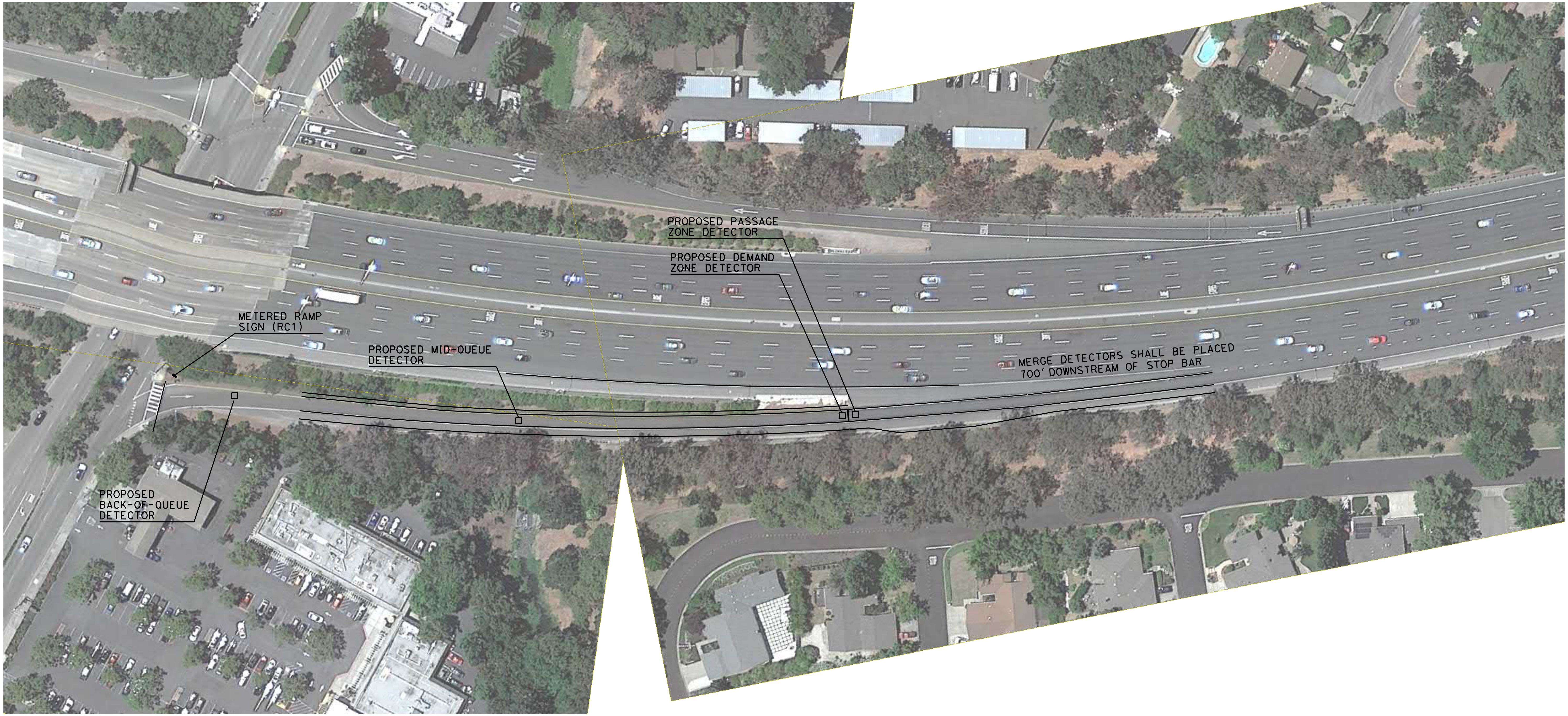


CONTRA COSTA transportation authority

INNOVATE 680
FEASIBILITY STUDY
NB & SB DIABLO Rd

SCALE: 1"=100'

L-13



CONTRA COSTA transportation authority

INNOVATE 680
FEASIBILITY STUDY
NB DIABLO Rd

SCALE: 1"=100'

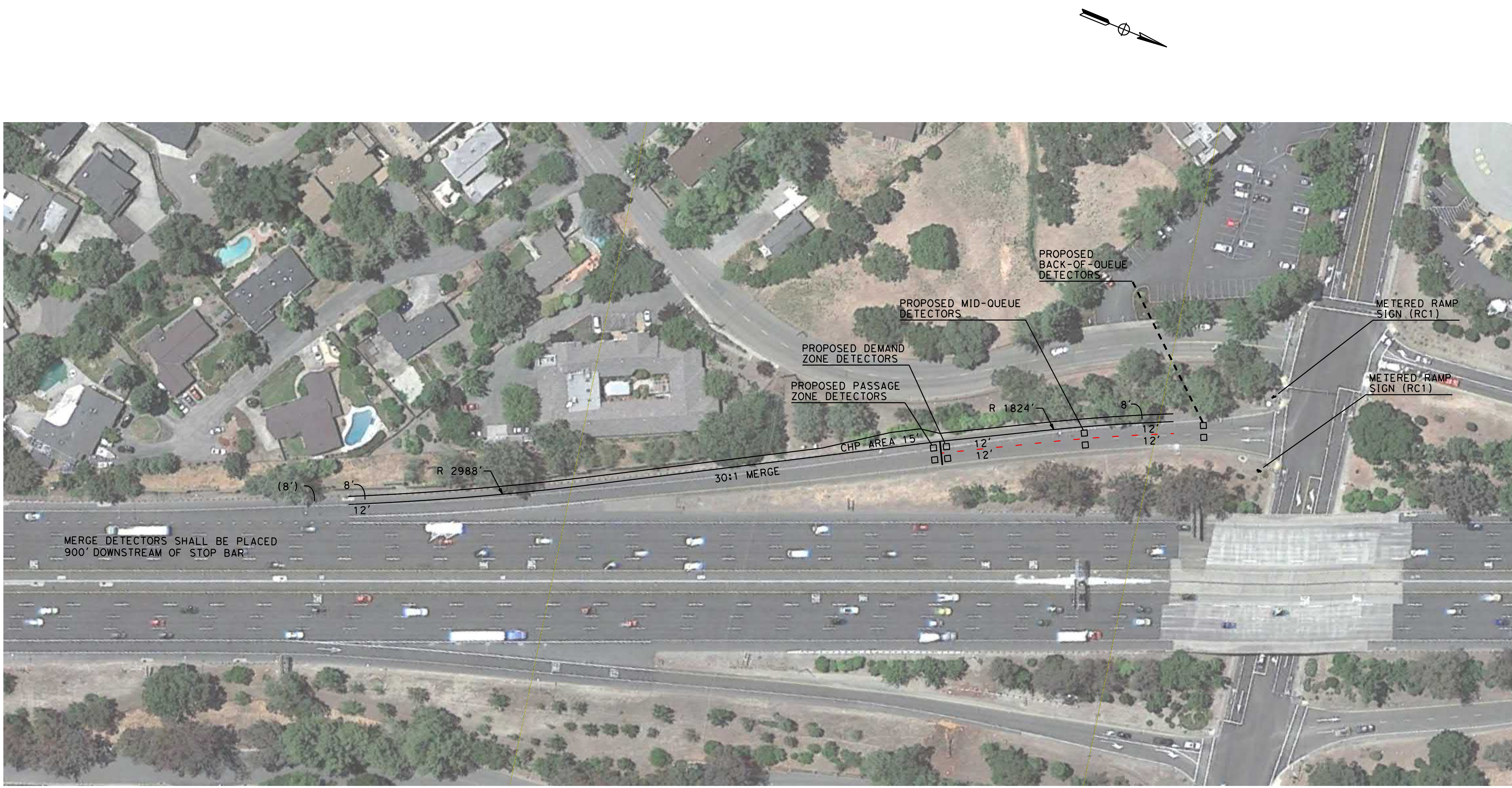
Caltrans

CONTRA COSTA transportation authority

wsp

INNOVATE 680
FEASIBILITY STUDY
NB EL CERRO Blvd

SCALE: 1"=100'



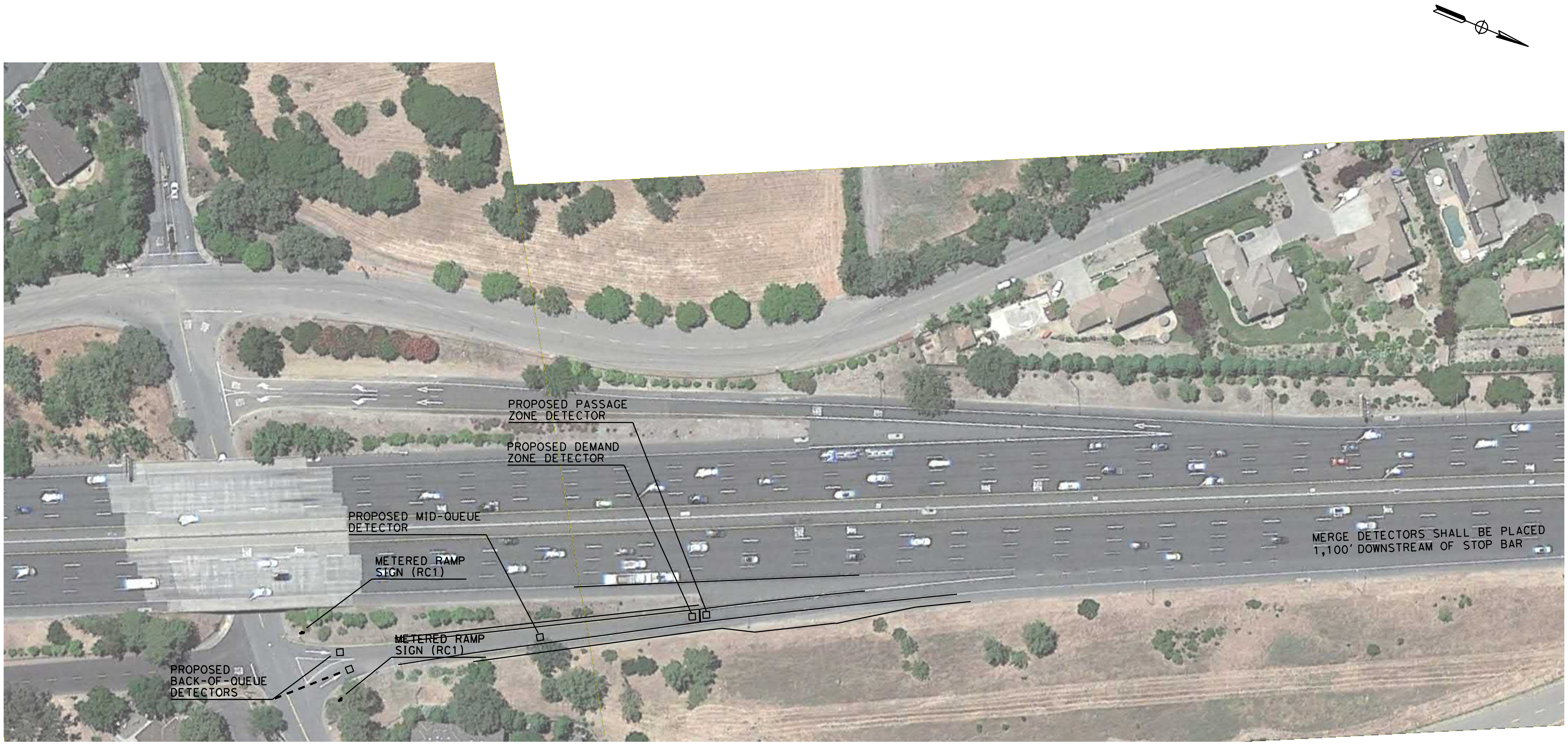
Caltrans

CONTRA COSTA
transportation
authority

wsp

INNOVATE 680
FEASIBILITY STUDY
SB EL CERRO Blvd

SCALE: 1"=100'



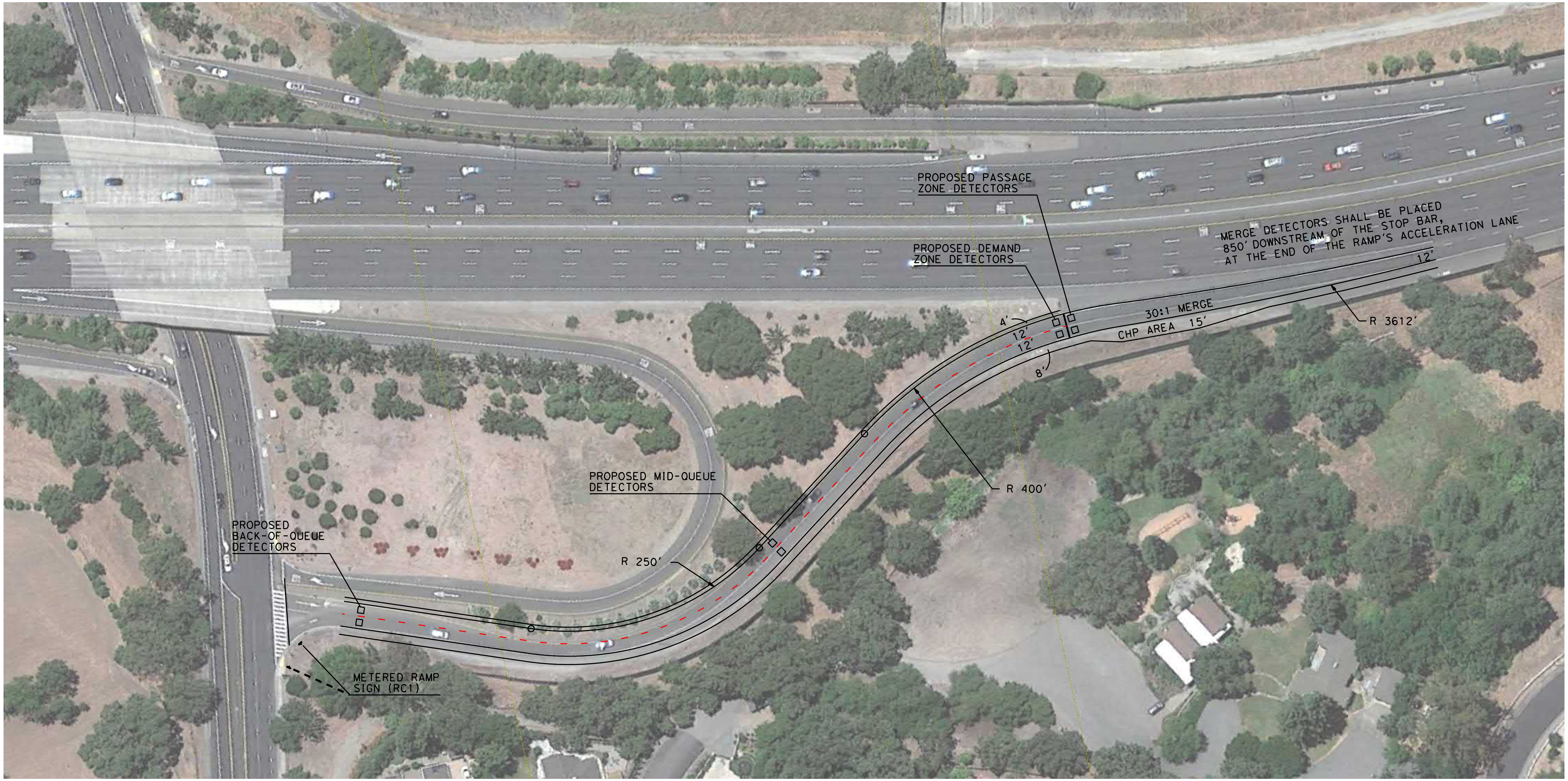
Caltrans

CONTRA COSTA transportation authority

wsp

INNOVATE 680
FEASIBILITY STUDY
NB EL PINTADO Rd

SCALE: 1"=100'



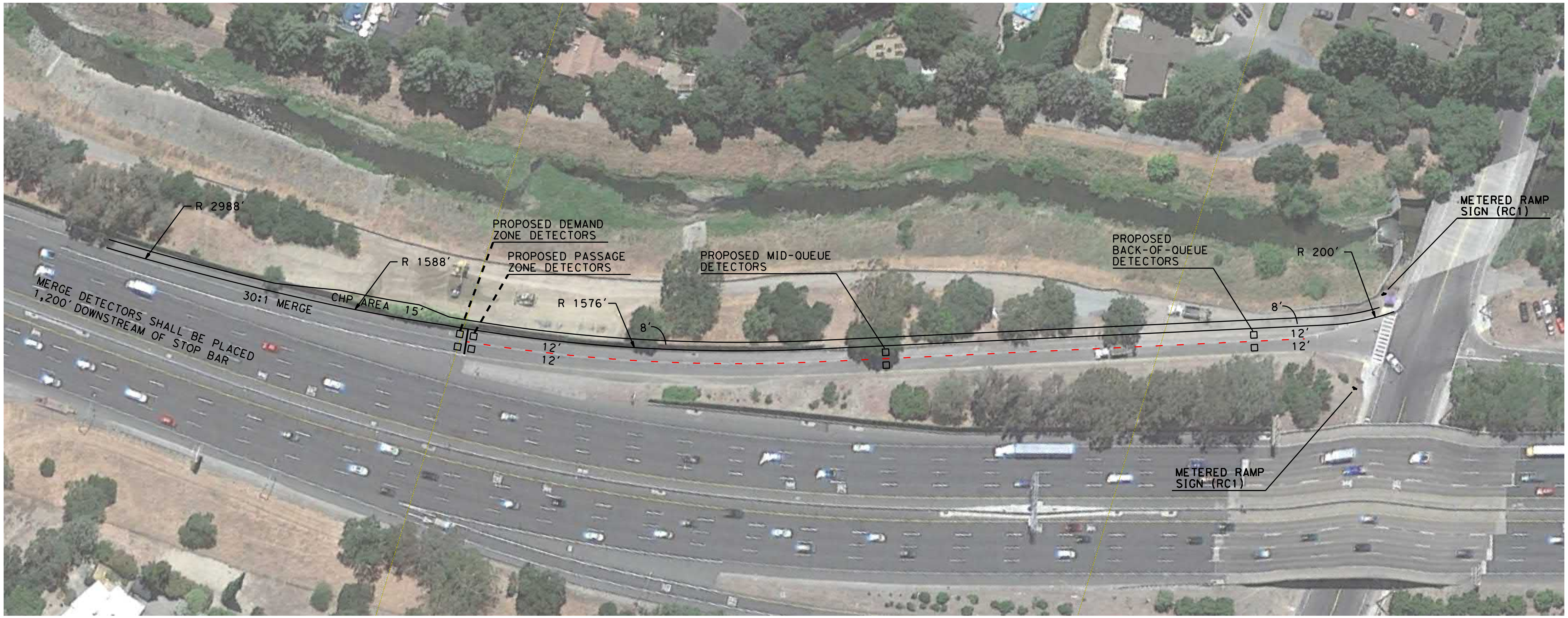
CONTRA COSTA transportation authority

INNOVATE 680 FEASIBILITY STUDY NB STONE VALLEY Rd

SCALE: 1"=100'

INNOVATE 680
FEASIBILITY STUDY
SB STONE VALLEY Rd

SCALE: 1"=100'



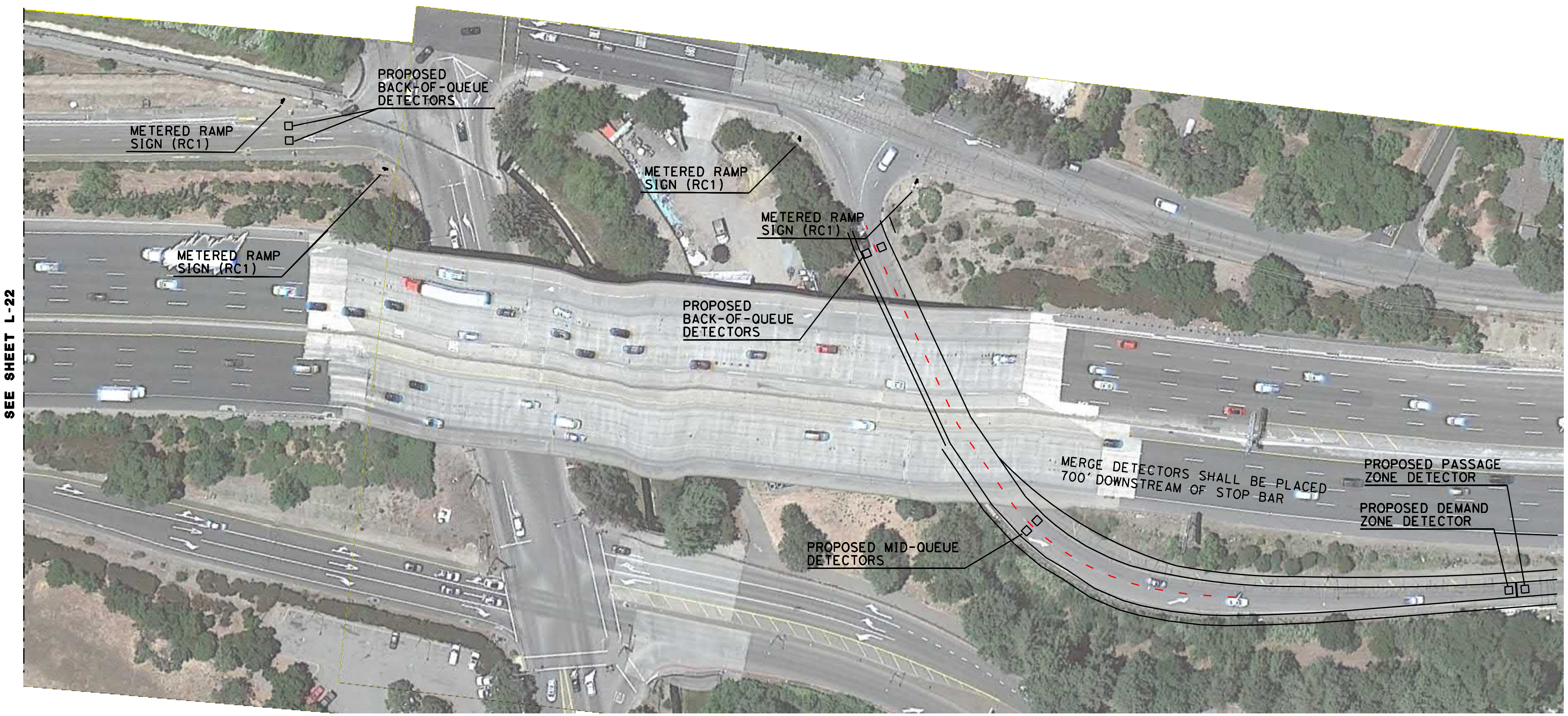
INNOVATE 680
FEASIBILITY STUDY
SB LIVORNA Rd

SCALE: 1"=100'

INNOVATE 680
FEASIBILITY STUDY
SB RUDGEAR Rd

SCALE: 1"=100'

L-22



Caltrans

CONTRA COSTA
transportation
authority

wsp

INNOVATE 680
FEASIBILITY STUDY
NB& SB RUDGEAR Rd

SCALE: 1"=100'

INNOVATE 680
FEASIBILITY STUDY
SB MAIN St

SCALE: 1"=100'

SEE SHEET L-24

CONTRA COSTA transportation authority

INNOVATE 680
FEASIBILITY STUDY
SB MAIN St

SCALE: 1"=100'

