Marin US 101 Northbound
Preliminary Ramp Metering Assessment

Marin County, California

January 2014

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Section 1
Executive Summary

EXECUTIVE SUMMARY

Motorists traveling along US 101 in Marin County currently experience significant delay during peak traffic conditions – southbound from Novato to San Rafael during the AM commute, and northbound from Mill Valley to the Sonoma County line during the PM commute.

An initial analysis, conducted in March 2013 for the Marin US 101 Freeway Performance Initiative (FPI) Ramp Metering Feasibility Study, of northbound US 101 showed that travel times from the Marin City on-ramp to the Marin-Sonoma county line during the weekday PM peak hour were more than twice as high as off-peak travel times. The travel time for this 24-mile trip took about 50 minutes, compared to about 24 minutes under free-flow conditions. Congestion regularly occurs approaching the Marin-Sonoma Narrows, Lucas Valley Road, Manuel Freitas Parkway, Second Street/ Central San Rafael, and Tamalpais Drive to as far south as State Route 1. The recurring bottlenecks and queues result in the potential for collisions, which further contributes to congestion.

Experience with ramp meters in the Bay Area and elsewhere in the country has shown safety, travel time, speed, throughput, and environmental benefits[1]. Ramp metering can improve safety by smoothing the flow of traffic entering the freeway and reducing stop-and-go driving behavior on the freeway. Experience in California and across the nation has demonstrated reductions in collisions of ranging from 15 to 50 percent. Metering can also improve overall system performance by increasing freeway throughput and travel speeds, which in turn decreases delay. These factors lead to reduced fuel consumption and vehicle emissions. Additionally, ramp metering can make diversion of short trips off of the freeway less desirable by requiring the traffic that exits the freeway to stop at a ramp meter to re-enter the freeway.

To address the congestion and safety concerns on US 101, the Metropolitan Transportation Commission (MTC) is working with Caltrans and the Transportation Authority of Marin (TAM) to evaluate the feasibility of implementing ramp metering along northbound US 101 corridor in southern Marin County. A preliminary assessment was performed to determine if northbound US 101 would show benefits similar to the benefits derived on other congested freeways, such as I-580 in Alameda County and US 101 in San Mateo and Santa Clara Counties. The analysis conducted for this assessment was based on traffic data for US 101, as compiled by Caltrans, MTC, and TAM, to reflect current conditions. A freeway operations analysis tool, FREQ, was used for this study.

The assessment evaluated an initial segment of northbound US 101 consisting of eight (8) freeway on-ramps from the Bridgeway/ Gate 6 on-ramp in northern Sausalito to the Sir Francis Drake Boulevard on-ramp in Larkspur.

[1] Ramp Management and Control Handbook, January 2006, Federal Highway Administration

Figure 1 identifies the freeway on-ramps included in the study:

1. Bridgeway / Gate 6
2. Highway 1/Pohono
3. Redwood Highway / Seminary
4. Blithedale Loop
5. Tiburon Diagonal
6. Tamalpais Loop
7. Tamalpais Diagonal
8. Sir Francis Drake Blvd