SEE SHEET L-27

Caltrans

CONTRA COSTA transportation authority

wsp

INNOVATE 680
FEASIBILITY STUDY
EB SR-24 TO SB I-680
SB OLYMPIC Blvd

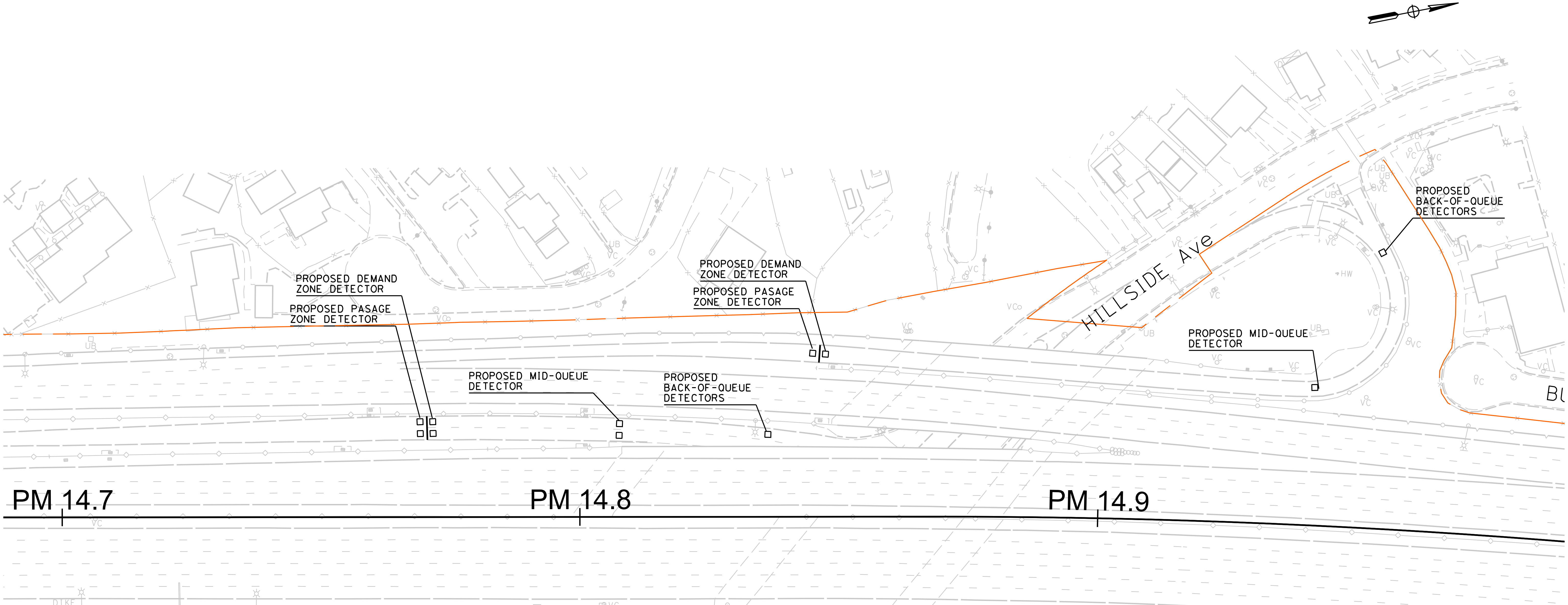
SCALE: 1"=100'

Caltrans

CONTRA COSTA transportation authority

wsp

INNOVATE 680
FEASIBILITY STUDY
EB SR-24 TO SB I-680
NB OLYMPIC Blvd
SCALE: 1"=100'



CONTRA COSTA
transportation authority

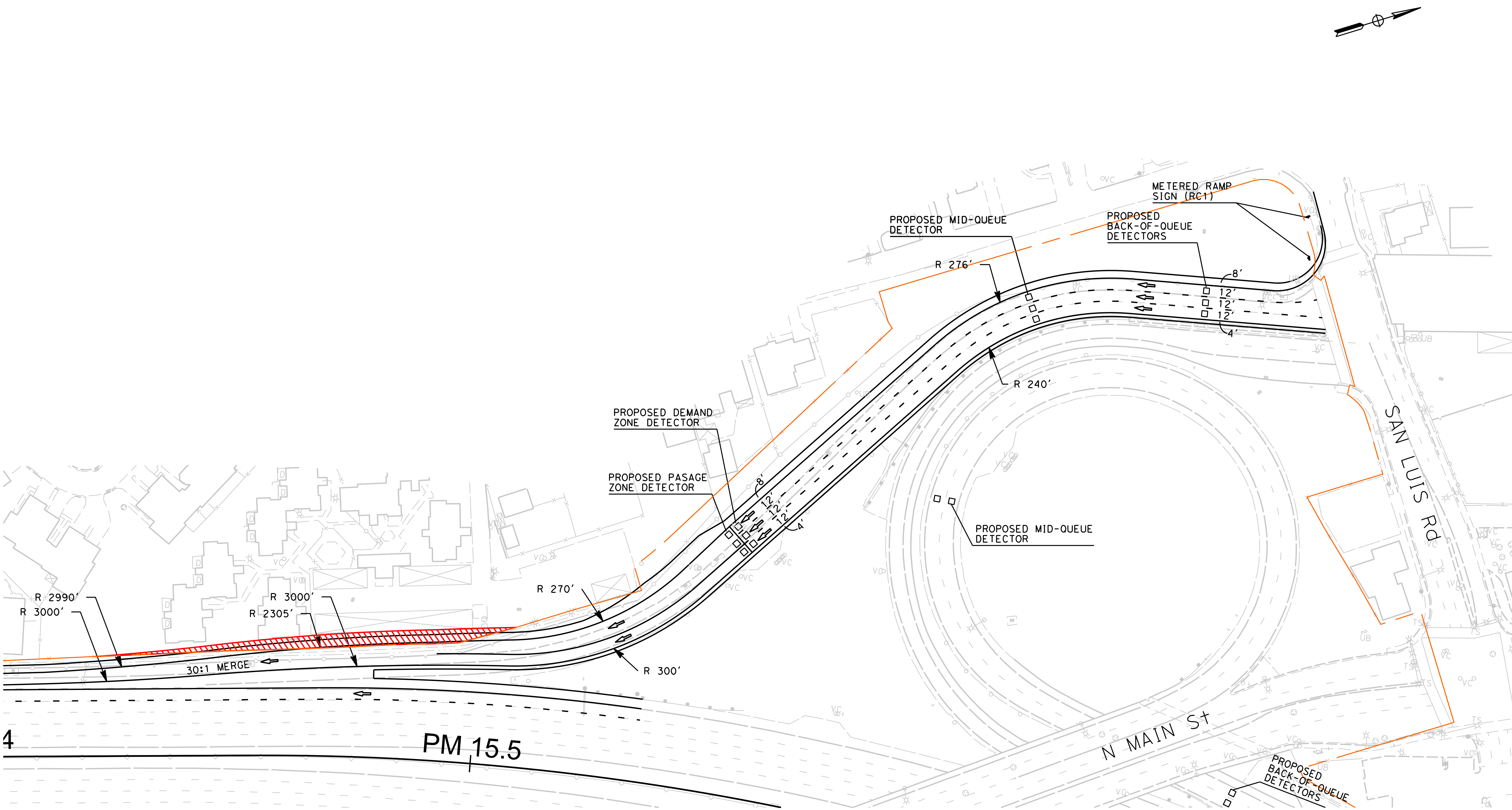
LEGEND

EXISTING CALTRANS R/W
R/W ACQUISITION
STRUCUTRE WIDENING
NEW RETAINING WALL

INNOVATE 680
FEASIBILITY STUDY
SB HILLSIDE Ave/
YGNACIO VALLEY Rd

SCALE: 1"=100'

L-28



CONTRA COSTA transportation authority

LEGEND

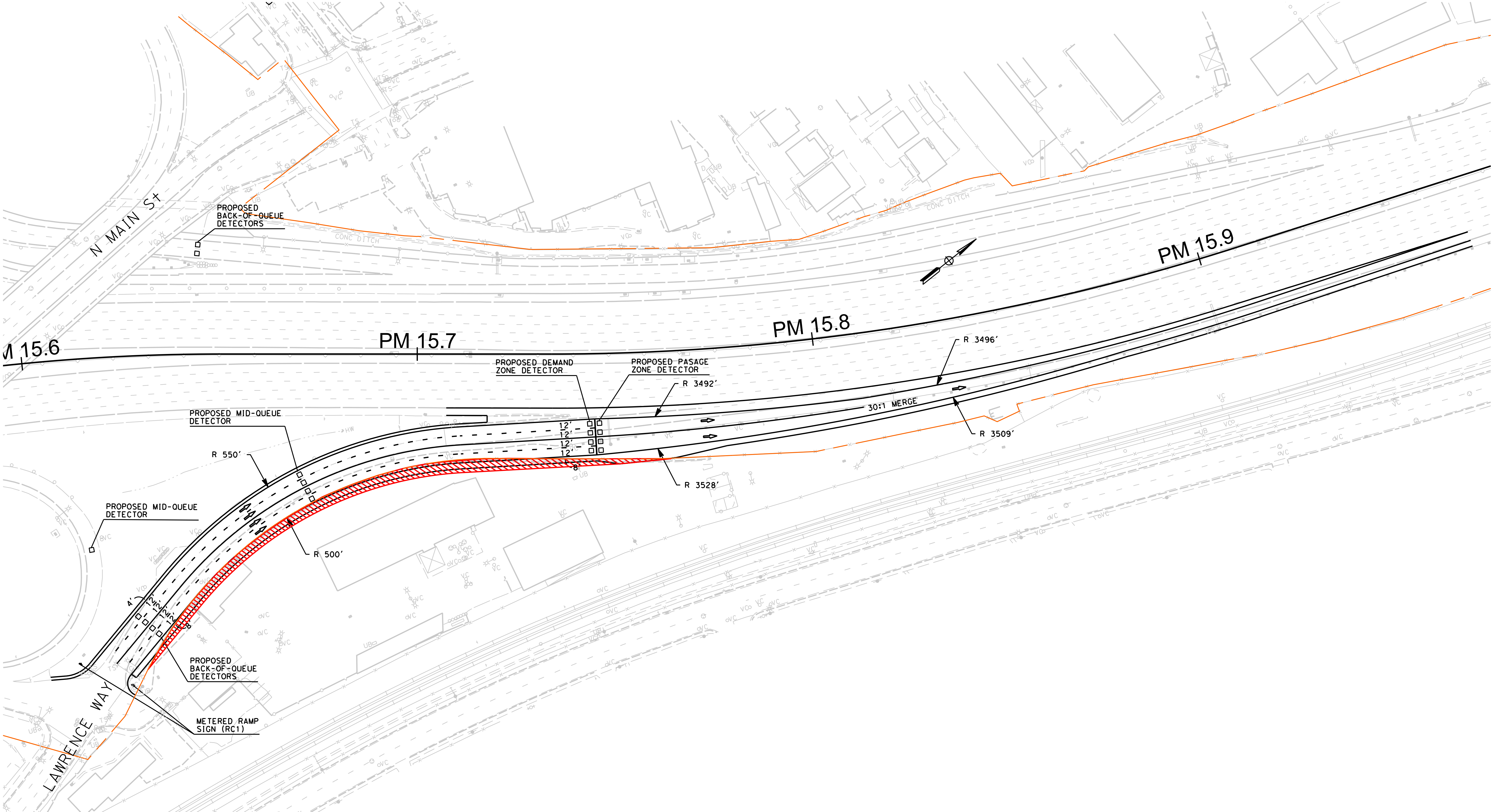
- EXISTING CALTRANS R/W
- R/W ACQUISITION
- STRUCUTRE WIDENING
- NEW RETAINING WALL

INNOVATE 680

FEASIBILITY STUDY
SAN LUIS Rd/ N MAIN St

SCALE: 1"=100'

L-29



Caltrans

CONTRA COSTA transportation authority

wsp

LEGEND

- EXISTING CALTRANS R/W
- R/W ACQUISITION
- STRUCUTRE WIDENING
- NEW RETAINING WALL

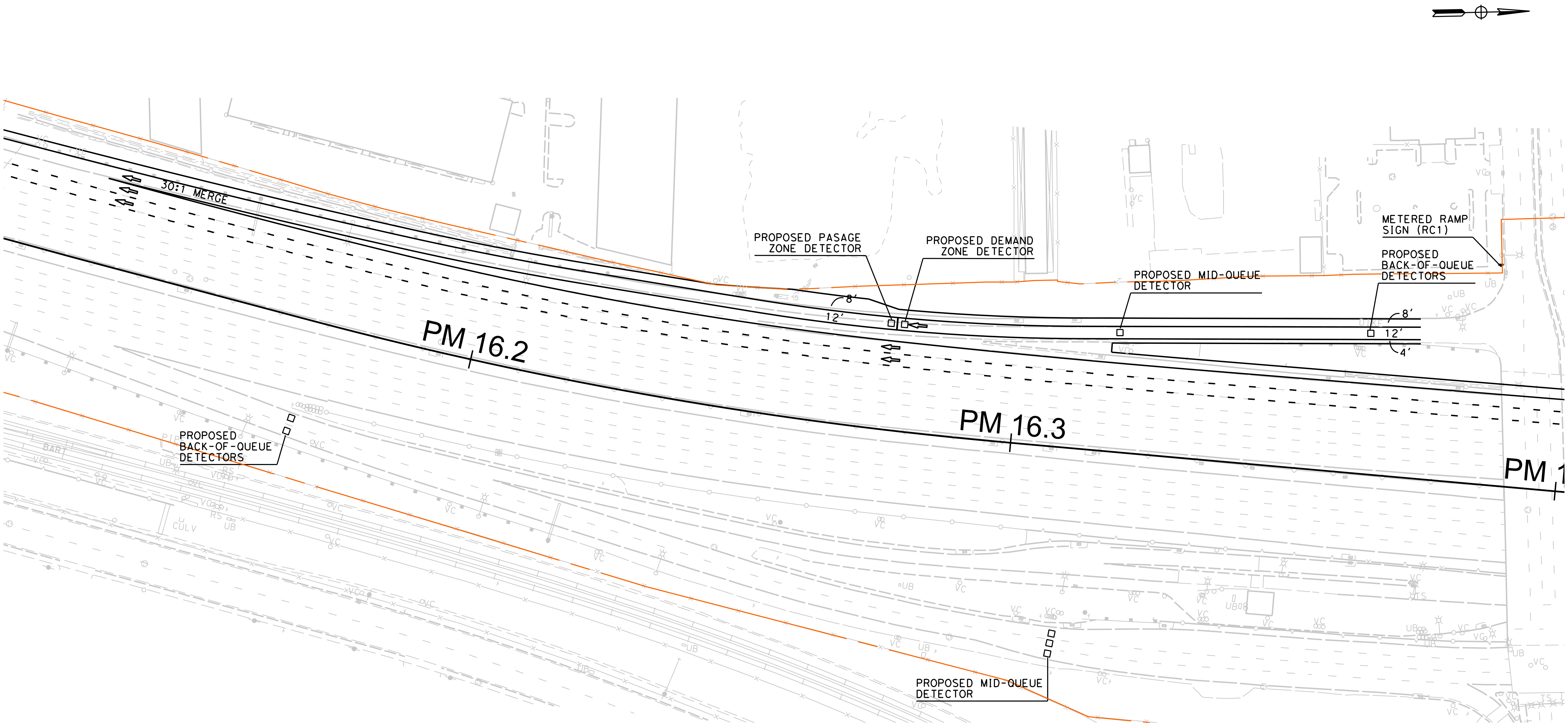
INNOVATE 680

FEASIBILITY STUDY

NB PENNIMAN WAY/ LAWRENCE WAY/ N MAIN St

SCALE: 1"=120'

L-30



CONTRA COSTA transportation authority

LEGEND

- EXISTING CALTRANS R/W
- R/W ACQUISITION
- STRUCUTRE WIDENING
- NEW RETAINING WALL

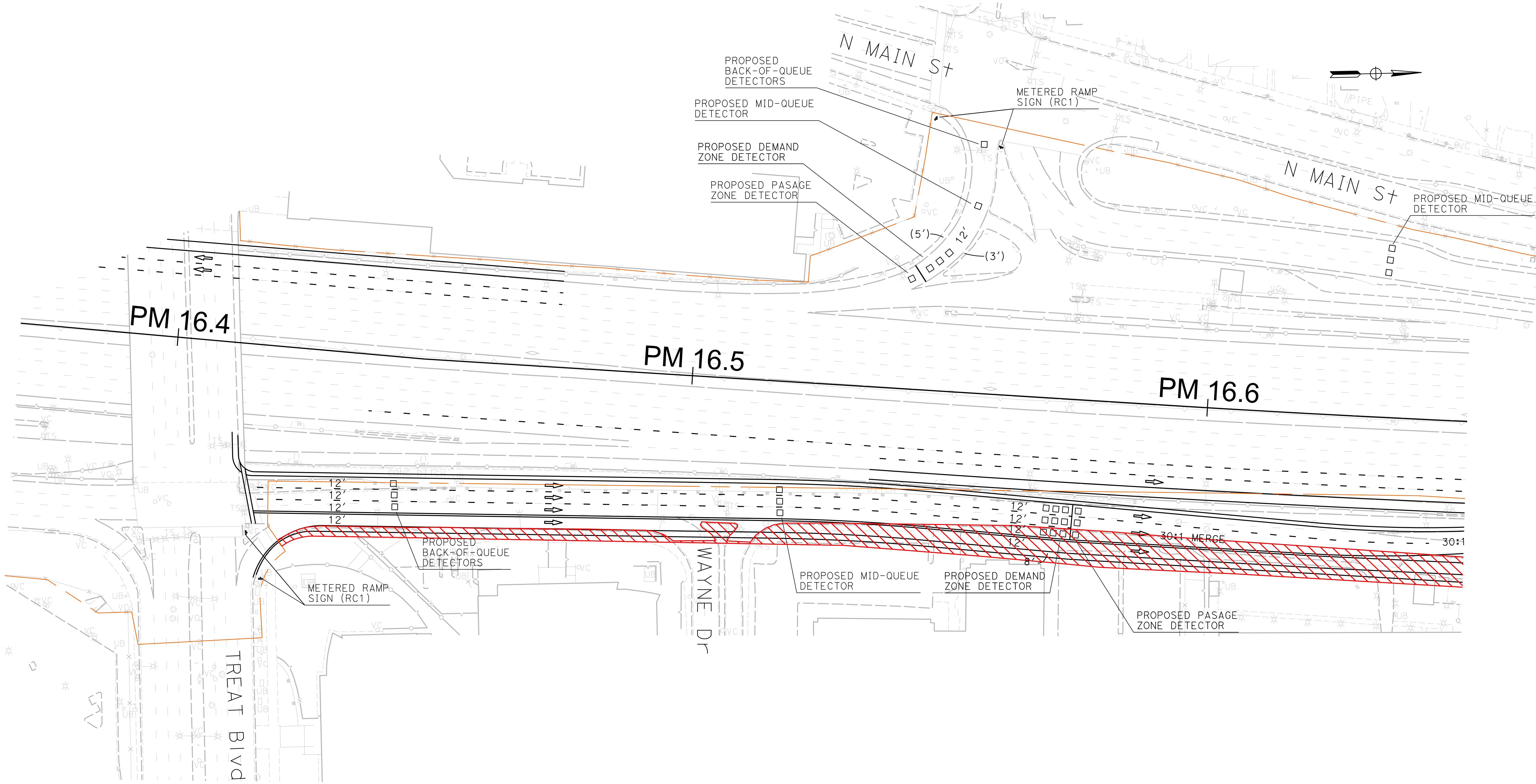
INNOVATE 680

FEASIBILITY STUDY

SB TREAT Blvd/ GEARY Rd

SCALE: 1"=100'

L-31



Caltrans

CONTRA COSTA transportation authority

wsp

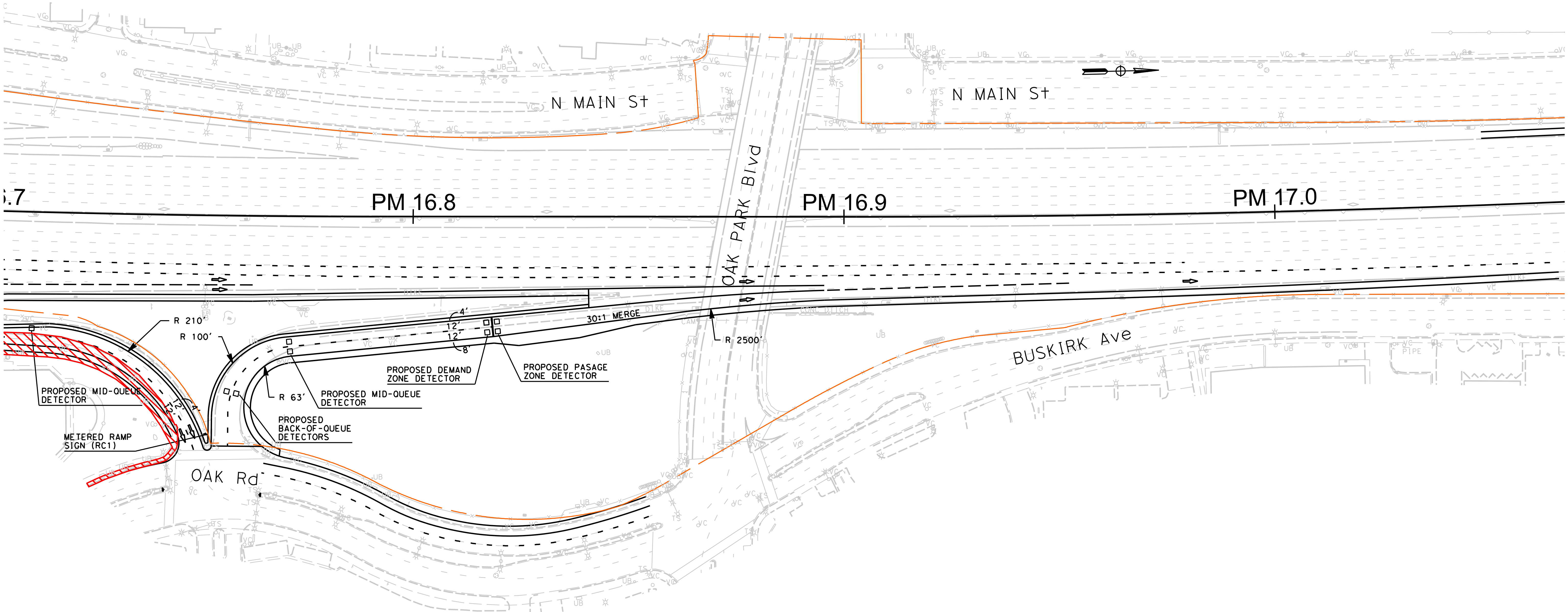
LEGEND

- EXISTING CALTRANS R/W
- R/W ACQUISITION
- STRUCUTRE WIDENING
- NEW RETAINING WALL

INNOVATE 680
FEASIBILITY STUDY
NB TREAT Blvd/ BUSKIRK Ave

SCALE: 1"=100'

L-32



Caltrans

CONTRA COSTA transportation authority

wsp

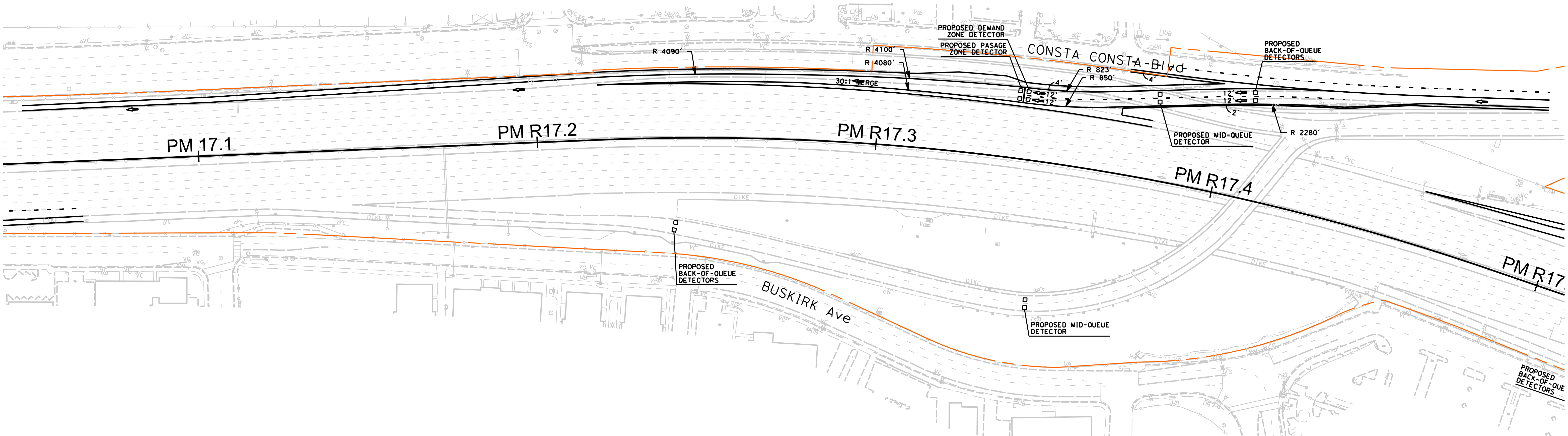
LEGEND

- EXISTING CALTRANS R/W
- R/W ACQUISITION
- STRUCUTRE WIDENING
- NEW RETAINING WALL

INNOVATE 680
FEASIBILITY STUDY
NB OAK Ave/ ELENA CT/ COGGINS Dr

SCALE: 1"=120'

L-33



Caltrans

CONTRA COSTA transportation authority

wsp

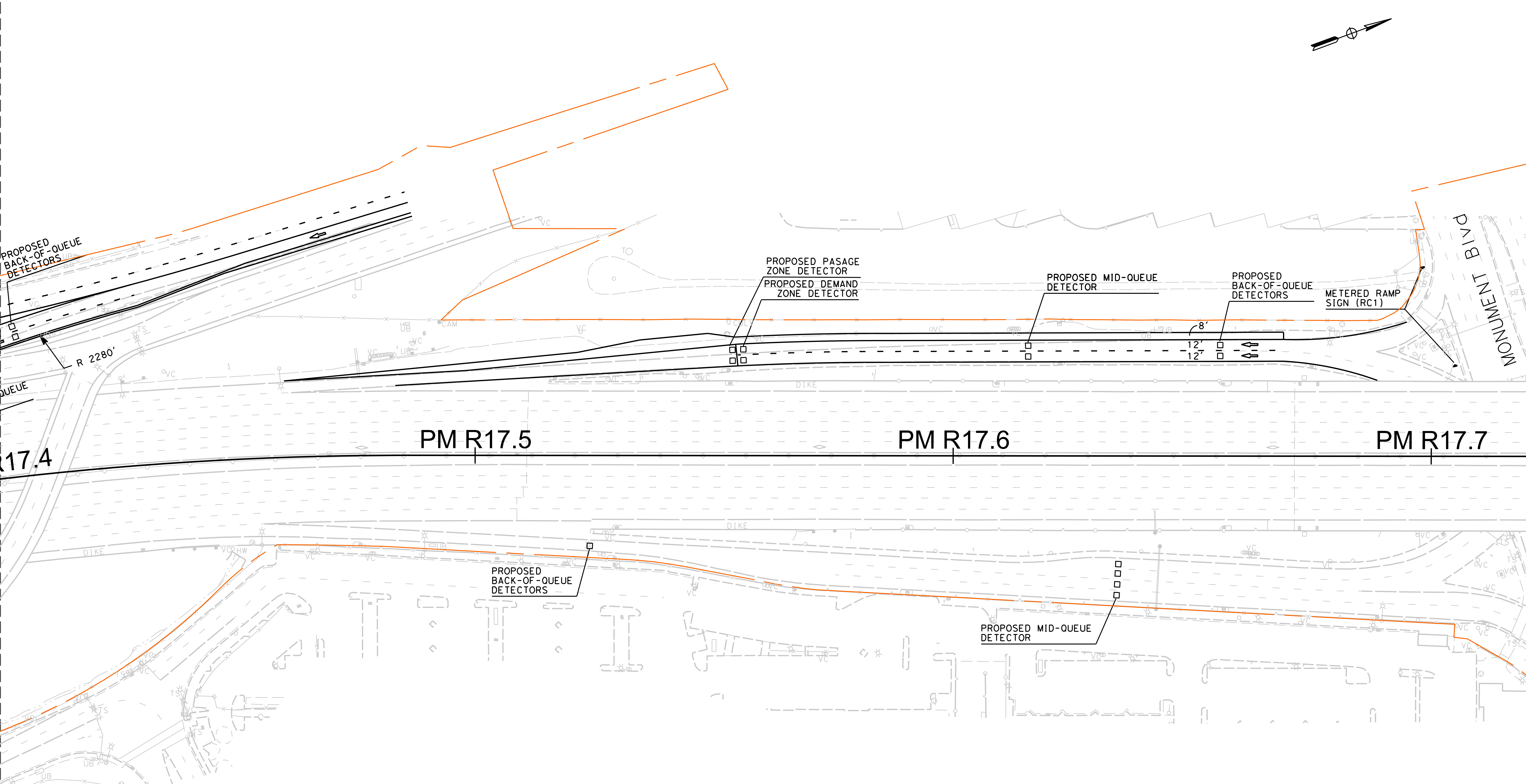
LEGEND

- EXISTING CALTRANS R/W
- R/W ACQUISITION
- STRUCUTRE WIDENING
- NEW RETAINING WALL

INNOVATE 680
FEASIBILITY STUDY
SB CONTRA COSTA Blvd/ BOYD Rd

SCALE: 1"=150'

L-34



CONTRA COSTA transportation authority

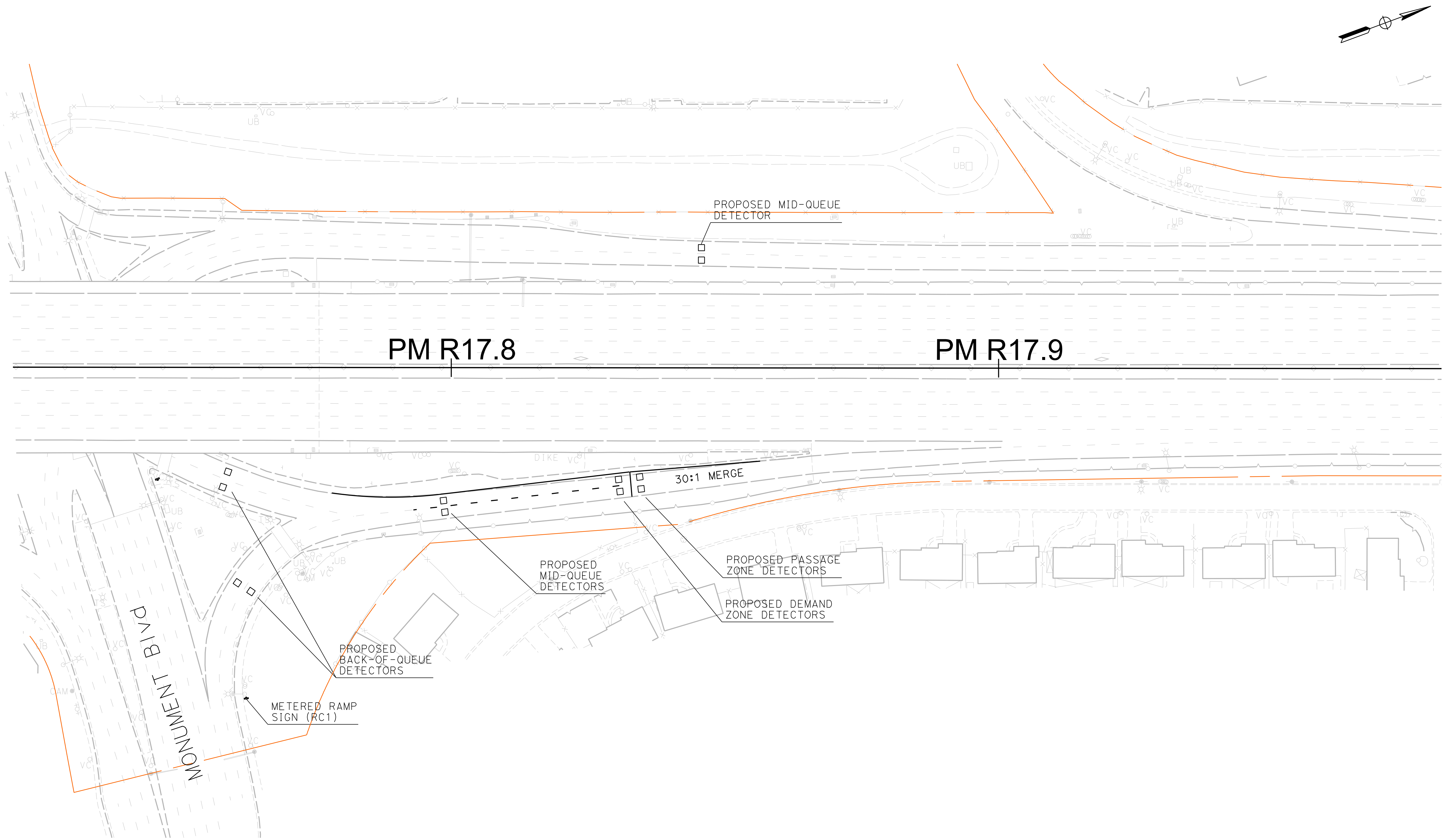
LEGEND

- EXISTING CALTRANS R/W
- R/W ACQUISITION
- STRUCUTRE WIDENING
- NEW RETAINING WALL

INNOVATE 680 FEASIBILITY STUDY SB MONUMENT Blvd

SCALE: 1"=100'

L-35



CONTRA COSTA transportation authority

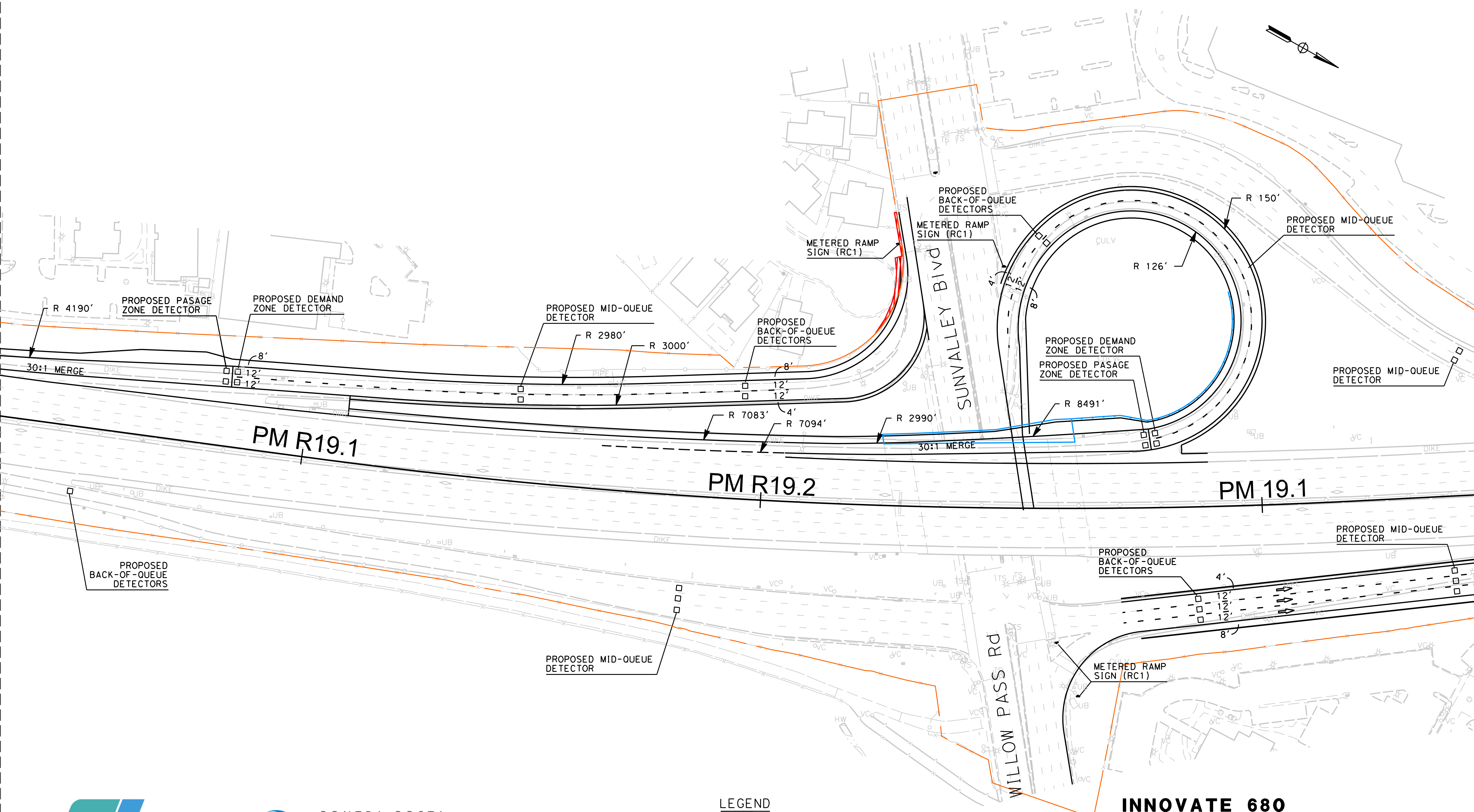
LEGEND

- EXISTING CALTRANS R/W
- R/W ACQUISITION
- STRUCUTRE WIDENING
- NEW RETAINING WALL

INNOVATE 680
FEASIBILITY STUDY
NB MONUMENT Blvd

L-36

SCALE: 1"=100'



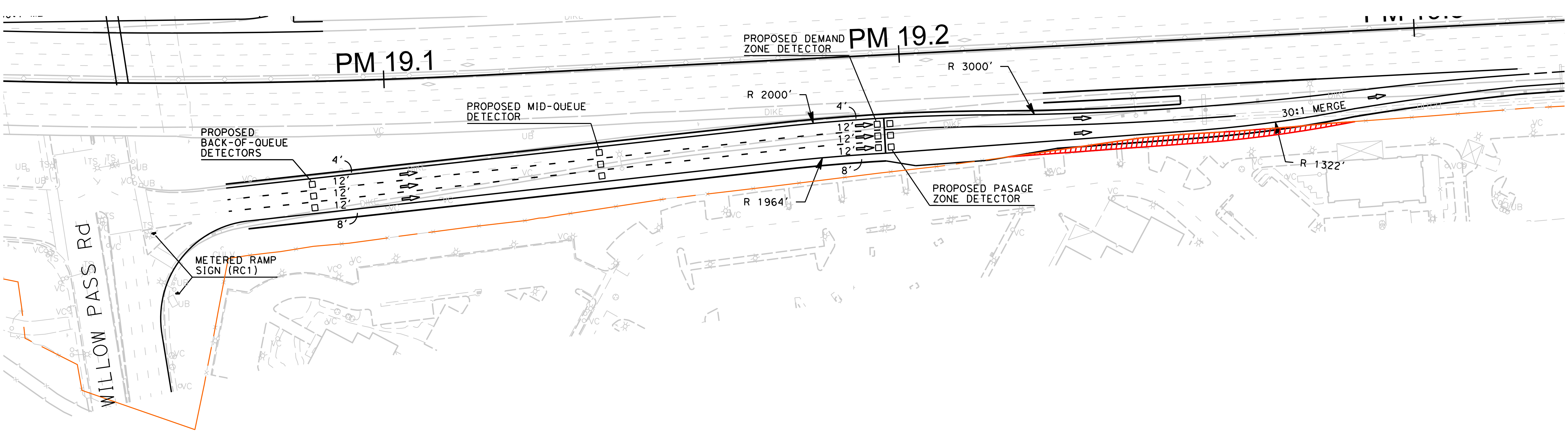
LEGEND

- EXISTING CALTRANS R/W
- R/W ACQUISITION
- STRUCUTRE WIDENING
- NEW RETAINING WALL

CONTRA COSTA transportation authority

INNOVATE 680
FEASIBILITY STUDY
SB WILLOW PASS Rd/ SUNVALLEY Blvd LOOP RAMP

SCALE: 1"=100'



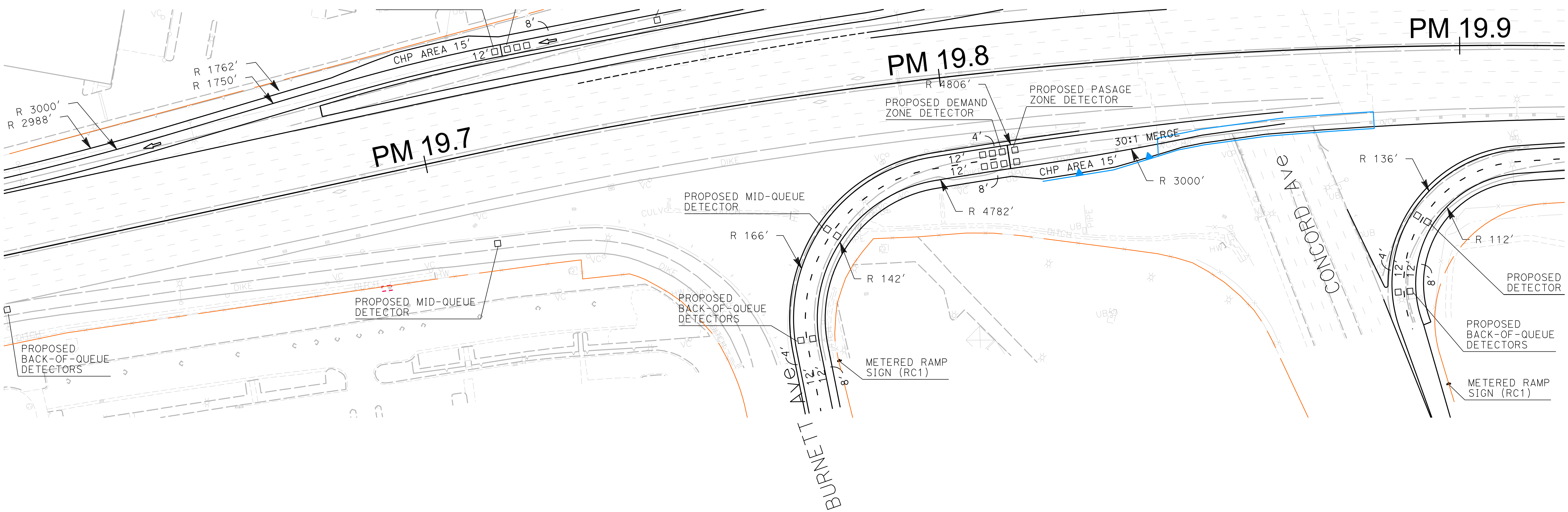
LEGEND
EXISTING CALTRANS R/W
R/W ACQUISITION
STRUCUTRE WIDENING
NEW RETAINING WALL

Caltrans
CONTRA COSTA transportation authority
wsp

INNOVATE 680
FEASIBILITY STUDY
NB WILLOW PASS Rd

SCALE: 1"=100'

L-38



CONTRA COSTA transportation authority

LEGEND

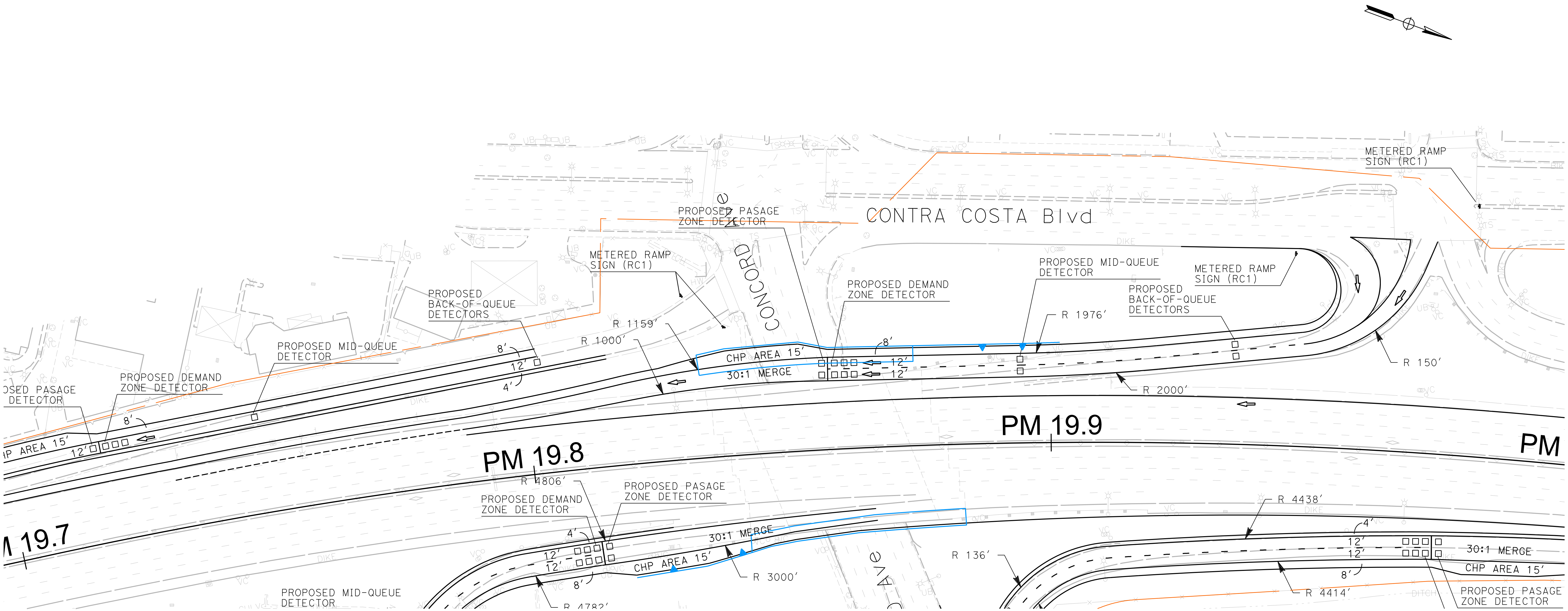
- EXISTING CALTRANS R/W
- R/W ACQUISITION
- STRUCUTRE WIDENING
- NEW RETAINING WALL

INNOVATE 680 FEASIBILITY STUDY

NB BURNETT Ave

L-39

SCALE: 1"=100'



LEGEND

- EXISTING CALTRANS R/W
- R/W ACQUISITION
- STRUCUTRE WIDENING
- NEW RETAINING WALL

Caltrans

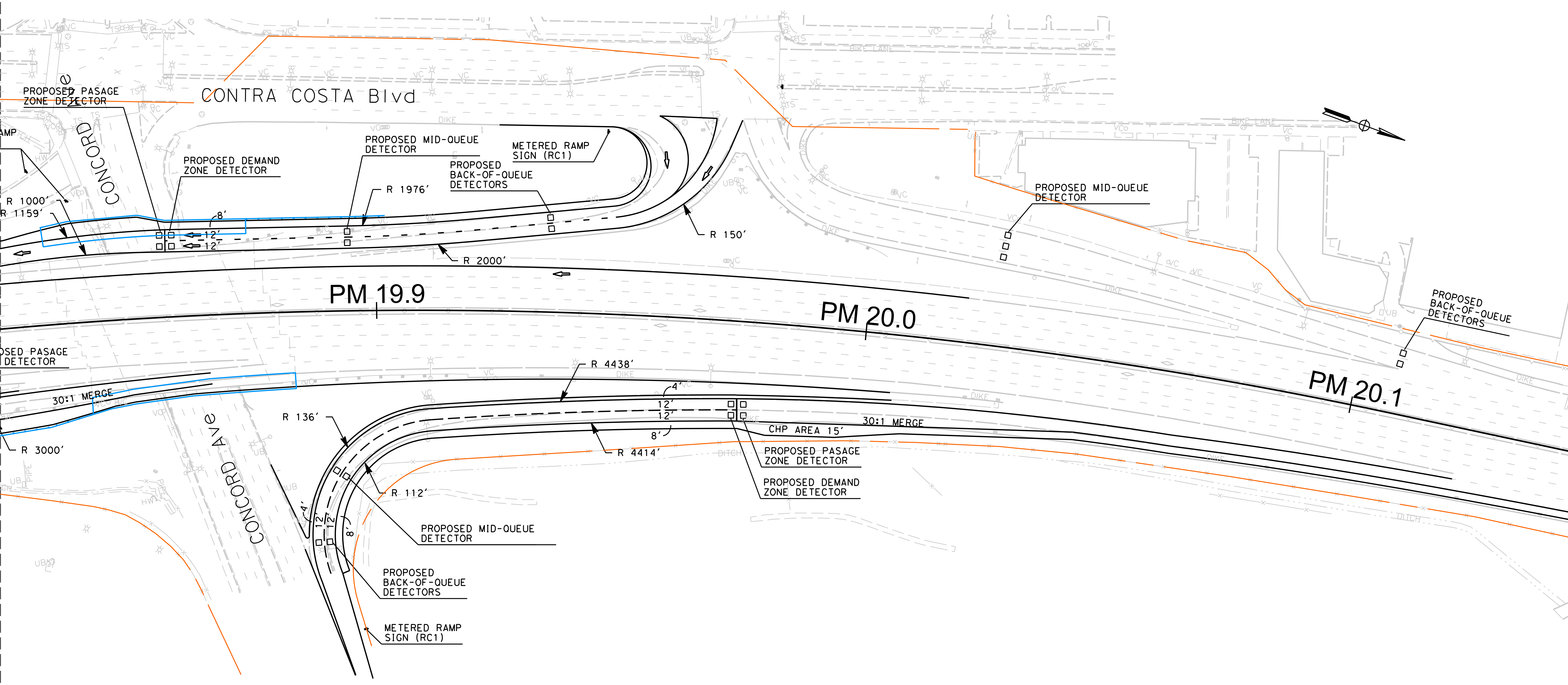
CONTRA COSTA transportation authority

wsp

INNOVATE 680
FEASIBILITY STUDY
SB CONTRA COSTA Blvd

L-40

SCALE: 1"=100'