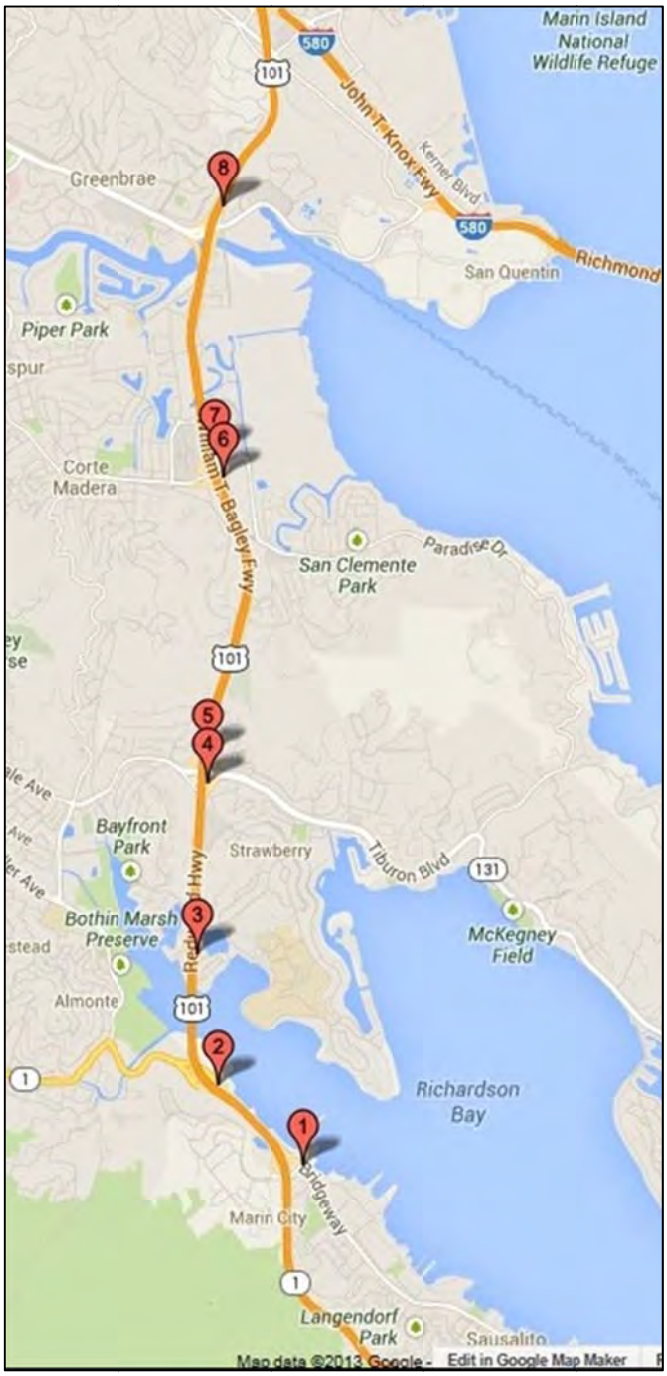


Figure 1: Study Area Showing Ramp Locations

Table 1 summarizes the five (5) on-ramps that would be widened as part of the capital improvement projects necessary for implementing ramp metering under MTC's Freeway Performance Initiative (FPI):

Table 1: FPI Northbound US 101 Ramp Widenings

On-Ramp Description	Existing # of Lanes	Proposed # of Lanes
Bridgeway On-Ramp	1 Mixed-flow	2 Mixed-flow
Blithedale Ave Loop On-Ramp	1 Mixed-flow	2 Mixed-flow
Tiburon Blvd Diagonal On-Ramp	1 Mixed-flow	1 HOV; 2 Mixed-flow
Tamalpais Dr Diagonal On-Ramp	1 Mixed-flow	1 HOV; 1 Mixed-flow
Sir Francis Drake Blvd On-Ramp	2 Mixed-flow	1 HOV; 2 Mixed-flow

After widening the ramps and implementing ramp metering, all on-ramps are expected to be able to store vehicle queues without negatively affecting traffic operations on the local streets. Specifically, vehicle queues are not expected to extend beyond the length of the ramp and spill onto local streets and intersections. The widening would have a positive effect in reducing or eliminating queues that currently affect local street traffic operations. Several examples of this type of improvement have been implemented under other ramp metering capital projects in the Bay Area, including those listed in Table 2.