Caltrans

CONTRA COSTA transportation authority

wsp

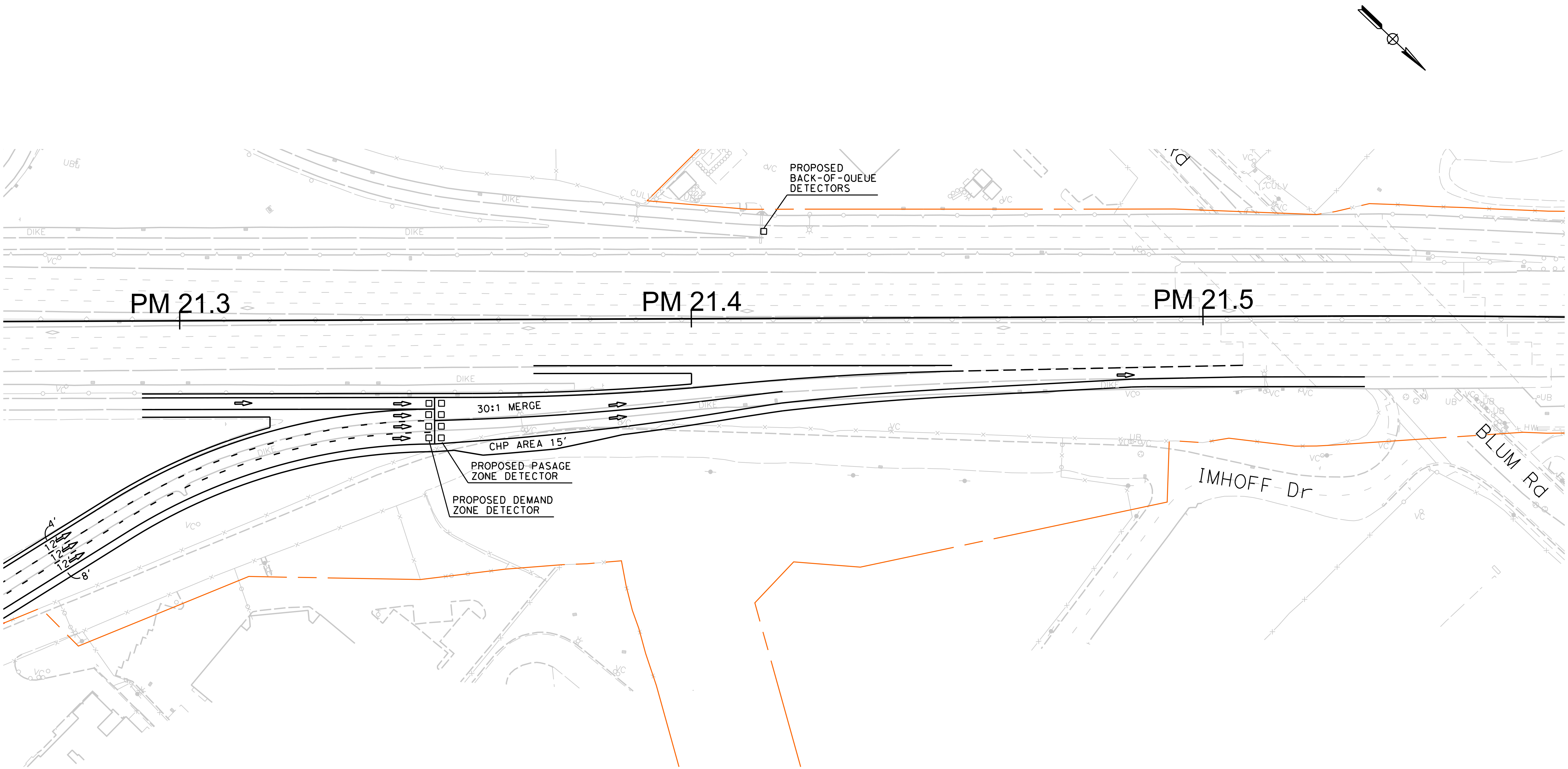
LEGEND

EXISTING CALTRANS R/W
R/W ACQUISITION
STRUCUTRE WIDENING
NEW RETAINING WALL

INNOVATE 680
FEASIBILITY STUDY
NB CONCORD Ave

SCALE: 1"=100'

L-41



CONTRA COSTA transportation authority

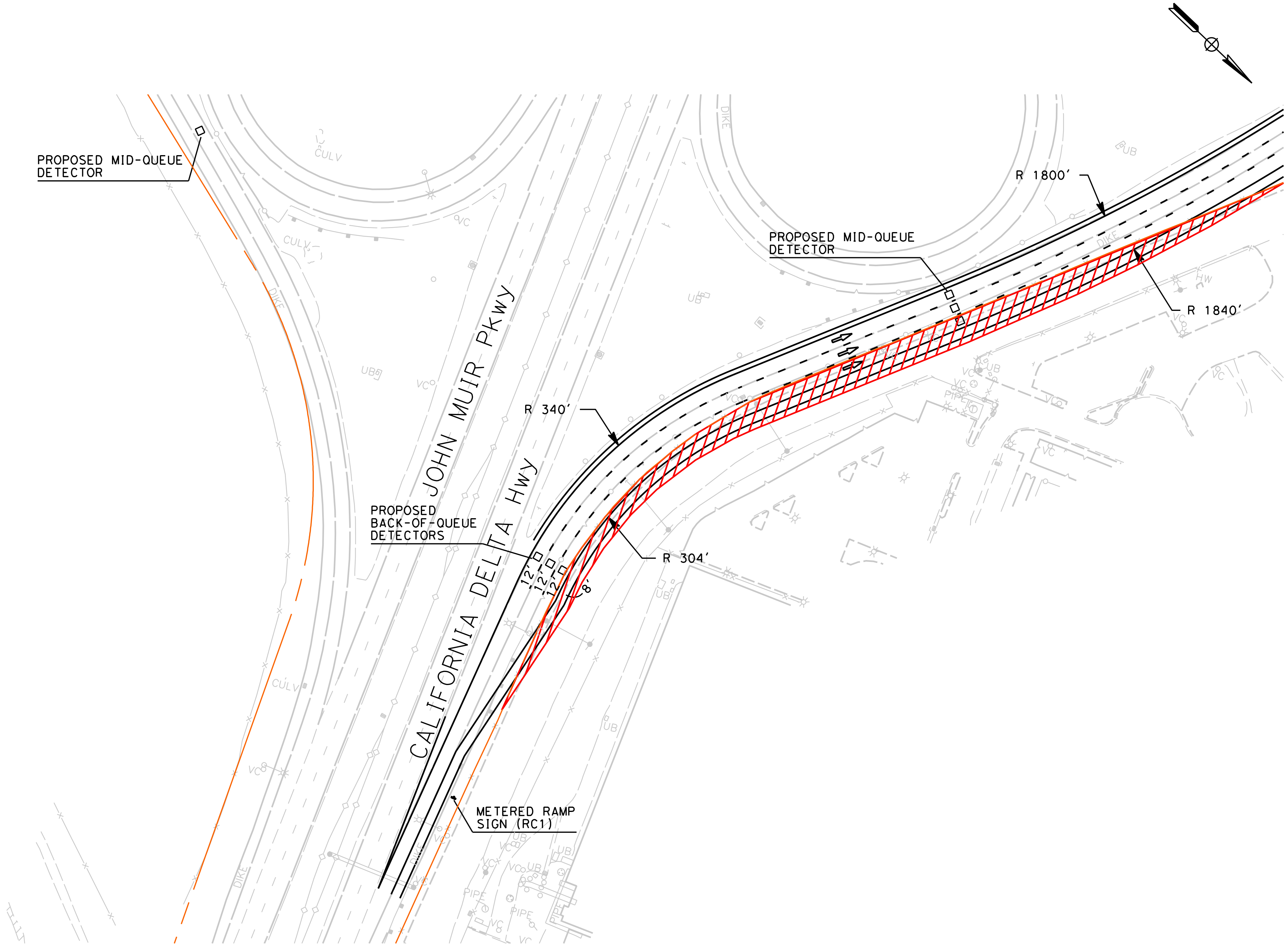
LEGEND

EXISTING CALTRANS R/W
R/W ACQUISITION
STRUCUTRE WIDENING
NEW RETAINING WALL

INNOVATE 680
FEASIBILITY STUDY
NB SR-4 INTERCHANGE

SCALE: 1"=100'

L-42

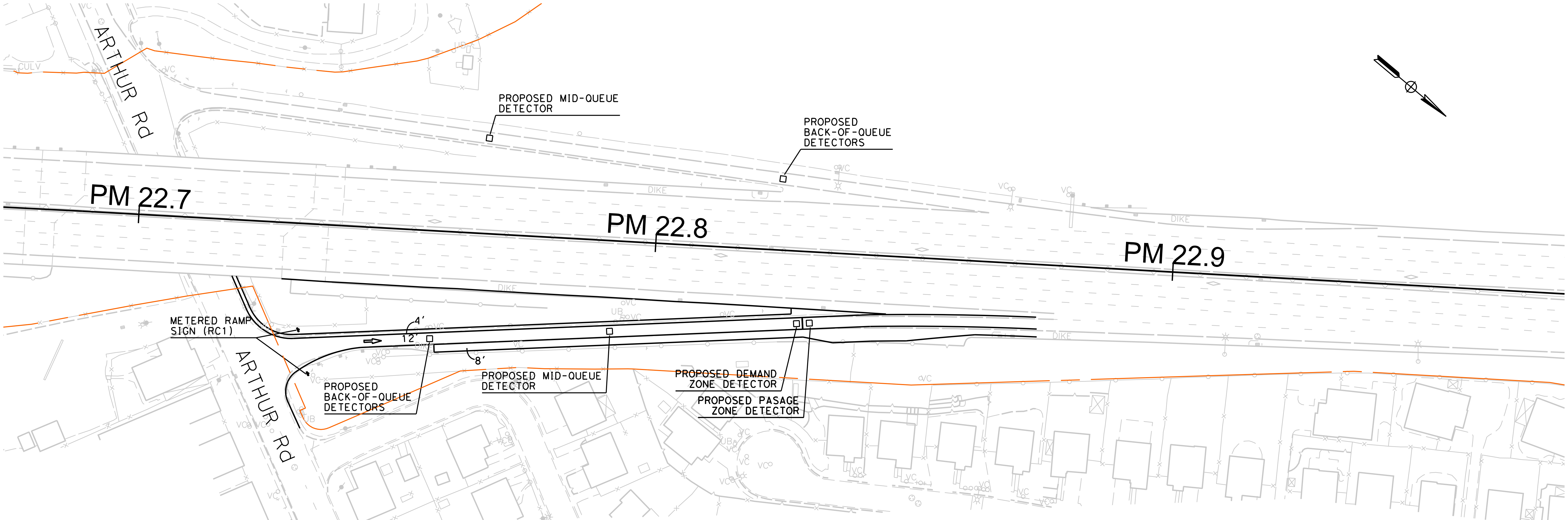


LEGEND
EXISTING CALTRANS R/W
R/W ACQUISITION
STRUCUTRE WIDENING
NEW RETAINING WALL

INNOVATE 680 FEASIBILITY STUDY
NB SR-4 INTERCHANGE

SCALE: 1"=100'

L-43



Caltrans

CONTRA COSTA transportation authority

wsp

LEGEND

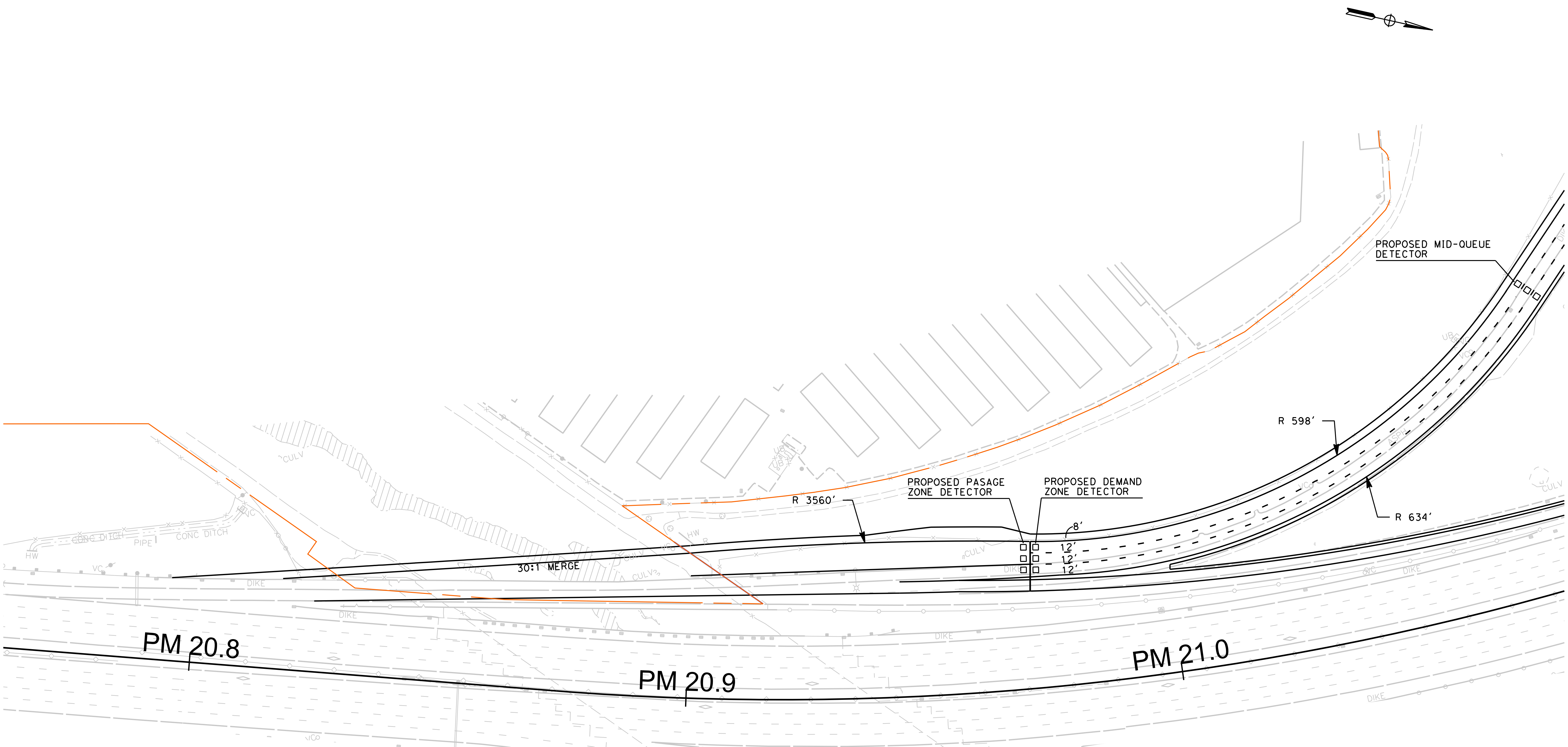
- EXISTING CALTRANS R/W
- R/W ACQUISITION
- STRUCUTRE WIDENING
- NEW RETAINING WALL

INNOVATE 680 FEASIBILITY STUDY

ARTHUR Rd

L-44

SCALE: 1"=100'



Caltrans

CONTRA COSTA
transportation
authority

wsp

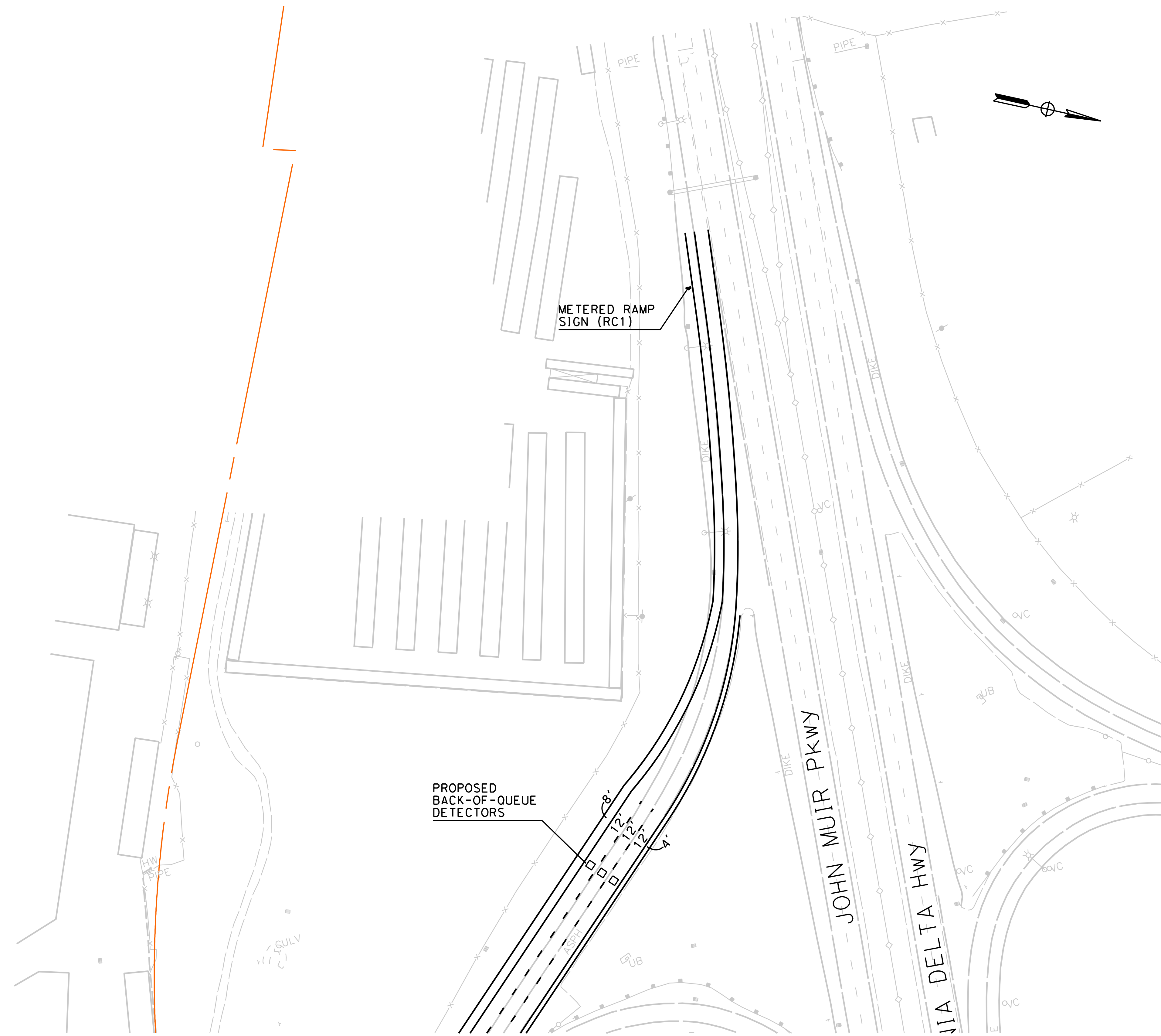
LEGEND

EXISTING CALTRANS R/W
R/W ACQUISITION
STRUCUTRE WIDENING
NEW RETAINING WALL

INNOVATE 680
FEASIBILITY STUDY
SB SR-4

SCALE: 1"=100'

L-45



Caltrans

CONTRA COSTA transportation authority

wsp

LEGEND

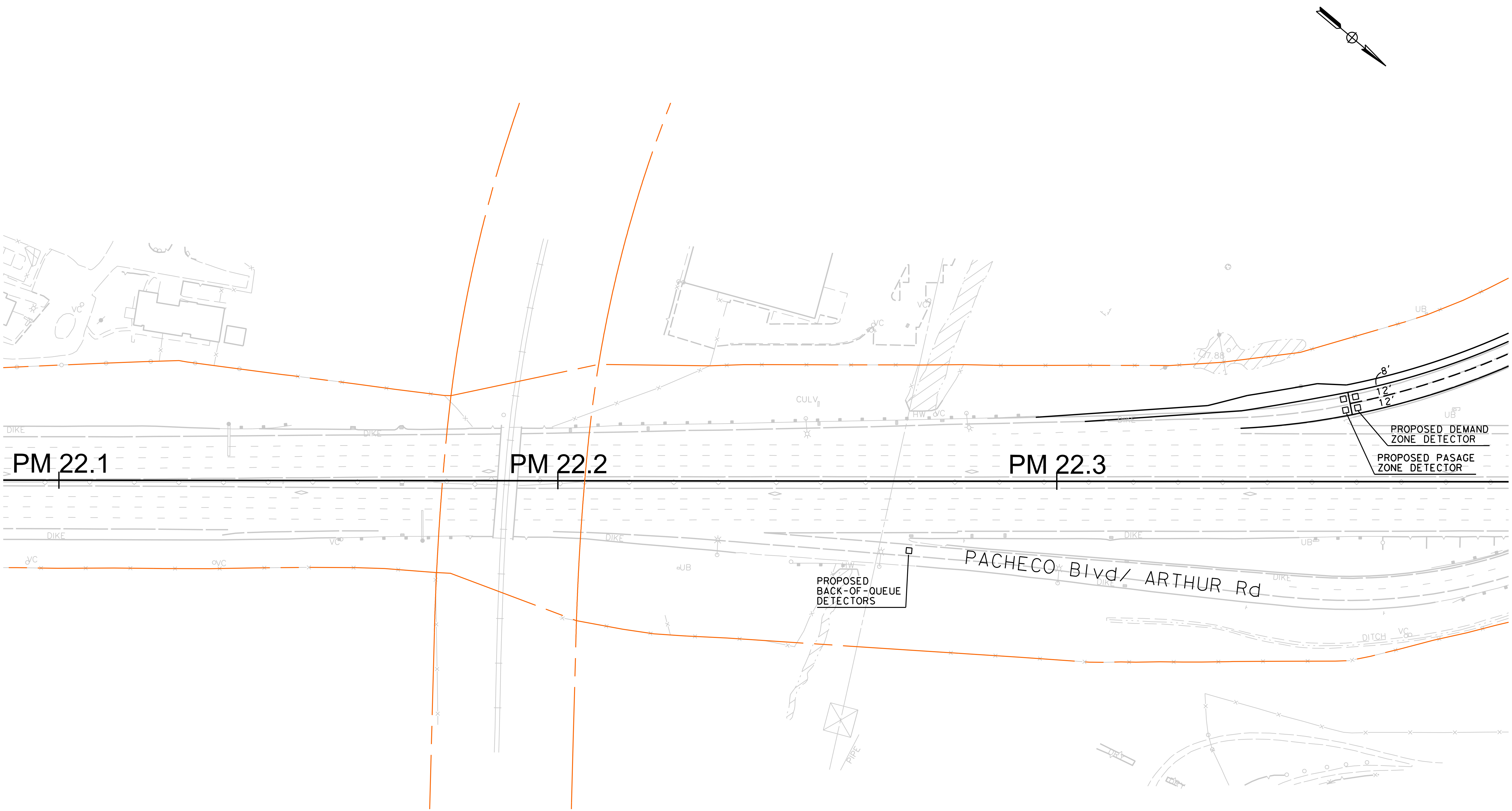
- EXISTING CALTRANS R/W
- R/W ACQUISITION
- STRUCUTRE WIDENING
- NEW RETAINING WALL

INNOVATE 680 FEASIBILITY STUDY

SB SR-4

SCALE: 1"=100'

L-46



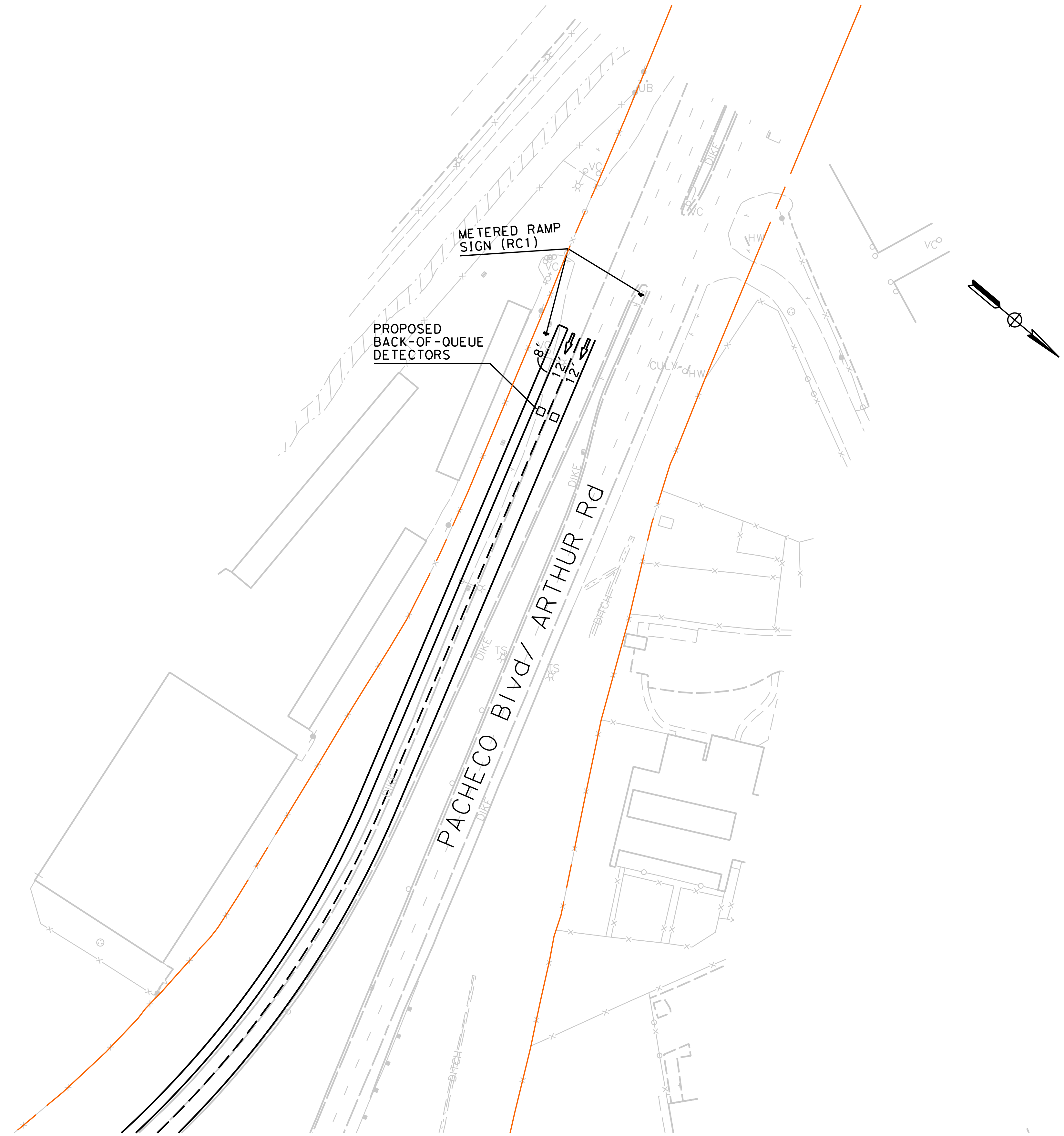
LEGEND

- EXISTING CALTRANS R/W
- R/W ACQUISITION
- STRUCUTRE WIDENING
- NEW RETAINING WALL

INNOVATE 680
FEASIBILITY STUDY
PACHECO Blvd

SCALE: 1"=100'

L-47



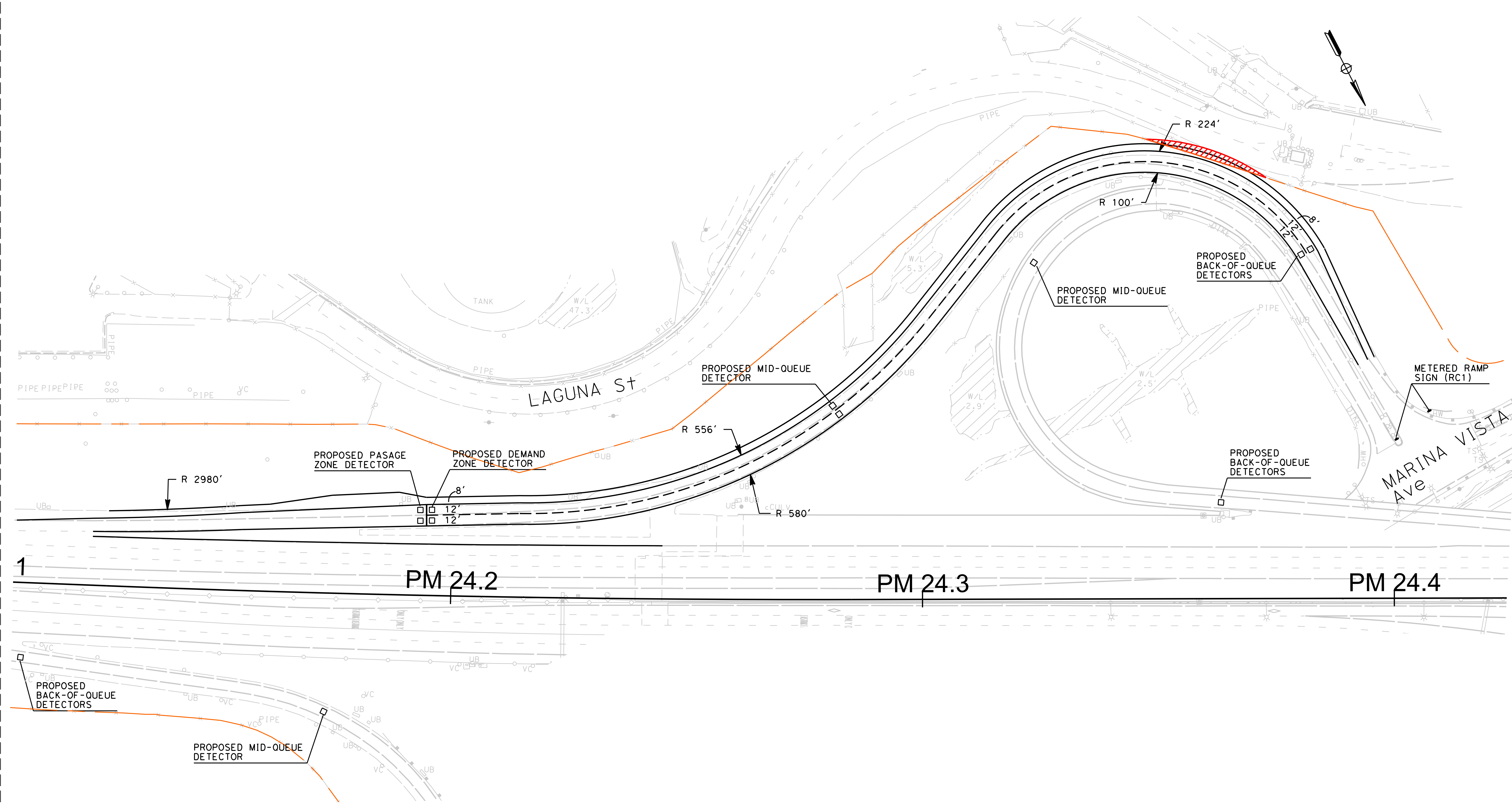
LEGEND
EXISTING CALTRANS R/W
R/W ACQUISITION
STRUCUTRE WIDENING
NEW RETAINING WALL

CONTRA COSTA transportation authority

INNOVATE 680 FEASIBILITY STUDY
PACHECO Blvd

L-48

SCALE: 1"=100'



CONTRA COSTA transportation authority

LEGEND

- EXISTING CALTRANS R/W
- R/W ACQUISITION
- STRUCUTRE WIDENING
- NEW RETAINING WALL

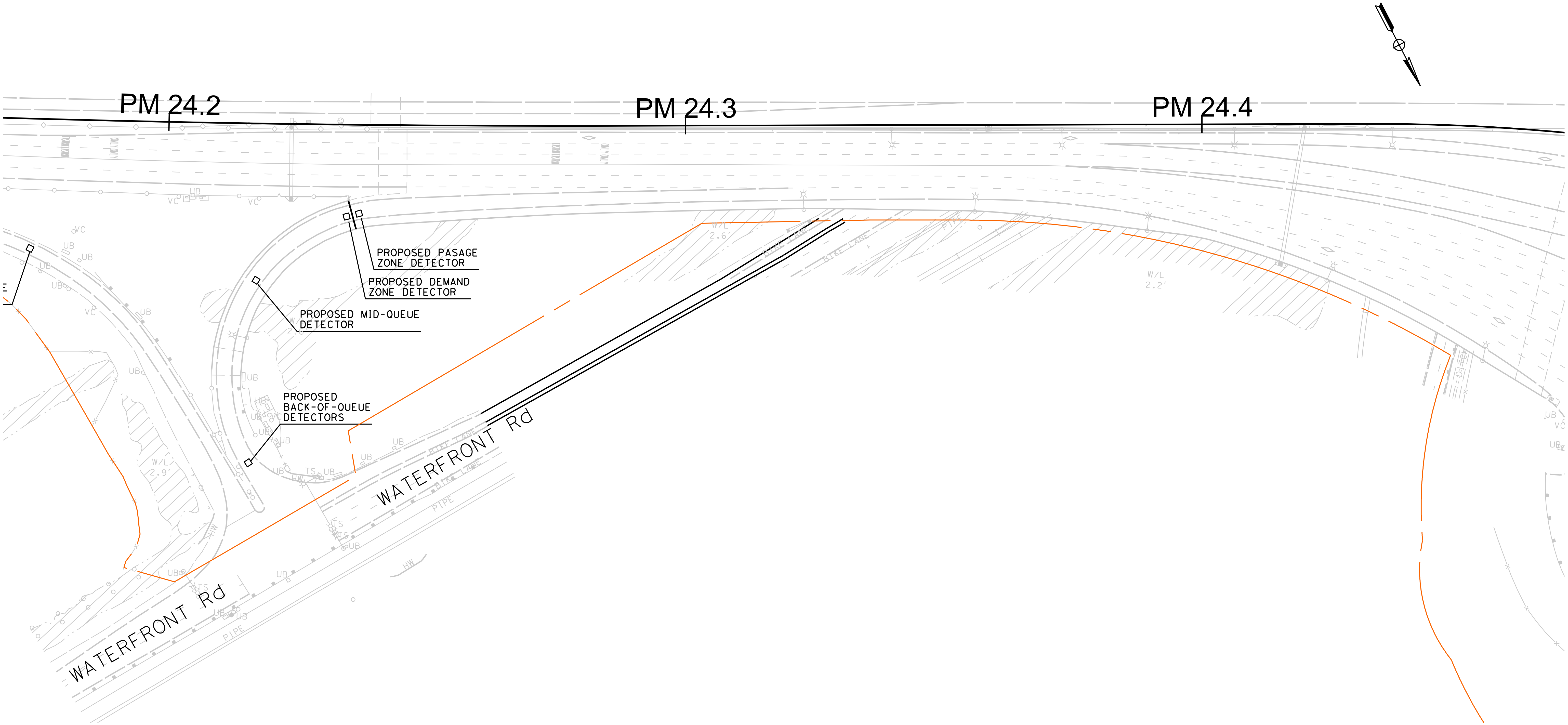
INNOVATE 680

FEASIBILITY STUDY

SB MARINA VISTA Ave/ WATERFRONT Rd

L-49

SCALE: 1"=100'



Caltrans

CONTRA COSTA transportation authority

wsp

LEGEND

- EXISTING CALTRANS R/W
- R/W ACQUISITION
- STRUCUTRE WIDENING
- NEW RETAINING WALL

INNOVATE 680
FEASIBILITY STUDY
NB MARINA VISTA Ave/ WATERFRONT Rd

SCALE: 1"=100'

L-50

Appendix E. Conceptual Civil Cost Estimates

This appendix provides conceptual cost estimates for the conceptual designs contained in Appendix D for interchange improvements necessary to initiate CARM operations on I-680 in Contra Costa County.

Northbound Civil Cost Estimates

Alternative 1

Innovate 680: Alcosta Estimate					
Item Description	Quantity	Unit	Cost Assumptions	Total Cost	Engineering Assumptions
Roadway					
Pavement	122,720	sq ft	$40	$4,908,800	
Remove Painted Pavement Marking	0	ft	$5	$0	Grinding away existing thermoplastic
Striping	7,890	ft	$1	$7,890	
Retaining Wall	2,030	sq ft	$350	$710,500	Not necessary
Sound Walls, assume avg H=14'	0	sq ft	$150	$0	Does not qualify
Permanent Concrete Barrier	0	ft	$120	$0	
Temporary Concrete Barrier	0	ft	$30	$0	K-Rail
			Roadway Total	$5,627,190	
Drainage				$281,360	5% of Roadway Costs
			Drainage Total	$281,360	
Utilities				$281,360	5% of Roadway Costs
			Utility Total	$281,360	
Structures					
New	0	sq ft	$300	$0	
Widening	0	sq ft	$200	$0	
			Structures Total	$0	
Right of Way					
Business	0	sq ft	$300	$0	
Residential	0	sq ft	$250	$0	
Public (Schools, parks, hospitals, etc.)	0	sq ft	$200	$0	
			R/W Total	$0	
			Sub Total	$6,189,909	
			Contingency	$2,166,468	35% of Sub Total
			Total	$8,400,000	Rounded Up

5/10/2022

Alternative 1

Innovate 680: Bollinger High Estimate					
Item Description	Quantity	Unit	Cost Assumptions	Total Cost	Engineering Assumptions
Roadway					
Pavement	77,720	sq ft	$40	$3,108,800	
Remove Painted Pavement Marking	0	ft	$5	$0	Grinding away existing thermoplastic
Striping	5,790	ft	$1	$5,790	
Retaining Wall	130	sq ft	$350	$45,500	Ground Anchor Wall beneath the OC
Sound Walls, assume avg H=14'	0	sq ft	$150	$0	Does not qualify
Permanent Concrete Barrier	1,130	ft	$120	$135,600	
Temporary Concrete Barrier	0	ft	$30	$0	K-Rail
			Roadway Total	$3,295,690	
Drainage				$164,785	5% of Roadway Costs
			Drainage Total	$164,785	
Utilities				$164,785	5% of Roadway Costs
			Utility Total	$164,785	
Structures					
New	0	sq ft	$300	$0	
Widening	0	sq ft	$200	$0	
			Structures Total	$0	
Right of Way					
Business	0	sq ft	$300	$0	
Residential	0	sq ft	$250	$0	
Public (Schools, parks, hospitals, etc.)	0	sq ft	$200	$0	
			R/W Total	$0	
			Sub Total	$3,625,259	
			Contingency	$1,268,841	35% of Sub Total
			Total	$4,900,000	Rounded Up

6/30/2022

Alternative 1

Innovate 680: Crow Estimate					
Item Description	Quantity	Unit	Cost Assumptions	Total Cost	Engineering Assumptions
Roadway					
Pavement	89,520	sq ft	$40	$3,580,800	
Remove Painted Pavement Marking	0	ft	$5	$0	Grinding away existing thermoplastic
Striping	6,180	ft	$1	$6,180	
Retaining Wall	0	sq ft	$350	$0	Not necessary
Sound Walls, assume avg H=14'	0	sq ft	$150	$0	Does not qualify
Permanent Concrete Barrier	1,020	ft	$120	$122,400	
Temporary Concrete Barrier	0	ft	$30	$0	K-Rail
			Roadway Total	$3,709,380	
Drainage				$185,469	5% of Roadway Costs
			Drainage Total	$185,469	
Utilities				$185,469	5% of Roadway Costs
			Utility Total	$185,469	
Structures					
New	0	sq ft	$300	$0	
Widening	0	sq ft	$200	$0	
			Structures Total	$0	
Right of Way					
Business	0	sq ft	$300	$0	
Residential	0	sq ft	$250	$0	
Public (Schools, parks, hospitals, etc.)	0	sq ft	$200	$0	
			R/W Total	$0	
			Sub Total	$4,080,318	
			Contingency	$1,428,111	35% of Sub Total
			Total	$5,600,000	Rounded Up

5/10/2022

Alternative 1

Innovate 680: Sycamore Estimate					
Item Description	Quantity	Unit	Cost Assumptions	Total Cost	Engineering Assumptions
Roadway					
Pavement	12,500	sq ft	$40	$500,000	
Remove Painted Pavement Marking	0	ft	$5	$0	Grinding away existing thermoplastic
Striping	1,410	ft	$1	$1,410	
Retaining Wall	0	sq ft	$350	$0	Not necessary
Sound Walls, assume avg H=14'	0	sq ft	$150	$0	Does not qualify
Permanent Concrete Barrier	0	ft	$120	$0	
Temporary Concrete Barrier	0	ft	$30	$0	K-Rail
			Roadway Total	$501,410	
Drainage				$25,071	5% of Roadway Costs
			Drainage Total	$25,071	
Utilities				$25,071	5% of Roadway Costs
			Utility Total	$25,071	
Structures					
New	0	sq ft	$300	$0	
Widening	0	sq ft	$200	$0	
			Structures Total	$0	
Right of Way					
Business	0	sq ft	$300	$0	
Residential	0	sq ft	$250	$0	
Public (Schools, parks, hospitals, etc.)	0	sq ft	$200	$0	
			R/W Total	$0	
			Sub Total	$551,551	
			Contingency	$193,043	35% of Sub Total
			Total	$750,000	Rounded Up

5/10/2022

Alternative 1

Innovate 680: Diablo Rd Estimate					
Item Description	Quantity	Unit	Cost Assumptions	Total Cost	Engineering Assumptions
Roadway					
Pavement	33,690	sq ft	$40	$1,347,600	
Remove Painted Pavement Marking	0	ft	$5	$0	Grinding away existing thermoplastic
Striping	2,330	ft	$1	$2,330	
Retaining Wall	0	sq ft	$350	$0	Not necessary
Sound Walls, assume avg H=14'	0	sq ft	$150	$0	Does not qualify
Permanent Concrete Barrier	0	ft	$120	$0	
Temporary Concrete Barrier	0	ft	$30	$0	K-Rail
			Roadway Total	$1,349,930	
Drainage				$67,497	5% of Roadway Costs
			Drainage Total	$67,497	
Utilities				$67,497	5% of Roadway Costs
			Utility Total	$67,497	
Structures					
New	0	sq ft	$300	$0	
Widening	4,800	sq ft	$200	$960,000	
			Structures Total	$960,000	
Right of Way					
Business	0	sq ft	$300	$0	
Residential	0	sq ft	$250	$0	
Public (Schools, parks, hospitals, etc.)	0	sq ft	$200	$0	
			R/W Total	$0	
			Sub Total	$2,444,923	
			Contingency	$855,723	35% of Sub Total
			Total	$3,400,000	Rounded Up

5/10/2022

Alternative 1

Innovate 680: El Cerro Estimate					
Item Description	Quantity	Unit	Cost Assumptions	Total Cost	Engineering Assumptions
Roadway					
Pavement	10,050	sq ft	$40	$402,000	
Remove Painted Pavement Marking	0	ft	$5	$0	Grinding away existing thermoplastic
Striping	1,090	ft	$1	$1,090	
Retaining Wall	0	sq ft	$350	$0	Not necessary
Sound Walls, assume avg H=14'	0	sq ft	$150	$0	Does not qualify
Permanent Concrete Barrier	0	ft	$120	$0	
Temporary Concrete Barrier	0	ft	$30	$0	K-Rail
			Roadway Total	$403,090	
Drainage				$20,155	5% of Roadway Costs
			Drainage Total	$20,155	
Utilities				$20,155	5% of Roadway Costs
			Utility Total	$20,155	
Structures					
New	0	sq ft	$300	$0	
Widening	0	sq ft	$200	$0	
			Structures Total	$0	
Right of Way					
Business	0	sq ft	$300	$0	
Residential	0	sq ft	$250	$0	
Public (Schools, parks, hospitals, etc.)	0	sq ft	$200	$0	
			R/W Total	$0	
			Sub Total	$443,399	
			Contingency	$155,190	35% of Sub Total
			Total	$600,000	Rounded Up

5/10/2022

Alternative 1

Innovate 680: El Pintado Estimate					
Item Description	Quantity	Unit	Cost Assumptions	Total Cost	Engineering Assumptions
Roadway					
Pavement	0	sq ft	$40	$0	
Remove Painted Pavement Marking	0	ft	$5	$0	Grinding away existing thermoplastic
Striping	0	ft	$1	$0	
Retaining Wall	0	sq ft	$350	$0	Not necessary
Sound Walls, assume avg H=14'	0	sq ft	$150	$0	Does not qualify
Permanent Concrete Barrier	0	ft	$120	$0	
Temporary Concrete Barrier	0	ft	$30	$0	K-Rail
			Roadway Total	$0	
Drainage				$0	5% of Roadway Costs
			Drainage Total	$0	
Utilities				$0	5% of Roadway Costs
			Utility Total	$0	
Structures					
New	0	sq ft	$300	$0	
Widening	0	sq ft	$200	$0	
			Structures Total	$0	
Right of Way					
Business	0	sq ft	$300	$0	
Residential	0	sq ft	$250	$0	
Public (Schools, parks, hospitals, etc.)	0	sq ft	$200	$0	
			R/W Total	$0	
			Sub Total	$0	
			Contingency	$0	35% of Sub Total
			Total	$0	Rounded Up

5/10/2022

Alternative 1

Innovate 680: Stone Valley Estimate					
Item Description	Quantity	Unit	Cost Assumptions	Total Cost	Engineering Assumptions
Roadway					
Pavement	39,330	sq ft	$40	$1,573,200	
Remove Painted Pavement Marking	0	ft	$5	$0	Grinding away existing thermoplastic
Striping	2,780	ft	$1	$2,780	
Retaining Wall	0	sq ft	$350	$0	Not necessary
Sound Walls, assume avg H=14'	0	sq ft	$150	$0	Does not qualify
Permanent Concrete Barrier	0	ft	$120	$0	
Temporary Concrete Barrier	0	ft	$30	$0	K-Rail
			Roadway Total	$1,575,980	
Drainage				$78,799	5% of Roadway Costs
			Drainage Total	$78,799	
Utilities				$78,799	5% of Roadway Costs
			Utility Total	$78,799	
Structures					
New	0	sq ft	$300	$0	
Widening	0	sq ft	$200	$0	
			Structures Total	$0	
Right of Way					
Business	0	sq ft	$300	$0	
Residential	0	sq ft	$250	$0	
Public (Schools, parks, hospitals, etc.)	0	sq ft	$200	$0	
			R/W Total	$0	
			Sub Total	$1,733,578	
			Contingency	$606,752	35% of Sub Total
			Total	$2,400,000	Rounded Up

5/10/2022

Alternative 1

Innovate 680: Livorna Estimate					
Item Description	Quantity	Unit	Cost Assumptions	Total Cost	Engineering Assumptions
Roadway					
Pavement	11,990	sq ft	$40	$479,600	
Remove Painted Pavement Marking	0	ft	$5	$0	Grinding away existing thermoplastic
Striping	1,150	ft	$1	$1,150	
Retaining Wall	0	sq ft	$350	$0	Not necessary
Sound Walls, assume avg H=14'	0	sq ft	$150	$0	Does not qualify
Permanent Concrete Barrier	0	ft	$120	$0	
Temporary Concrete Barrier	0	ft	$30	$0	K-Rail
			Roadway Total	$480,750	
Drainage				$24,038	5% of Roadway Costs
			Drainage Total	$24,038	
Utilities				$24,038	5% of Roadway Costs
			Utility Total	$24,038	
Structures					
New	0	sq ft	$300	$0	
Widening	0	sq ft	$200	$0	
			Structures Total	$0	
Right of Way					
Business	0	sq ft	$300	$0	
Residential	0	sq ft	$250	$0	
Public (Schools, parks, hospitals, etc.)	0	sq ft	$200	$0	
			R/W Total	$0	
			Sub Total	$528,825	
			Contingency	$185,089	35% of Sub Total
			Total	$720,000	Rounded Up

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Alternative 1

Innovate 680: Rudgear Estimate					
Item Description	Quantity	Unit	Cost Assumptions	Total Cost	Engineering Assumptions
Roadway					
Pavement	0	sq ft	$40	$0	
Remove Painted Pavement Marking	0	ft	$5	$0	Grinding away existing thermoplastic
Striping	0	ft	$1	$0	
Retaining Wall	0	sq ft	$350	$0	Not necessary
Sound Walls, assume avg H=14'	0	sq ft	$150	$0	Does not qualify
Permanent Concrete Barrier	0	ft	$120	$0	
Temporary Concrete Barrier	0	ft	$30	$0	K-Rail
			Roadway Total	$0	
Drainage				$0	5% of Roadway Costs
			Drainage Total	$0	
Utilities				$0	5% of Roadway Costs
			Utility Total	$0	
Structures					
New	0	sq ft	$300	$0	
Widening	0	sq ft	$200	$0	
			Structures Total	$0	
Right of Way					
Business	0	sq ft	$300	$0	
Residential	0	sq ft	$250	$0	
Public (Schools, parks, hospitals, etc.)	0	sq ft	$200	$0	
			R/W Total	$0	
			Sub Total	$0	
			Contingency	$0	35% of Sub Total
			Total	$0	Rounded Up

5/10/2022

Alternative 1

Innovate 680: Olympic Estimate					
Item Description	Quantity	Unit	Cost Assumptions	Total Cost	Engineering Assumptions
Roadway					
Pavement	18,300	sq ft	$40	$732,000	
Remove Painted Pavement Marking	0	ft	$5	$0	Grinding away existing thermoplastic
Striping	2,340	ft	$1	$2,340	
Retaining Wall	0	sq ft	$350	$0	Not necessary
Sound Walls, assume avg H=14'	0	sq ft	$150	$0	Does not qualify
Permanent Concrete Barrier	0	ft	$120	$0	
Temporary Concrete Barrier	0	ft	$30	$0	K-Rail
			Roadway Total	$734,340	
Drainage				$36,717	5% of Roadway Costs
			Drainage Total	$36,717	
Utilities				$36,717	5% of Roadway Costs
			Utility Total	$36,717	
Structures					
New	0	sq ft	$300	$0	
Widening	0	sq ft	$200	$0	
			Structures Total	$0	
Right of Way					
Business	0	sq ft	$300	$0	
Residential	0	sq ft	$250	$0	
Public (Schools, parks, hospitals, etc.)	0	sq ft	$200	$0	
			R/W Total	$0	
			Sub Total	$807,774	
			Contingency	$282,721	35% of Sub Total
			Total	$1,100,000	Rounded Up

5/10/2022

Alternative 1

Innovate 680: SR-24 Estimate					
Item Description	Quantity	Unit	Cost Assumptions	Total Cost	Engineering Assumptions
Roadway					
Pavement	0	sq ft	$40	$0	
Remove Painted Pavement Marking	0	ft	$5	$0	Grinding away existing thermoplastic
Striping	0	ft	$1	$0	
Retaining Wall	0	sq ft	$350	$0	Not necessary
Sound Walls, assume avg H=14'	0	sq ft	$150	$0	Does not qualify
Permanent Concrete Barrier	0	ft	$120	$0	
Temporary Concrete Barrier	0	ft	$30	$0	K-Rail
			Roadway Total	$0	
Drainage				$0	5% of Roadway Costs
			Drainage Total	$0	
Utilities				$0	5% of Roadway Costs
			Utility Total	$0	
Structures					
New	0	sq ft	$300	$0	
Widening	0	sq ft	$200	$0	
			Structures Total	$0	
Right of Way					
Business	0	sq ft	$300	$0	
Residential	0	sq ft	$250	$0	
Public (Schools, parks, hospitals, etc.)	0	sq ft	$200	$0	
			R/W Total	$0	
			Sub Total	$0	
			Contingency	$0	35% of Sub Total
			Total	$0	Rounded Up

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Alternative 1

Innovate 680: N Main Street Estimate					
Item Description	Quantity	Unit	Cost Assumptions	Total Cost	Engineering Assumptions
Roadway					
Pavement	95,250	sq ft	$40	$3,810,000	
Remove Painted Pavement Marking	0	ft	$5	$0	Grinding away existing thermoplastic
Striping	6,900	ft	$1	$6,900	
Retaining Wall	0	sq ft	$350	$0	Not necessary
Sound Walls, assume avg H=14'	0	sq ft	$150	$0	Does not qualify
Permanent Concrete Barrier	0	ft	$120	$0	
Temporary Concrete Barrier	0	ft	$30	$0	K-Rail
			Roadway Total	$3,816,900	
Drainage				$190,845	5% of Roadway Costs
			Drainage Total	$190,845	
Utilities				$190,845	5% of Roadway Costs
			Utility Total	$190,845	
Structures					
New	0	sq ft	$300	$0	
Widening	0	sq ft	$200	$0	
			Structures Total	$0	
Right of Way					
Business	0	sq ft	$300	$0	
Residential	0	sq ft	$250	$0	
Public (Schools, parks, hospitals, etc.)	9,560	sq ft	$200	$1,912,000	
			R/W Total	$1,912,000	
			Sub Total	$6,110,590	
			Contingency	$2,138,707	35% of Sub Total
			Total	$8,250,000	Rounded Up

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Alternative 1

Innovate 680: Truck Scales Estimate					
Item Description	Quantity	Unit	Cost Assumptions	Total Cost	Engineering Assumptions
Roadway					
Pavement	0	sq ft	$40	$0	
Remove Painted Pavement Marking	0	ft	$5	$0	Grinding away existing thermoplastic
Striping	0	ft	$1	$0	
Retaining Wall	0	sq ft	$350	$0	Not necessary
Sound Walls, assume avg H=14'	0	sq ft	$150	$0	Does not qualify
Permanent Concrete Barrier	0	ft	$120	$0	
Temporary Concrete Barrier	0	ft	$30	$0	K-Rail
			Roadway Total	$0	
Drainage				$0	5% of Roadway Costs
			Drainage Total	$0	
Utilities				$0	5% of Roadway Costs
			Utility Total	$0	
Structures					
New	0	sq ft	$300	$0	
Widening	0	sq ft	$200	$0	
			Structures Total	$0	
Right of Way					
Business	0	sq ft	$300	$0	
Residential	0	sq ft	$250	$0	
Public (Schools, parks, hospitals, etc.)	0	sq ft	$200	$0	
			R/W Total	$0	
			Sub Total	$0	
			Contingency	$0	35% of Sub Total
			Total	$0	Rounded Up

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Alternative 1

Innovate 680: Treat Estimate					
Item Description	Quantity	Unit	Cost Assumptions	Total Cost	Engineering Assumptions
Roadway					
Pavement	115,210	sq ft	$40	$4,608,400	
Remove Painted Pavement Marking	0	ft	$5	$0	Grinding away existing thermoplastic
Striping	10,520	ft	$1	$10,520	
Retaining Wall	0	sq ft	$350	$0	Not necessary
Sound Walls, assume avg H=14'	0	sq ft	$150	$0	Does not qualify
Permanent Concrete Barrier	0	ft	$120	$0	
Temporary Concrete Barrier	0	ft	$30	$0	K-Rail
			Roadway Total	$4,618,920	
Drainage				$230,946	5% of Roadway Costs
			Drainage Total	$230,946	
Utilities				$230,946	5% of Roadway Costs
			Utility Total	$230,946	
Structures					
New	0	sq ft	$300	$0	
Widening	0	sq ft	$200	$0	
			Structures Total	$0	
Right of Way					
Business	43,080	sq ft	$300	$12,924,000	
Residential	0	sq ft	$250	$0	
Public (Schools, parks, hospitals, etc.)	0	sq ft	$200	$0	
			R/W Total	$12,924,000	
			Sub Total	$18,004,812	
			Contingency	$6,301,684	35% of Sub Total
			Total	$24,310,000	Rounded Up

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Alternative 1

Innovate 680: Coggins Estimate					
Item Description	Quantity	Unit	Cost Assumptions	Total Cost	Engineering Assumptions
Roadway					
Pavement	44,560	sq ft	$40	$1,782,400	
Remove Painted Pavement Marking	0	ft	$5	$0	Grinding away existing thermoplastic
Striping	4,560	ft	$1	$4,560	
Retaining Wall	0	sq ft	$350	$0	Not necessary
Sound Walls, assume avg H=14'	0	sq ft	$150	$0	Does not qualify
Permanent Concrete Barrier	0	ft	$120	$0	
Temporary Concrete Barrier	0	ft	$30	$0	K-Rail
			Roadway Total	$1,786,960	
Drainage				$89,348	5% of Roadway Costs
			Drainage Total	$89,348	
Utilities				$89,348	5% of Roadway Costs
			Utility Total	$89,348	
Structures					
New	0	sq ft	$300	$0	
Widening	0	sq ft	$200	$0	
			Structures Total	$0	
Right of Way					
Business	0	sq ft	$300	$0	
Residential	0	sq ft	$250	$0	
Public (Schools, parks, hospitals, etc.)	0	sq ft	$200	$0	
			R/W Total	$0	
			Sub Total	$1,965,656	
			Contingency	$687,980	35% of Sub Total
			Total	$2,660,000	Rounded Up

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Alternative 1

Innovate 680: Monument Estimate					
Item Description	Quantity	Unit	Cost Assumptions	Total Cost	Engineering Assumptions
Roadway					
Pavement	200	sq ft	$40	$8,000	
Remove Painted Pavement Marking	300	ft	$5	$1,500	Grinding away existing thermoplastic
Striping	300	ft	$1	$300	
Retaining Wall	200	sq ft	$350	$70,000	Conservative without left shld design exception
Sound Walls, assume avg H=14'	0	sq ft	$150	$0	Does not qualify
Permanent Concrete Barrier	0	ft	$120	$0	
Temporary Concrete Barrier	0	ft	$30	$0	K-Rail
			Roadway Total	$79,800	
Drainage				$3,990	5% of Roadway Costs
			Drainage Total	$3,990	
Utilities				$3,990	5% of Roadway Costs
			Utility Total	$3,990	
Structures					
New	0	sq ft	$300	$0	
Widening	0	sq ft	$200	$0	
			Structures Total	$0	
Right of Way					
Business	0	sq ft	$300	$0	
Residential	0	sq ft	$250	$0	
Public (Schools, parks, hospitals, etc.)	0	sq ft	$200	$0	
			R/W Total	$0	
			Sub Total	$87,780	
			Contingency	$30,723	35% of Sub Total
			Total	$120,000	Rounded Up

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Alternative 1

Innovate 680: Willow Estimate					
Item Description	Quantity	Unit	Cost Assumptions	Total Cost	Engineering Assumptions
Roadway					
Pavement	61,910	sq ft	$40	$2,476,400	
Remove Painted Pavement Marking	0	ft	$5	$0	Grinding away existing thermoplastic
Striping	4,640	ft	$1	$4,640	
Retaining Wall	0	sq ft	$350	$0	Not necessary
Sound Walls, assume avg H=14'	0	sq ft	$150	$0	Does not qualify
Permanent Concrete Barrier	0	ft	$120	$0	
Temporary Concrete Barrier	0	ft	$30	$0	K-Rail
			Roadway Total	$2,481,040	
Drainage				$124,052	5% of Roadway Costs
			Drainage Total	$124,052	
Utilities				$124,052	5% of Roadway Costs
			Utility Total	$124,052	
Structures					
New	0	sq ft	$300	$0	
Widening	0	sq ft	$200	$0	
			Structures Total	$0	
Right of Way					
Business	2,230	sq ft	$300	$669,000	
Residential	0	sq ft	$250	$0	
Public (Schools, parks, hospitals, etc.)	0	sq ft	$200	$0	
			R/W Total	$669,000	
			Sub Total	$3,398,144	
			Contingency	$1,189,350	35% of Sub Total
			Total	$4,590,000	Rounded Up

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Alternative 1

Innovate 680: Burnett Estimate					
Item Description	Quantity	Unit	Cost Assumptions	Total Cost	Engineering Assumptions
Roadway					
Pavement	21,840	sq ft	$40	$873,600	
Remove Painted Pavement Marking	0	ft	$5	$0	Grinding away existing thermoplastic
Striping	1,620	ft	$1	$1,620	
Retaining Wall	600	sq ft	$350	$210,000	
Sound Walls, assume avg H=14'	0	sq ft	$150	$0	Does not qualify
Permanent Concrete Barrier	0	ft	$120	$0	
Temporary Concrete Barrier	0	ft	$30	$0	K-Rail
			Roadway Total	$1,085,220	
Drainage				$54,261	5% of Roadway Costs
			Drainage Total	$54,261	
Utilities				$54,261	5% of Roadway Costs
			Utility Total	$54,261	
Structures					
New	0	sq ft	$300	$0	
Widening	3,630	sq ft	$200	$726,000	
			Structures Total	$726,000	
Right of Way					
Business	0	sq ft	$300	$0	
Residential	0	sq ft	$250	$0	
Public (Schools, parks, hospitals, etc.)	0	sq ft	$200	$0	
			R/W Total	$0	
			Sub Total	$1,919,742	
			Contingency	$671,910	35% of Sub Total
			Total	$2,600,000	Rounded Up

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Alternative 1

Innovate 680: Concord Estimate					
Item Description	Quantity	Unit	Cost Assumptions	Total Cost	Engineering Assumptions
Roadway					
Pavement	47,950	sq ft	$40	$1,918,000	
Remove Painted Pavement Marking	0	ft	$5	$0	Grinding away existing thermoplastic
Striping	3,880	ft	$1	$3,880	
Retaining Wall	0	sq ft	$350	$0	Not necessary
Sound Walls, assume avg H=14'	0	sq ft	$150	$0	Does not qualify
Permanent Concrete Barrier	0	ft	$120	$0	
Temporary Concrete Barrier	0	ft	$30	$0	K-Rail
			Roadway Total	$1,921,880	
Drainage	Drainage			$96,094	5% of Roadway Costs
			Drainage Total	$96,094	
Utilities				$96,094	5% of Roadway Costs
			Utility Total	$96,094	
Structures					
New	0	sq ft	$300	$0	
Widening	0	sq ft	$200	$0	
			Structures Total	$0	
Right of Way					
Business	0	sq ft	$300	$0	
Residential	0	sq ft	$250	$0	
Public (Schools, parks, hospitals, etc.)	0	sq ft	$200	$0	
			R/W Total	$0	
			Sub Total	$2,114,068	
			Contingency	$739,924	35% of Sub Total
			Total	$2,860,000	Rounded Up

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Alternative 1

Innovate 680: SR-4 Interchange Estimate					
Item Description	Quantity	Unit	Cost Assumptions	Total Cost	Engineering Assumptions
Roadway					
Pavement	109,880	sq ft	$40	$4,395,200	
Remove Painted Pavement Marking	0	ft	$5	$0	Grinding away existing thermoplastic
Striping	8,830	ft	$1	$8,830	
Retaining Wall	0	sq ft	$350	$0	Not necessary
Sound Walls, assume avg H=14'	0	sq ft	$150	$0	Does not qualify
Permanent Concrete Barrier	0	ft	$120	$0	
Temporary Concrete Barrier	0	ft	$30	$0	K-Rail
			Roadway Total	$4,404,030	
Drainage				$220,202	5% of Roadway Costs
			Drainage Total	$220,202	
Utilities				$220,202	5% of Roadway Costs
			Utility Total	$220,202	
Structures					
New	0	sq ft	$300	$0	
Widening	0	sq ft	$200	$0	
			Structures Total	$0	
Right of Way					
Business	0	sq ft	$300	$0	
Residential	0	sq ft	$250	$0	
Public (Schools, parks, hospitals, etc.)	13,730	sq ft	$200	$2,746,000	
			R/W Total	$2,746,000	
			Sub Total	$7,590,433	
			Contingency	$2,656,652	35% of Sub Total
			Total	$10,250,000	Rounded Up

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Alternative 1

Innovate 680: Arthur Estimate					
Item Description	Quantity	Unit	Cost Assumptions	Total Cost	Engineering Assumptions
Roadway					
Pavement	20,840	sq ft	$40	$833,600	
Remove Painted Pavement Marking	2,020	ft	$5	$10,100	Grinding away existing thermoplastic
Striping	0	ft	$1	$0	
Retaining Wall	0	sq ft	$350	$0	Not necessary
Sound Walls, assume avg H=14'	0	sq ft	$150	$0	Does not qualify
Permanent Concrete Barrier	0	ft	$120	$0	
Temporary Concrete Barrier	0	ft	$30	$0	K-Rail
			Roadway Total	$843,700	
Drainage				$42,185	5% of Roadway Costs
			Drainage Total	$42,185	
Utilities				$42,185	5% of Roadway Costs
			Utility Total	$42,185	
Structures					
New	0	sq ft	$300	$0	
Widening	0	sq ft	$200	$0	
			Structures Total	$0	
Right of Way					
Business	0	sq ft	$300	$0	
Residential	0	sq ft	$250	$0	
Public (Schools, parks, hospitals, etc.)	0	sq ft	$200	$0	
			R/W Total	$0	
			Sub Total	$928,070	
			Contingency	$324,825	35% of Sub Total
			Total	$1,260,000	Rounded Up

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Alternative 1

Innovate 680: Marina Estimate					
Item Description	Quantity	Unit	Cost Assumptions	Total Cost	Engineering Assumptions
Roadway					
Pavement	0	sq ft	$40	$0	
Remove Painted Pavement Marking	2,000	ft	$5	$10,000	Grinding away existing thermoplastic
Striping	2,400	ft	$1	$2,400	
Retaining Wall	0	sq ft	$350	$0	Not necessary
Sound Walls, assume avg H=14'	0	sq ft	$150	$0	Does not qualify
Permanent Concrete Barrier	0	ft	$120	$0	
Temporary Concrete Barrier	0	ft	$30	$0	K-Rail
			Roadway Total	$12,400	
Drainage				$620	5% of Roadway Costs
			Drainage Total	$620	
Utilities				$620	5% of Roadway Costs
			Utility Total	$620	
Structures					
New	0	sq ft	$300	$0	
Widening	0	sq ft	$200	$0	
			Structures Total	$0	
Right of Way					
Business	0	sq ft	$300	$0	
Residential	0	sq ft	$250	$0	
Public (Schools, parks, hospitals, etc.)	0	sq ft	$200	$0	
			R/W Total	$0	
			Sub Total	$13,640	
			Contingency	$4,774	35% of Sub Total
			Total	$20,000	Rounded Up

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Southbound Civil Cost Estimates

Alternative 1

Innovate 680: Marina Estimate					
Item Description	Quantity	Unit	Cost Assumptions	Total Cost	Engineering Assumptions
Roadway					
Pavement	65,020	sq ft	$40	$2,600,800	
Remove Painted Pavement Marking	0	ft	$5	$0	Grinding away existing thermoplastic
Striping	4,060	ft	$1	$4,060	
Retaining Wall	0	sq ft	$350	$0	Not necessary
Sound Walls, assume avg H=14'	0	sq ft	$150	$0	Does not qualify
Permanent Concrete Barrier	0	ft	$120	$0	
Temporary Concrete Barrier	0	ft	$30	$0	K-Rail
			Roadway Total	$2,604,860	
Drainage				$130,243	5% of Roadway Costs
			Drainage Total	$130,243	
Utilities				$130,243	5% of Roadway Costs
			Utility Total	$130,243	
Structures					
New	0	sq ft	$300	$0	
Widening	0	sq ft	$200	$0	
			Structures Total	$0	
Right of Way					
Business	0	sq ft	$300	$0	
Residential	0	sq ft	$250	$0	
Public (Schools, parks, hospitals, etc.)	960	sq ft	$200	$192,000	
			R/W Total	$192,000	
			Sub Total	$3,057,346	
			Contingency	$1,070,071	35% of Sub Total
			Total	$4,130,000	Rounded Up

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Alternative 1

Innovate 680: Pacheco Estimate					
Item Description	Quantity	Unit	Cost Assumptions	Total Cost	Engineering Assumptions
Roadway					
Pavement	41,830	sq ft	$40	$1,673,200	
Remove Painted Pavement Marking	0	ft	$5	$0	Grinding away existing thermoplastic
Striping	2,050	ft	$1	$2,050	
Retaining Wall	0	sq ft	$350	$0	Not necessary
Sound Walls, assume avg H=14'	0	sq ft	$150	$0	Does not qualify
Permanent Concrete Barrier	0	ft	$120	$0	
Temporary Concrete Barrier	0	ft	$30	$0	K-Rail
			Roadway Total	$1,675,250	
Drainage				$83,763	5% of Roadway Costs
			Drainage Total	$83,763	
Utilities				$83,763	5% of Roadway Costs
			Utility Total	$83,763	
Structures					
New	0	sq ft	$300	$0	
Widening	0	sq ft	$200	$0	
			Structures Total	$0	
Right of Way					
Business	0	sq ft	$300	$0	
Residential	0	sq ft	$250	$0	
Public (Schools, parks, hospitals, etc.)	0	sq ft	$200	$0	
			R/W Total	$0	
			Sub Total	$1,842,775	
			Contingency	$644,971	35% of Sub Total
			Total	$2,490,000	Rounded Up

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Alternative 1

Innovate 680: SR-4 Estimate					
Item Description	Quantity	Unit	Cost Assumptions	Total Cost	Engineering Assumptions
Roadway					
Pavement	162,370	sq ft	$40	$6,494,800	
Remove Painted Pavement Marking	0	ft	$5	$0	Grinding away existing thermoplastic
Striping	9,620	ft	$1	$9,620	
Retaining Wall	0	sq ft	$350	$0	Not necessary
Sound Walls, assume avg H=14'	0	sq ft	$150	$0	Does not qualify
Permanent Concrete Barrier	0	ft	$120	$0	
Temporary Concrete Barrier	0	ft	$30	$0	K-Rail
			Roadway Total	$6,504,420	
Drainage				$325,221	5% of Roadway Costs
			Drainage Total	$325,221	
Utilities				$325,221	5% of Roadway Costs
			Utility Total	$325,221	
Structures					
New	0	sq ft	$300	$0	
Widening	0	sq ft	$200	$0	
			Structures Total	$0	
Right of Way					
Business	0	sq ft	$300	$0	
Residential	0	sq ft	$250	$0	
Public (Schools, parks, hospitals, etc.)	0	sq ft	$200	$0	
			R/W Total	$0	
			Sub Total	$7,154,862	
			Contingency	$2,504,202	35% of Sub Total
			Total	$9,660,000	Rounded Up

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Alternative 1

Innovate 680: Contra Costa Estimate					
Item Description	Quantity	Unit	Cost Assumptions	Total Cost	Engineering Assumptions
Roadway					
Pavement	45,450	sq ft	$40	$1,818,000	
Remove Painted Pavement Marking	0	ft	$5	$0	Grinding away existing thermoplastic
Striping	2,910	ft	$1	$2,910	
Retaining Wall	750	sq ft	$350	$262,500	
Sound Walls, assume avg H=14'	0	sq ft	$150	$0	Does not qualify
Permanent Concrete Barrier	0	ft	$120	$0	
Temporary Concrete Barrier	0	ft	$30	$0	K-Rail
			Roadway Total	$2,083,410	
Drainage				$104,171	5% of Roadway Costs
			Drainage Total	$104,171	
Utilities				$104,171	5% of Roadway Costs
			Utility Total	$104,171	
Structures					
New	3,520	sq ft	$300	$1,056,000	
Widening	0	sq ft	$200	$0	
			Structures Total	$1,056,000	
Right of Way					
Business	0	sq ft	$300	$0	
Residential	0	sq ft	$250	$0	
Public (Schools, parks, hospitals, etc.)	0	sq ft	$200	$0	
			R/W Total	$0	
			Sub Total	$3,347,751	
			Contingency	$1,171,713	35% of Sub Total
			Total	$4,520,000	Rounded Up

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Alternative 1

Innovate 680: Concord Estimate					
Item Description	Quantity	Unit	Cost Assumptions	Total Cost	Engineering Assumptions
Roadway					
Pavement	21,000	sq ft	$40	$840,000	
Remove Painted Pavement Marking	0	ft	$5	$0	Grinding away existing thermoplastic
Striping	3,100	ft	$1	$3,100	
Retaining Wall	0	sq ft	$350	$0	Not necessary
Sound Walls, assume avg H=14'	0	sq ft	$150	$0	Does not qualify
Permanent Concrete Barrier	0	ft	$120	$0	
Temporary Concrete Barrier	0	ft	$30	$0	K-Rail
			Roadway Total	$843,100	
Drainage				$42,155	5% of Roadway Costs
			Drainage Total	$42,155	
Utilities				$42,155	5% of Roadway Costs
			Utility Total	$42,155	
Structures					
New	0	sq ft	$300	$0	
Widening	0	sq ft	$200	$0	
			Structures Total	$0	
Right of Way					
Business	0	sq ft	$300	$0	
Residential	0	sq ft	$250	$0	
Public (Schools, parks, hospitals, etc.)	0	sq ft	$200	$0	
			R/W Total	$0	
			Sub Total	$927,410	
			Contingency	$324,594	35% of Sub Total
			Total	$1,260,000	Rounded Up

5/10/2022

Alternative 1

Innovate 680: Sunvalley Loop Ramp Estimate					
Item Description	Quantity	Unit	Cost Assumptions	Total Cost	Engineering Assumptions
Roadway					
Pavement	48,500	sq ft	$40	$1,940,000	
Remove Painted Pavement Marking	0	ft	$5	$0	Grinding away existing thermoplastic
Striping	5,720	ft	$1	$5,720	
Retaining Wall	0	sq ft	$350	$0	Not necessary
Sound Walls, assume avg H=14'	0	sq ft	$150	$0	Does not qualify
Permanent Concrete Barrier	0	ft	$120	$0	
Temporary Concrete Barrier	0	ft	$30	$0	K-Rail
			Roadway Total	$1,945,720	
Drainage				$97,286	5% of Roadway Costs
			Drainage Total	$97,286	
Utilities				$97,286	5% of Roadway Costs
			Utility Total	$97,286	
Structures					
New	3,180	sq ft	$300	$954,000	
Widening	0	sq ft	$200	$0	
			Structures Total	$954,000	
Right of Way					
Business	0	sq ft	$300	$0	
Residential	0	sq ft	$250	$0	
Public (Schools, parks, hospitals, etc.)	0	sq ft	$200	$0	
			R/W Total	$0	
			Sub Total	$3,094,292	
			Contingency	$1,083,002	35% of Sub Total
			Total	$4,180,000	Rounded Up

5/10/2022

Alternative 1

Innovate 680: Sunvalley Directional Estimate					
Item Description	Quantity	Unit	Cost Assumptions	Total Cost	Engineering Assumptions
Roadway					
Pavement	49,410	sq ft	$40	$1,976,400	
Remove Painted Pavement Marking	0	ft	$5	$0	Grinding away existing thermoplastic
Striping	3,220	ft	$1	$3,220	
Retaining Wall	0	sq ft	$350	$0	Not necessary
Sound Walls, assume avg H=14'	0	sq ft	$150	$0	Does not qualify
Permanent Concrete Barrier	0	ft	$120	$0	
Temporary Concrete Barrier	0	ft	$30	$0	K-Rail
			Roadway Total	$1,979,620	
Drainage				$98,981	5% of Roadway Costs
			Drainage Total	$98,981	
Utilities				$98,981	5% of Roadway Costs
			Utility Total	$98,981	
Structures					
New	0	sq ft	$300	$0	
Widening	0	sq ft	$200	$0	
			Structures Total	$0	
Right of Way					
Business	0	sq ft	$300	$0	
Residential	530	sq ft	$250	$132,500	
Public (Schools, parks, hospitals, etc.)	0	sq ft	$200	$0	
			R/W Total	$132,500	
			Sub Total	$2,310,082	
			Contingency	$808,529	35% of Sub Total
			Total	$3,120,000	Rounded Up

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Alternative 1

Innovate 680: SR-242 Estimate					
Item Description	Quantity	Unit	Cost Assumptions	Total Cost	Engineering Assumptions
Roadway					
Pavement	0	sq ft	$40	$0	
Remove Painted Pavement Marking	0	ft	$5	$0	Grinding away existing thermoplastic
Striping	0	ft	$1	$0	
Retaining Wall	0	sq ft	$350	$0	Not necessary
Sound Walls, assume avg H=14'	0	sq ft	$150	$0	Does not qualify
Permanent Concrete Barrier	0	ft	$120	$0	
Temporary Concrete Barrier	0	ft	$30	$0	K-Rail
			Roadway Total	$0	
Drainage				$0	5% of Roadway Costs
			Drainage Total	$0	
Utilities				$0	5% of Roadway Costs
			Utility Total	$0	
Structures					
New	0	sq ft	$300	$0	
Widening	0	sq ft	$200	$0	
			Structures Total	$0	
Right of Way					
Business	0	sq ft	$300	$0	
Residential	0	sq ft	$250	$0	
Public (Schools, parks, hospitals, etc.)	0	sq ft	$200	$0	
			R/W Total	$0	
			Sub Total	$0	
			Contingency	$0	35% of Sub Total
			Total	$0	Rounded Up

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Alternative 1

Innovate 680: Monument Estimate					
Item Description	Quantity	Unit	Cost Assumptions	Total Cost	Engineering Assumptions
Roadway					
Pavement	33,040	sq ft	$40	$1,321,600	
Remove Painted Pavement Marking	0	ft	$5	$0	Grinding away existing thermoplastic
Striping	1,590	ft	$1	$1,590	
Retaining Wall	0	sq ft	$350	$0	Not necessary
Sound Walls, assume avg H=14'	0	sq ft	$150	$0	Does not qualify
Permanent Concrete Barrier	0	ft	$120	$0	
Temporary Concrete Barrier	0	ft	$30	$0	K-Rail
			Roadway Total	$1,323,190	
Drainage				$66,160	5% of Roadway Costs
			Drainage Total	$66,160	
Utilities				$66,160	5% of Roadway Costs
			Utility Total	$66,160	
Structures					
New	0	sq ft	$300	$0	
Widening	0	sq ft	$200	$0	
			Structures Total	$0	
Right of Way					
Business	0	sq ft	$300	$0	
Residential	0	sq ft	$250	$0	
Public (Schools, parks, hospitals, etc.)	0	sq ft	$200	$0	
			R/W Total	$0	
			Sub Total	$1,455,509	
			Contingency	$509,428	35% of Sub Total
			Total	$1,970,000	Rounded Up

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Alternative 1

Innovate 680: Boyd Estimate					
Item Description	Quantity	Unit	Cost Assumptions	Total Cost	Engineering Assumptions
Roadway					
Pavement	45,330	sq ft	$40	$1,813,200	
Remove Painted Pavement Marking	0	ft	$5	$0	Grinding away existing thermoplastic
Striping	6,810	ft	$1	$6,810	
Retaining Wall	0	sq ft	$350	$0	Not necessary
Sound Walls, assume avg H=14'	0	sq ft	$150	$0	Does not qualify
Permanent Concrete Barrier	0	ft	$120	$0	
Temporary Concrete Barrier	0	ft	$30	$0	K-Rail
			Roadway Total	$1,820,010	
Drainage				$91,001	5% of Roadway Costs
			Drainage Total	$91,001	
Utilities				$91,001	5% of Roadway Costs
			Utility Total	$91,001	
Structures					
New	0	sq ft	$300	$0	
Widening	0	sq ft	$200	$0	
			Structures Total	$0	
Right of Way					
Business	0	sq ft	$300	$0	
Residential	0	sq ft	$250	$0	
Public (Schools, parks, hospitals, etc.)	0	sq ft	$200	$0	
			R/W Total	$0	
			Sub Total	$2,002,011	
			Contingency	$700,704	35% of Sub Total
			Total	$2,710,000	Rounded Up

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Alternative 1

Innovate 680: Sunnyvale Estimate					
Item Description	Quantity	Unit	Cost Assumptions	Total Cost	Engineering Assumptions
Roadway					
Pavement	0	sq ft	$40	$0	
Remove Painted Pavement Marking	0	ft	$5	$0	Grinding away existing thermoplastic
Striping	0	ft	$1	$0	
Retaining Wall	0	sq ft	$350	$0	Not necessary
Sound Walls, assume avg H=14'	0	sq ft	$150	$0	Does not qualify
Permanent Concrete Barrier	0	ft	$120	$0	
Temporary Concrete Barrier	0	ft	$30	$0	K-Rail
			Roadway Total	$0	
Drainage				$0	5% of Roadway Costs
			Drainage Total	$0	
Utilities				$0	5% of Roadway Costs
			Utility Total	$0	
Structures					
New	0	sq ft	$300	$0	
Widening	0	sq ft	$200	$0	
			Structures Total	$0	
Right of Way					
Business	0	sq ft	$300	$0	
Residential	0	sq ft	$250	$0	
Public (Schools, parks, hospitals, etc.)	0	sq ft	$200	$0	
			R/W Total	$0	
			Sub Total	$0	
			Contingency	$0	35% of Sub Total
			Total	$0	Rounded Up

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Alternative 1

Innovate 680: Treat Estimate					
Item Description	Quantity	Unit	Cost Assumptions	Total Cost	Engineering Assumptions
Roadway					
Pavement	49,840	sq ft	$40	$1,993,600	
Remove Painted Pavement Marking	0	ft	$5	$0	Grinding away existing thermoplastic
Striping	6,930	ft	$1	$6,930	
Retaining Wall	0	sq ft	$350	$0	Not necessary
Sound Walls, assume avg H=14'	0	sq ft	$150	$0	Does not qualify
Permanent Concrete Barrier	0	ft	$120	$0	
Temporary Concrete Barrier	0	ft	$30	$0	K-Rail
			Roadway Total	$2,000,530	
Drainage				$100,027	5% of Roadway Costs
			Drainage Total	$100,027	
Utilities				$100,027	5% of Roadway Costs
			Utility Total	$100,027	
Structures					
New	0	sq ft	$300	$0	
Widening	0	sq ft	$200	$0	
			Structures Total	$0	
Right of Way					
Business	0	sq ft	$300	$0	
Residential	0	sq ft	$250	$0	
Public (Schools, parks, hospitals, etc.)	0	sq ft	$200	$0	
			R/W Total	$0	
			Sub Total	$2,200,583	
			Contingency	$770,204	35% of Sub Total
			Total	$2,980,000	Rounded Up

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Alternative 1

Innovate 680: North Main Street Estimate					
Item Description	Quantity	Unit	Cost Assumptions	Total Cost	Engineering Assumptions
Roadway					
Pavement	73,500	sq ft	$40	$2,940,000	
Remove Painted Pavement Marking	0	ft	$5	$0	Grinding away existing thermoplastic
Striping	5,840	ft	$1	$5,840	
Retaining Wall	0	sq ft	$350	$0	Not necessary
Sound Walls, assume avg H=14'	0	sq ft	$150	$0	Does not qualify
Permanent Concrete Barrier	0	ft	$120	$0	
Temporary Concrete Barrier	0	ft	$30	$0	K-Rail
			Roadway Total	$2,945,840	
Drainage				$147,292	5% of Roadway Costs
			Drainage Total	$147,292	
Utilities				$147,292	5% of Roadway Costs
			Utility Total	$147,292	
Structures					
New	0	sq ft	$300	$0	
Widening	0	sq ft	$200	$0	
			Structures Total	$0	
Right of Way					
Business	0	sq ft	$300	$0	
Residential	4,040	sq ft	$250	$1,010,000	
Public (Schools, parks, hospitals, etc.)	0	sq ft	$200	$0	
			R/W Total	$1,010,000	
			Sub Total	$4,250,424	
			Contingency	$1,487,648	35% of Sub Total
			Total	$5,740,000	Rounded Up

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Alternative 1

Innovate 680: Ygnacio					
Item Description	Quantity	Unit	Cost Assumptions	Total Cost	Engineering Assumptions
Roadway					
Pavement	0	sq ft	$40	$0	
Remove Painted Pavement Marking	0	ft	$5	$0	Grinding away existing thermoplastic
Striping	0	ft	$1	$0	
Retaining Wall	0	sq ft	$350	$0	Not necessary
Sound Walls, assume avg H=14'	0	sq ft	$150	$0	Does not qualify
Permanent Concrete Barrier	0	ft	$120	$0	
Temporary Concrete Barrier	0	ft	$30	$0	K-Rail
			Roadway Total	$0	
Drainage				$0	5% of Roadway Costs
			Drainage Total	$0	
Utilities				$0	5% of Roadway Costs
			Utility Total	$0	
Structures					
New	0	sq ft	$300	$0	
Widening	0	sq ft	$200	$0	
			Structures Total	$0	
Right of Way					
Business	0	sq ft	$300	$0	
Residential	0	sq ft	$250	$0	
Public (Schools, parks, hospitals, etc.)	0	sq ft	$200	$0	
			R/W Total	$0	
			Sub Total	$0	
			Contingency	$0	35% of Sub Total
			Total	$0	Rounded Up

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Alternative 1

Innovate 680: Hillside to SR-24					
Item Description	Quantity	Unit	Cost Assumptions	Total Cost	Engineering Assumptions
Roadway					
Pavement	0	sq ft	$40	$0	
Remove Painted Pavement Marking	0	ft	$5	$0	Grinding away existing thermoplastic
Striping	0	ft	$1	$0	
Retaining Wall	0	sq ft	$350	$0	Not necessary
Sound Walls, assume avg H=14'	0	sq ft	$150	$0	Does not qualify
Permanent Concrete Barrier	0	ft	$120	$0	
Temporary Concrete Barrier	0	ft	$30	$0	K-Rail
			Roadway Total	$0	
Drainage				$0	5% of Roadway Costs
			Drainage Total	$0	
Utilities				$0	5% of Roadway Costs
			Utility Total	$0	
Structures					
New	0	sq ft	$300	$0	
Widening	0	sq ft	$200	$0	
			Structures Total	$0	
Right of Way					
Business	0	sq ft	$300	$0	
Residential	0	sq ft	$250	$0	
Public (Schools, parks, hospitals, etc.)	0	sq ft	$200	$0	
			R/W Total	$0	
			Sub Total	$0	
			Contingency	$0	35% of Sub Total
			Total	$0	Rounded Up

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Alternative 1

Innovate 680: SR-24 Connector Estimate					
Item Description	Quantity	Unit	Cost Assumptions	Total Cost	Engineering Assumptions
Roadway					
Pavement	31,690	sq ft	$40	$1,267,600	
Remove Painted Pavement Marking	0	ft	$5	$0	Grinding away existing thermoplastic
Striping	1,920	ft	$1	$1,920	
Retaining Wall	0	sq ft	$350	$0	Not necessary
Sound Walls, assume avg H=14'	120	sq ft	$150	$18,000	Replacing Existing Soundwall
Permanent Concrete Barrier	570	ft	$120	$68,400	
Temporary Concrete Barrier	0	ft	$30	$0	K-Rail
			Roadway Total	$1,355,920	
Drainage				$67,796	5% of Roadway Costs
			Drainage Total	$67,796	
Utilities				$67,796	5% of Roadway Costs
			Utility Total	$67,796	
Structures					
New	0	sq ft	$300	$0	
Widening	0	sq ft	$200	$0	
			Structures Total	$0	
Right of Way					
Business	0	sq ft	$300	$0	
Residential	0	sq ft	$250	$0	
Public (Schools, parks, hospitals, etc.)	0	sq ft	$200	$0	
			R/W Total	$0	
			Sub Total	$1,491,512	
			Contingency	$522,029	35% of Sub Total
			Total	$2,020,000	Rounded Up

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Alternative 1

Innovate 680: Olympic Estimate					
Item Description	Quantity	Unit	Cost Assumptions	Total Cost	Engineering Assumptions
Roadway					
Pavement	0	sq ft	$40	$0	
Remove Painted Pavement Marking	0	ft	$5	$0	Grinding away existing thermoplastic
Striping	0	ft	$1	$0	
Retaining Wall	0	sq ft	$350	$0	Not necessary
Sound Walls, assume avg H=14'	0	sq ft	$150	$0	Does not qualify
Permanent Concrete Barrier	0	ft	$120	$0	
Temporary Concrete Barrier	0	ft	$30	$0	K-Rail
			Roadway Total	$0	
Drainage				$0	5% of Roadway Costs
			Drainage Total	$0	
Utilities				$0	5% of Roadway Costs
			Utility Total	$0	
Structures					
New	0	sq ft	$300	$0	
Widening	0	sq ft	$200	$0	
			Structures Total	$0	
Right of Way					
Business	0	sq ft	$300	$0	
Residential	0	sq ft	$250	$0	
Public (Schools, parks, hospitals, etc.)	0	sq ft	$200	$0	
			R/W Total	$0	
			Sub Total	$0	
			Contingency	$0	35% of Sub Total
			Total	$0	Rounded Up

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Alternative 1

Innovate 680: Main Street Estimate					
Item Description	Quantity	Unit	Cost Assumptions	Total Cost	Engineering Assumptions
Roadway					
Pavement	0	sq ft	$40	$0	
Remove Painted Pavement Marking	0	ft	$5	$0	Grinding away existing thermoplastic
Striping	0	ft	$1	$0	
Retaining Wall	0	sq ft	$350	$0	Not necessary
Sound Walls, assume avg H=14'	0	sq ft	$150	$0	Does not qualify
Permanent Concrete Barrier	0	ft	$120	$0	
Temporary Concrete Barrier	0	ft	$30	$0	K-Rail
			Roadway Total	$0	
Drainage				$0	5% of Roadway Costs
			Drainage Total	$0	
Utilities				$0	5% of Roadway Costs
			Utility Total	$0	
Structures					
New	0	sq ft	$300	$0	
Widening	0	sq ft	$200	$0	
			Structures Total	$0	
Right of Way					
Business	0	sq ft	$300	$0	
Residential	0	sq ft	$250	$0	
Public (Schools, parks, hospitals, etc.)	0	sq ft	$200	$0	
			R/W Total	$0	
No civil improvements are proposed for SB Main because it already has sufficient storage and meters. Estimate is $0.			Sub Total	$0	
			Contingency	$0	35% of Sub Total
			Total	$0	Rounded Up

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Alternative 1

Innovate 680: Rudgear Estimate					
Item Description	Quantity	Unit	Cost Assumptions	Total Cost	Engineering Assumptions
Roadway					
Pavement	0	sq ft	$40	$0	
Remove Painted Pavement Marking	0	ft	$5	$0	Grinding away existing thermoplastic
Striping	0	ft	$1	$0	
Retaining Wall	0	sq ft	$350	$0	Not necessary
Sound Walls, assume avg H=14'	0	sq ft	$150	$0	Does not qualify
Permanent Concrete Barrier	0	ft	$120	$0	
Temporary Concrete Barrier	0	ft	$30	$0	K-Rail
			Roadway Total	$0	
Drainage				$0	5% of Roadway Costs
			Drainage Total	$0	
Utilities				$0	5% of Roadway Costs
			Utility Total	$0	
Structures					
New	0	sq ft	$300	$0	
Widening	0	sq ft	$200	$0	
			Structures Total	$0	
Right of Way					
Business	0	sq ft	$300	$0	
Residential	0	sq ft	$250	$0	
Public (Schools, parks, hospitals, etc.)	0	sq ft	$200	$0	
			R/W Total	$0	
No civil improvements are proposed for SB Rudgear because it already has sufficient storage and meters. Estimate is $0.			Sub Total	$0	
			Contingency	$0	35% of Sub Total
			Total	$0	Rounded Up

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Alternative 1

Innovate 680: Livorna Estimate					
Item Description	Quantity	Unit	Cost Assumptions	Total Cost	Engineering Assumptions
Roadway					
Pavement	19,280	sq ft	$40	$771,200	
Remove Painted Pavement Marking	0	ft	$5	$0	Grinding away existing thermoplastic
Striping	1,650	ft	$1	$1,650	
Retaining Wall	0	sq ft	$350	$0	Not necessary
Sound Walls, assume avg H=14'	0	sq ft	$150	$0	Does not qualify
Permanent Concrete Barrier	0	ft	$120	$0	
Temporary Concrete Barrier	0	ft	$30	$0	K-Rail
			Roadway Total	$772,850	
Drainage				$38,643	5% of Roadway Costs
			Drainage Total	$38,643	
Utilities				$38,643	5% of Roadway Costs
			Utility Total	$38,643	
Structures					
New	0	sq ft	$300	$0	
Widening	0	sq ft	$200	$0	
			Structures Total	$0	
Right of Way					
Business	0	sq ft	$300	$0	
Residential	0	sq ft	$250	$0	
Public (Schools, parks, hospitals, etc.)	0	sq ft	$200	$0	
			R/W Total	$0	
			Sub Total	$850,135	
			Contingency	$297,547	35% of Sub Total
			Total	$1,150,000	Rounded Up

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Alternative 1

Innovate 680: Stone Valley Estimate					
Item Description	Quantity	Unit	Cost Assumptions	Total Cost	Engineering Assumptions
Roadway					
Pavement	30,480	sq ft	$40	$1,219,200	
Remove Painted Pavement Marking	0	ft	$5	$0	Grinding away existing thermoplastic
Striping	1,650	ft	$1	$1,650	
Retaining Wall	0	sq ft	$350	$0	Not necessary
Sound Walls, assume avg H=14'	0	sq ft	$150	$0	Does not qualify
Permanent Concrete Barrier	0	ft	$120	$0	
Temporary Concrete Barrier	0	ft	$30	$0	K-Rail
			Roadway Total	$1,220,850	
Drainage				$61,043	5% of Roadway Costs
			Drainage Total	$61,043	
Utilities				$61,043	5% of Roadway Costs
			Utility Total	$61,043	
Structures					
New	0	sq ft	$300	$0	
Widening	0	sq ft	$200	$0	
			Structures Total	$0	
Right of Way					
Business	0	sq ft	$300	$0	
Residential	0	sq ft	$250	$0	
Public (Schools, parks, hospitals, etc.)	0	sq ft	$200	$0	
			R/W Total	$0	
			Sub Total	$1,342,935	
			Contingency	$470,027	35% of Sub Total
			Total	$1,900,000	Rounded Up

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Alternative 1

Innovate 680: El Cerro Estimate					
Item Description	Quantity	Unit	Cost Assumptions	Total Cost	Engineering Assumptions
Roadway					
Pavement	10,050	sq ft	$40	$402,000	
Remove Painted Pavement Marking	0	ft	$5	$0	Grinding away existing thermoplastic
Striping	1,090	ft	$1	$1,090	
Retaining Wall	0	sq ft	$350	$0	Not necessary
Sound Walls, assume avg H=14'	0	sq ft	$150	$0	Does not qualify
Permanent Concrete Barrier	0	ft	$120	$0	
Temporary Concrete Barrier	0	ft	$30	$0	K-Rail
			Roadway Total	$403,090	
Drainage				$20,155	5% of Roadway Costs
			Drainage Total	$20,155	
Utilities				$20,155	5% of Roadway Costs
			Utility Total	$20,155	
Structures					
New	0	sq ft	$300	$0	
Widening	0	sq ft	$200	$0	
			Structures Total	$0	
Right of Way					
Business	0	sq ft	$300	$0	
Residential	0	sq ft	$250	$0	
Public (Schools, parks, hospitals, etc.)	0	sq ft	$200	$0	
			R/W Total	$0	
			Sub Total	$443,399	
			Contingency	$155,190	35% of Sub Total
			Total	$600,000	Rounded Up

5/11/2022

Alternative 1

Innovate 680: Diablo Rd Estimate					
Item Description	Quantity	Unit	Cost Assumptions	Total Cost	Engineering Assumptions
Roadway					
Pavement	33,690	sq ft	$40	$1,347,600	
Remove Painted Pavement Marking	0	ft	$5	$0	Grinding away existing thermoplastic
Striping	2,330	ft	$1	$2,330	
Retaining Wall	0	sq ft	$350	$0	Not necessary
Sound Walls, assume avg H=14'	0	sq ft	$150	$0	Does not qualify
Permanent Concrete Barrier	0	ft	$120	$0	
Temporary Concrete Barrier	0	ft	$30	$0	K-Rail
			Roadway Total	$1,349,930	
Drainage				$67,497	5% of Roadway Costs
			Drainage Total	$67,497	
Utilities				$67,497	5% of Roadway Costs
			Utility Total	$67,497	
Structures					
New	0	sq ft	$300	$0	
Widening	4,800	sq ft	$200	$960,000	
	D		Structures Total	$960,000	
Right of Way					
Business	0	sq ft	$300	$0	
Residential	0	sq ft	$250	$0	
Public (Schools, parks, hospitals, etc.)	0	sq ft	$200	$0	
			R/W Total	$0	
			Sub Total	$2,444,923	
			Contingency	$855,723	35% of Sub Total
			Total	$3,400,000	Rounded Up

5/11/2022

Alternative 1

Innovate 680: Sycamore Estimate					
Item Description	Quantity	Unit	Cost Assumptions	Total Cost	Engineering Assumptions
Roadway					
Pavement	0	sq ft	$40	$0	
Remove Painted Pavement Marking	0	ft	$5	$0	Grinding away existing thermoplastic
Striping	0	ft	$1	$0	
Retaining Wall	0	sq ft	$350	$0	Not necessary
Sound Walls, assume avg H=14'	0	sq ft	$150	$0	Does not qualify
Permanent Concrete Barrier	0	ft	$120	$0	
Temporary Concrete Barrier	0	ft	$30	$0	K-Rail
			Roadway Total	$0	
Drainage				$0	5% of Roadway Costs
			Drainage Total	$0	
Utilities				$0	5% of Roadway Costs
			Utility Total	$0	
Structures					
New	0	sq ft	$300	$0	
Widening	0	sq ft	$200	$0	
			Structures Total	$0	
Right of Way					
Business	0	sq ft	$300	$0	
Residential	0	sq ft	$250	$0	
Public (Schools, parks, hospitals, etc.)	0	sq ft	$200	$0	
			R/W Total	$0	
			Sub Total	$0	
			Contingency	$0	35% of Sub Total
			Total	$0	Rounded Up

5/11/2022

Alternative 1

Innovate 680: Crow Estimate					
Item Description	Quantity	Unit	Cost Assumptions	Total Cost	Engineering Assumptions
Roadway					
Pavement	89,520	sq ft	$40	$3,580,800	
Remove Painted Pavement Marking	0	ft	$5	$0	Grinding away existing thermoplastic
Striping	6,180	ft	$1	$6,180	
Retaining Wall	0	sq ft	$350	$0	Not necessary
Sound Walls, assume avg H=14'	0	sq ft	$150	$0	Does not qualify
Permanent Concrete Barrier	1,020	ft	$120	$122,400	
Temporary Concrete Barrier		ft	$30	$0	K-Rail
			Roadway Total	$3,709,380	
Drainage				$185,469	5% of Roadway Costs
			Drainage Total	$185,469	
Utilities				$185,469	5% of Roadway Costs
			Utility Total	$185,469	
Structures					
New	0	sq ft	$300	$0	
Widening	0	sq ft	$200	$0	
			Structures Total	$0	
Right of Way					
Business	0	sq ft	$300	$0	
Residential	0	sq ft	$250	$0	
Public (Schools, parks, hospitals, etc.)	0	sq ft	$200	$0	
			R/W Total	$0	
			Sub Total	$4,080,318	
			Contingency	$1,428,111	35% of Sub Total
			Total	$5,600,000	Rounded Up

5/11/2022

Alternative 1

Innovate 680: Bollinger Estimate					
Item Description	Quantity	Unit	Cost Assumptions	Total Cost	Engineering Assumptions
Roadway					
Pavement	103,000	sq ft	$40	$4,120,000	
Remove Painted Pavement Marking	0	ft	$5	$0	Grinding away existing thermoplastic
Striping	6,900	ft	$1	$6,900	
Retaining Wall	13,600	sq ft	$350	$4,760,000	Ground Anchor Wall beneath the OC
Sound Walls, assume avg H=14'	0	sq ft	$150	$0	Does not qualify
Permanent Concrete Barrier	1,400	ft	$120	$168,000	
Temporary Concrete Barrier	0	ft	$30	$0	K-Rail
			Roadway Total	$9,054,900	
Drainage				$452,745	5% of Roadway Costs
			Drainage Total	$452,745	
Utilities				$452,745	5% of Roadway Costs
			Utility Total	$452,745	
Structures					
New	0	sq ft	$300	$0	
Widening	0	sq ft	$200	$0	
			Structures Total	$0	
Right of Way					
Business	2,000	sq ft	$300	$600,000	
Residential	0	sq ft	$250	$0	
Public (Schools, parks, hospitals, etc.)	0	sq ft	$200	$0	
			R/W Total	$600,000	
			Sub Total	$10,560,390	
			Contingency	$3,696,137	35% of Sub Total
			Total	$14,300,000	Rounded Up

6/30/2022

Alternative 1

Innovate 680: Alcosta Estimate					
Item Description	Quantity	Unit	Cost Assumptions	Total Cost	Engineering Assumptions
Roadway					
Pavement	122,720	sq ft	$40	$4,908,800	
Remove Painted Pavement Marking	0	ft	$5	$0	Grinding away existing thermoplastic
Striping	7,890	ft	$1	$7,890	
Retaining Wall	2,030	sq ft	$350	$710,500	Not necessary
Sound Walls, assume avg H=14'	0	sq ft	$150	$0	Does not qualify
Permanent Concrete Barrier	0	ft	$120	$0	
Temporary Concrete Barrier	0	ft	$30	$0	K-Rail
			Roadway Total	$5,627,190	
Drainage				$281,360	5% of Roadway Costs
			Drainage Total	$281,360	
Utilities				$281,360	5% of Roadway Costs
			Utility Total	$281,360	
Structures					
New	0	sq ft	$300	$0	
Widening	0	sq ft	$200	$0	
			Structures Total	$0	
Right of Way					
Business	0	sq ft	$300	$0	
Residential	0	sq ft	$250	$0	
Public (Schools, parks, hospitals, etc.)	0	sq ft	$200	$0	
			R/W Total	$0	
			Sub Total	$6,189,909	
			Contingency	$2,166,468	35% of Sub Total
			Total	$8,400,000	Rounded Up

5/11/2022

Appendix F. Conceptual ITS Cost Estimates

This appendix provides conceptual cost estimates for the ITS improvements needed initiate CARM operations on I-680 in Contra Costa County. Standard costs were developed to install ramp metering equipment at interchanges with 4 lanes, 3 lanes, 2 lane and 1 lane at the stop bar, as shown below.

Interchange ITS Cost Tables

4 Lane Ramp Meter ITS Cost							
Item	Quanity	Unit	Cost Assumptions		Total Cost		
Overall							
Labor and expenses for delivery and installation	1	LS	$	20,000	$	20,000	
Traffic Control	1	LS	$	12,500	$	12,500	
Full ramp wiring	1	Each	$	15,000	$	15,000	Original $10k added $5k for RC-1 (x2)
Mobilization	1	LS	$	8,500	$	8,500	
Power Drop	2	Each	$	7,500	$	15,000	Ramp Meter (RM) and Exit Ramp Cabinet for detection
3" PVC conduit (Trenched)	200	LF	$	55	$	11,000	
3" PVC conduit (Jacked)	500	LF	$	65	$	32,500	Under Ramp or Arterial for RC-1
2" PVC conduit (Trenched)	1500	LF	$	30	$	45,000	Loops (Ent + Ex) / AWS / RC-1s
Traffic Signal and Cabinet							
Furnish and install type 332 cabinet with ATC controller	1	Each	$	28,000	$	28,000	Includes foundation
Furnish and install new Type 15 traffic signal pole	1	Each	$	6,000	$	6,000	Includes foundation
Furnish and install new Type 1-B traffic signal pole	1	Each	$	4,000	$	4,000	Includes foundation
Furnish and install new four-lane traffic signal pole with mast arm	1	Each	$	30,000	$	30,000	Includes foundation
3 section vehicle head	6	Each	$	600	$	3,600	
Loop Detector	28	Each	$	1,400	$	39,200	24 Ent / 4 Ex
Pull box	13	Each	$	1,000	$	13,000	4 Ent Loops / 4 RC1 / 2 AWS / 2 Ex Loops / 1 Controller cabinet home run
Fiber Optic Cable (6 Strand Drop)	1125	LF	$	2	$	2,250	Drops to RM / Exit Ramp Cabinets
Exit Ramp Back of queue Cabinet (communications)	1	Each	$	11,000	$	11,000	
Ethernet switch	4	Each	$	4,000	$	16,000	RM Cabinet and Exit Ramp Cabinet for detection
Ethernet Cable (Cat 5)	1500	LF	$	2	$	3,000	Connections from RM to RC-1
Signage							
End of ramp RC-1 sign	2	Each	$	10,000	$	20,000	RC-1 small DMS for ramp control
RC-1 Pole / Cabinet and foundation	2	Each	$	7,500	$	15,000	
Type 1-A on new foundation	4	Each	$	5,000	$	20,000	Warning Sign (AWS) AW-I and AW-II
Remove and relocate sign and post	0	Each	$	600	$	-	If existing AWS reused
			ITS Total		$	370,550	
			Contingency (35%)		$	129,693	
			Total		$	500,243	

3 Lane Ramp Meter ITS Cost							
Item	Quanity	Unit	Cost Assumptions		Total Cost		
Overall							
Labor and expenses for delivery and installation	1	LS	$	20,000	$	20,000	
Traffic Control	1	LS	$	12,500	$	12,500	
Full ramp wiring	1	Each	$	15,000	$	15,000	Original $10k added $5k for RC-1 (x2)
Mobilization	1	LS	$	8,500	$	8,500	
Power Drop	2	Each	$	7,500	$	15,000	Ramp Meter (RM) and Exit Ramp Cabinet for detection
3" PVC conduit (Trenched)	200	LF	$	55	$	11,000	
3" PVC conduit (Jacked)	500	LF	$	65	$	32,500	Under Ramp or Arterial for RC-1
2" PVC conduit (Trenched)	1500	LF	$	30	$	45,000	Loops (Ent + Ex) / AWS / RC-1s
Traffic Signal and Cabinet							
Furnish and install type 332 cabinet with ATC controller	1	Each	$	28,000	$	28,000	Includes foundation
Furnish and install new Type 15 traffic signal pole	1	Each	$	6,000	$	6,000	Includes foundation
Furnish and install new Type 1-B traffic signal pole	1	Each	$	4,000	$	4,000	Includes foundation
Furnish and install new three-lane traffic signal pole with mast arm	1	Each	$	25,000	$	25,000	Includes foundation
3 section vehicle head	5	Each	$	600	$	3,000	
Loop Detector	22	Each	$	1,400	$	30,800	18 Ent / 4 Ex
Pull box	13	Each	$	1,000	$	13,000	4 Ent Loops / 4 RC1 / 2 AWS / 2 Ex Loops / 1 Controller cabinet home run
Fiber Optic Cable (6 Strand Drop)	1125	LF	$	2	$	2,250	Drops to RM / Exit Ramp Cabinets
Exit Ramp Back of queue Cabinet (communications)	1	Each	$	11,000	$	11,000	
Ethernet switch	4	Each	$	4,000	$	16,000	RM Cabinet and Exit Ramp Cabinet for detection
Ethernet Cable (Cat 5)	1500	LF	$	2	$	3,000	Connections from RM to RC-1
Signage							
End of ramp RC-1 sign	2	Each	$	10,000	$	20,000	RC-1 small DMS for ramp control
RC-1 Pole / Cabinet and foundation	2	Each	$	7,500	$	15,000	
Type 1-A on new foundation	4	Each	$	5,000	$	20,000	Warning Sign (AWS) AW-I and AW-II
Remove and relocate sign and post	0	Each	$	600	$	-	If existing AWS reused
			ITS Total		$	356,550	
			Contingency (35%)		$	124,793	
			Total		$	481,343	

2 Lane Ramp Meter ITS Cost					
Item	Quanity	Unit	Cost Assumptions	Total Cost	
Overall					
Labor and expenses for delivery and installation	1	LS	$ 20,000	$ 20,000	
Traffic Control	1	LS	$ 12,500	$ 12,500	
Full ramp wiring	1	Each	$ 15,000	$ 15,000	Original $10k added $5k for RC-1 (x2)
Mobilization	1	LS	$ 8,500	$ 8,500	
Power Drop	2	Each	$ 7,500	$ 15,000	Ramp Meter (RM) and Exit Ramp Cabinet for detection
3" PVC conduit (Trenched)	200	LF	$ 55	$ 11,000	
3" PVC conduit (Jacked)	500	LF	$ 65	$ 32,500	Under Ramp or Arterial for RC-1
2" PVC conduit (Trenched)	1500	LF	$ 30	$ 45,000	Loops (Ent + Ex) / AWS / RC-1s
Traffic Signal and Cabinet					
Furnish and install type 332 cabinet with ATC controller	1	Each	$ 28,000	$ 28,000	Includes foundation
Furnish and install new Type 15 traffic signal pole	1	Each	$ 6,000	$ 6,000	Includes foundation
Furnish and install new Type 1-B traffic signal pole	1	Each	$ 4,000	$ 4,000	Includes foundation
Furnish and install new two-lane traffic signal pole with mast arm	1	Each	$ 20,000	$ 20,000	Includes foundation
3 section vehicle head	4	Each	$ 600	$ 2,400	
Loop Detector	16	Each	$ 1,400	$ 22,400	12 Ent / 4 Ex
Pull box	13	Each	$ 1,000	$ 13,000	4 Ent Loops / 4 RC1 / 2 AWS / 2 Ex Loops / 1 Controller cabinet home run
Fiber Optic Cable (6 Strand Drop)	1125	LF	$ 2	$ 2,250	Drops to RM / Exit Ramp Cabinets
Exit Ramp Back of queue Cabinet (communications)	1	Each	$ 11,000	$ 11,000	
Ethernet switch	4	Each	$ 4,000	$ 16,000	RM Cabinet and Exit Ramp Cabinet for detection
Ethernet Cable (Cat 5)	1500	LF	$ 2	$ 3,000	Connections from RM to RC-1
Signage					
End of ramp RC-1 sign	2	Each	$ 10,000	$ 20,000	RC-1 small DMS for ramp control
RC-1 Pole / Cabinet and foundation	2	Each	$ 7,500	$ 15,000	
Type 1-A on new foundation	4	Each	$ 5,000	$ 20,000	Warning Sign (AWS) AW-I and AW-II
Remove and relocate sign and post	0	Each	$ 600	$ -	If existing AWS reused
			ITS Total	$ 342,550	
			Contingency (35%)	$ 119,893	
			Total	$ 462,443	

1 Lane Ramp Meter ITS Cost					
Item	Quanity	Unit	Cost Assumptions	Total Cost	
Overall					
Labor and expenses for delivery and installation	1	LS	$ 20,000	$ 20,000	
Traffic Control	1	LS	$ 12,500	$ 12,500	
Full ramp wiring	1	Each	$ 15,000	$ 15,000	Original $10k added $5k for RC-1 (x2)
Mobilization	1	LS	$ 8,500	$ 8,500	
Power Drop	2	Each	$ 7,500	$ 15,000	Ramp Meter (RM) and Exit Ramp Cabinet for detection
3" PVC conduit (Trenched)	200	LF	$ 55	$ 11,000	
3" PVC conduit (Jacked)	500	LF	$ 65	$ 32,500	Under Ramp or Arterial for RC-1
2" PVC conduit (Trenched)	1500	LF	$ 30	$ 45,000	Loops (Ent + Ex) / AWS / RC-1s
Traffic Signal and Cabinet					
Furnish and install type 332 cabinet with ATC controller	1	Each	$ 28,000	$ 28,000	Includes foundation
Furnish and install new Type 15 traffic signal pole	1	Each	$ 6,000	$ 6,000	Includes foundation
Furnish and install new Type 1-B traffic signal pole	0	Each	$ 4,000	$ -	Includes foundation
3 section vehicle head	2	Each	$ 600	$ 1,200	
Loop Detector	10	Each	$ 1,400	$ 14,000	6 Ent / 4 Ex
Pull box	13	Each	$ 1,000	$ 13,000	4 Ent Loops / 4 RC1 / 2 AWS / 2 Ex Loops / 1 Controller cabinet home run
Fiber Optic Cable (6 Strand Drop)	1125	LF	$ 2	$ 2,250	Drops to RM / Exit Ramp Cabinets
Exit Ramp Back of queue Cabinet (communications)	1	Each	$ 11,000	$ 11,000	
Ethernet switch	4	Each	$ 4,000	$ 16,000	RM Cabinet and Exit Ramp Cabinet for detection
Ethernet Cable (Cat 5)	1500	LF	$ 2	$ 3,000	Connections from RM to RC-1
Signage					
End of ramp RC-1 sign	2	Each	$ 10,000	$ 20,000	RC-1 small DMS for ramp control
RC-1 Pole / Cabinet and foundation	2	Each	$ 7,500	$ 15,000	
Type 1-A on new foundation	4	Each	$ 5,000	$ 20,000	Warning Sign (AWS) AW-I and AW-II
Remove and relocate sign and post	0	Each	$ 600	$ -	If existing AWS reused
			ITS Total	$ 308,950	
			Contingency (35%)	$ 108,133	
			Total	$ 417,083	

Mainline Detection ITS Cost Tables

The ITS cost estimate includes separate calculation for mainline detection on the four analysis segments of I-680 in Contra Costa County.

I-680 Area - NORTHBOUND (North of SR-24) Mainline Detection				
Item	**Quanity**	**Unit**	**Cost Assumptions**	**Total Cost**
Tirtl RX and TX in barrier	39	Each	$ 75,000	$ 2,925,000
Pull Box (Communication)	39	Each	$ 2,000	$ 78,000
2" PVC conduit (Trenched)	3900	LF	$ 30	$ 117,000
2" PVC conduit (Jacked)	3900	LF	$ 40	$ 156,000
Fiber Optic Cable (6 Strand Drop)	8970	LF	$ 2	$ 17,940
Fiber Optic Termination Panel (6 Strand)	39	Each	$ 1,000	$ 39,000
Ethernet Switch - Field Processor	39	Each	$ 4,000	$ 156,000
Power Drop	39	Each	$ 7,500	$ 292,500
Communications Cabinet	39	Each	$ 11,000	$ 429,000
			ITS Total	**$ 4,210,440**
			Contingency	**$ 1,473,654**
			Total	**$ 5,700,000**

I-680 Area - NORTHBOUND (South of SR-24) Mainline Detection				
Item	**Quanity**	**Unit**	**Cost Assumptions**	**Total Cost**
Tirtl RX and TX in barrier	53	Each	$ 75,000	$ 3,975,000
Pull Box (Communication)	53	Each	$ 2,000	$ 106,000
2" PVC conduit (Trenched)	5300	LF	$ 30	$ 159,000
2" PVC conduit (Jacked)	5300	LF	$ 40	$ 212,000
Fiber Optic Cable (6 Strand Drop)	12190	LF	$ 2	$ 24,380
Fiber Optic Termination Panel (6 Strand)	53	Each	$ 1,000	$ 53,000
Ethernet Switch - Field Processor	53	Each	$ 4,000	$ 212,000
Power Drop	53	Each	$ 7,500	$ 397,500
Communications Cabinet	53	Each	$ 11,000	$ 583,000
			ITS Total	**$ 5,721,880**
			Contingency	**$ 2,002,658**
			Total	**$ 7,800,000**

I-680 Area - SOUTHBOUND (North of SR-24) Mainline Detection				
Item	**Quanity**	**Unit**	**Cost Assumptions**	**Total Cost**
Tirtl RX and TX in barrier	40	Each	$ 75,000	$ 3,000,000
Pull Box (Communication)	40	Each	$ 2,000	$ 80,000
2" PVC conduit (Trenched)	4000	LF	$ 30	$ 120,000
2" PVC conduit (Jacked)	4000	LF	$ 40	$ 160,000
Fiber Optic Cable (6 Strand Drop)	9200	LF	$ 2	$ 18,400
Fiber Optic Termination Panel (6 Strand)	40	Each	$ 1,000	$ 40,000
Ethernet Switch - Field Processor	40	Each	$ 4,000	$ 160,000
Power Drop	40	Each	$ 7,500	$ 300,000
Communications Cabinet	40	Each	$ 11,000	$ 440,000
			ITS Total	**$ 4,318,400**
			Contingency	**$ 1,511,440**
			Total	**$ 5,900,000**

I-680 Area - SOUTHBOUND (South of SR-24) Mainline Detection				
Item	**Quanity**	**Unit**	**Cost Assumptions**	**Total Cost**
Tirtl RX and TX in barrier	48	Each	$ 75,000	$ 3,600,000
Pull Box (Communication)	48	Each	$ 2,000	$ 96,000
2" PVC conduit (Trenched)	4800	LF	$ 30	$ 144,000
2" PVC conduit (Jacked)	4800	LF	$ 40	$ 192,000
Fiber Optic Cable (6 Strand Drop)	11040	LF	$ 2	$ 22,080
Fiber Optic Termination Panel (6 Strand)	48	Each	$ 1,000	$ 48,000
Ethernet Switch - Field Processor	48	Each	$ 4,000	$ 192,000
Power Drop	48	Each	$ 7,500	$ 360,000
Communications Cabinet	48	Each	$ 11,000	$ 528,000
			ITS Total	**$ 5,182,080**
			Contingency	**$ 1,813,728**
			Total	**$ 7,000,000**

Arterial Dynamic Message Sign Pilot ITS Cost Table

Arterial dynamic message signs (DMSs) are a complementary feature for CARM and provide motorists with real-time information about the operation of the CARM system. CCTA intends to launch a DMS pilot at 16 intersections on parallel routes to I-680 northbound in San Ramon, CA between Bollinger Canyon Road and Sycamore Valley Road. DMSs are not proposed to be installed in any other location on the I-680 corridor in Contra Costa County. The ITS cost estimate includes separate calculation for the DMS sign pilot, which is provided below.

Arterial DMS Pilot: Traveler Information				
Item	Quanity	Unit	Cost Assumptions	Total Cost
DMS Sign	16	Each	$ 50,000	$ 800,000
Butterfly Mount Structure (30'Pole)	16	Each	$ 40,000	$ 640,000
2" PVC conduit (Trenched)	8000	LF	$ 30	$ 240,000
2" PVC conduit (Jacked)	4000	LF	$ 40	$ 160,000
Fiber Optic Cable (6 Strand Drop)	32000	LF	$ 2	$ 64,000
Fiber Optic Termination Panel (6 Strand)	16	Each	$ 1,000	$ 16,000
Ethernet Switch - Field Processor	16	Each	$ 4,000	$ 64,000
Power Drop	16	Each	$ 7,500	$ 120,000
Communications Cabinet	16	Each	$ 11,000	$ 176,000
			ITS Total	$ 2,280,000
			Contingency	$ 798,000
			Total	**$ 3,100,000**

ITS Operations and Maintenance Cost Table

The annual operations and maintenance costs for the CARM system will have three components: 1) annual licensing and hosting fees paid to Transmax to utilize the STREAMS® integrated ITS platform, 2) device support charges to link ITS devices to the STREAMS® platform, and ITS device maintenance costs, including a 25% fee for expedited repairs to ensure that the CARM operations return to normal as quickly as possible. These costs are provided in the table below.

Annual Fees			***Totals***
Functionality Licensing			$575,000
Hosting and Support			$350,000
Subtotal			***$925,000***
Device Support	***Units***	***Cost***	
Ramps	47	$81,775	$3,843,425
Field Processors	290	$427	$123,830
Loop Detectors	188	$5,900	$1,109,200
TIRTL	180	$5,900	$1,062,000
Arterial DMS	16	$2,750	$44,000
Subtotal			***$6,182,455***
Device Annual Maintenance	***Units***	***Cost***	
Ramps	47	$5,603	$263,329
Field Processors	290	$1,825	$529,250
Loop Detectors	801	$730	$584,730
TIRTL	180	$4,380	$788,400
RC-1 Signs	54	$2,778	$149,993
Arterial DMS	16	$2,778	$44,442
Subtotal Annual Maintenance			*$2,360,145*
25% Quick Response Payments			$590,036
Subtotal			***$2,950,181***
Total Annual Maintenance and Operations Costs			**$10,057,636**

Notes

Ramps	NB (22) SB (25)
Field Processors	Field processers could be reduced based on design, assumed 2 per meter, 1 per TIRTL, and 1 per Arterial DMS
Loop Detectors	Does not include standard Count Loop, down stream of passage loop
TIRTL	NB (92) SB (88)
RC-1 Signs	Two Per Entrance Ramp NB (26) SB (28), could be less; full matrix recommended, located close to Arterial DMS
Arterial DMS	Southern end only, not assuming any additional will be included in this project