Table 2: Other Bay Area Ramp Metering Capital Projects

On-Ramp Description	Original # of Lanes	Converted # of Lanes
Bernal Road loop on-ramp to northbound US 101 (San Jose)	1 HOV; 1 Mixed-flow	2 Mixed-flow
Blossom Hill Road loop on-ramp to northbound US 101 (San Jose)	1 Mixed-flow	2 Mixed-flow
Tasman Drive loop on-ramp to northbound I-880 (Milpitas)	1 Mixed-flow	2 Mixed-flow
Zanker Road on-ramp to westbound SR-237 (San Jose)	1 Mixed-flow	2 Mixed-flow
Hillsdale Boulevard loop on-ramp to southbound US 101 (San Mateo)	1 Mixed-flow	2 Mixed-flow

The results of the analysis indicate that the implementation of ramp metering on northbound US 101 in southern Marin County is expected to reduce travel times for those who travel the entire corridor (from Marin City to Bellam Boulevard/I-580) by 24 percent and increase the throughput of vehicles during congested periods. However, there would be less travel time savings for motorists entering the freeway midway through the segment. The improved travel times will result from less congestion and a steadier

flow of traffic with fewer occurrences of stop-and-go conditions. This smoother traffic flow on the freeway is expected to improve traffic safety and air quality, consistent with the improvements experienced on other congested freeways where ramp metering has been implemented. Table 3 provides travel time comparisons for 4:00 – 5:00 PM and 5:00 – 6:00 PM.

Table 3: Travel Time Comparison

	Without Ramp Metering	With Ramp Metering	Difference	
Analysis Time Period	Minutes	Minutes	Minutes	Percent
4:00 – 5:00 PM	11.0	9.2	-1.8	-16%
5:00 – 6:00 PM	17.3	13.1	-4.2	-24%

From Marin City off-ramp to Bellam Blvd/I-580 off-ramp (6.44 miles)
Source: FREQ model

As noted earlier, the capital project will provide sufficient on-ramp storage to accommodate the anticipated vehicle demand in this initial segment of US 101. After implementation of ramp metering, motorists at the ramp meters may encounter more delay at the ramps than they currently experience. The average delay would be 1.5 minutes during the highest peak hour when the freeway is most congested. While motorists may encounter delays at the metered on-ramps, these additional delays would be compensated, to some extent, by improved travel times after they enter the freeway. As ramp metering is extended beyond the limits of this initial section of US 101, greater travel time savings will be realized for those who enter the freeway at ramp meters.

Currently, during congested periods, drivers seek alternative routes that would save them travel time, and traffic exits the freeway earlier to avoid freeway congestion. Ramp metering will reduce this by improving traffic flow on the freeway mainline, discouraging diversion, and by requiring that traffic exiting the freeway stop at a ramp meter to re-enter the freeway.

The primary conclusion of this preliminary study of ramp metering on northbound US 101 in southern Marin County is that ramp metering is feasible and will provide significant benefits for motorists in Marin County. Prior to implementation, MTC, Caltrans, and TAM will prepare an Implementation Plan to refine ramp metering rates to balance ramp delay across all on-ramps along the corridor.

Section 2
Analysis and Findings

ANALYSIS AND FINDINGS

CORRIDOR LIMITS AND STUDY PURPOSE:

The purpose of this study was to perform a high-level ramp metering feasibility assessment at eight northbound on-ramps along the Marin US 101 Highway. The FREQ model developed previously for the Marin 101 Ramp Metering Feasibility Study was used in the analysis. The FREQ analysis was performed for the PM peak period using hourly analysis periods for a two-hour peak period. This analysis approach was developed as a reasonable means of determining if ramp metering would be beneficial along the study corridor.

The following eight (8) on-ramps along the northbound US-101 corridor in Marin County are shown in Figure 2:

1. Bridgeway / Gate 6
2. Highway 1/Pohono
3. Redwood Highway / Seminary
4. Blithedale Loop
5. Tiburon Diagonal
6. Tamalpais Loop
7. Tamalpais Diagonal
8. Sir Francis Drake Blvd

This preliminary assessment is based on a previous, more detailed evaluation of a longer section of the corridor conducted in March 2013 for the Marin US 101 Ramp Metering Feasibility Study. The FREQ model developed for the March 2013 Feasibility Study was modified for this preliminary evaluation as follows:

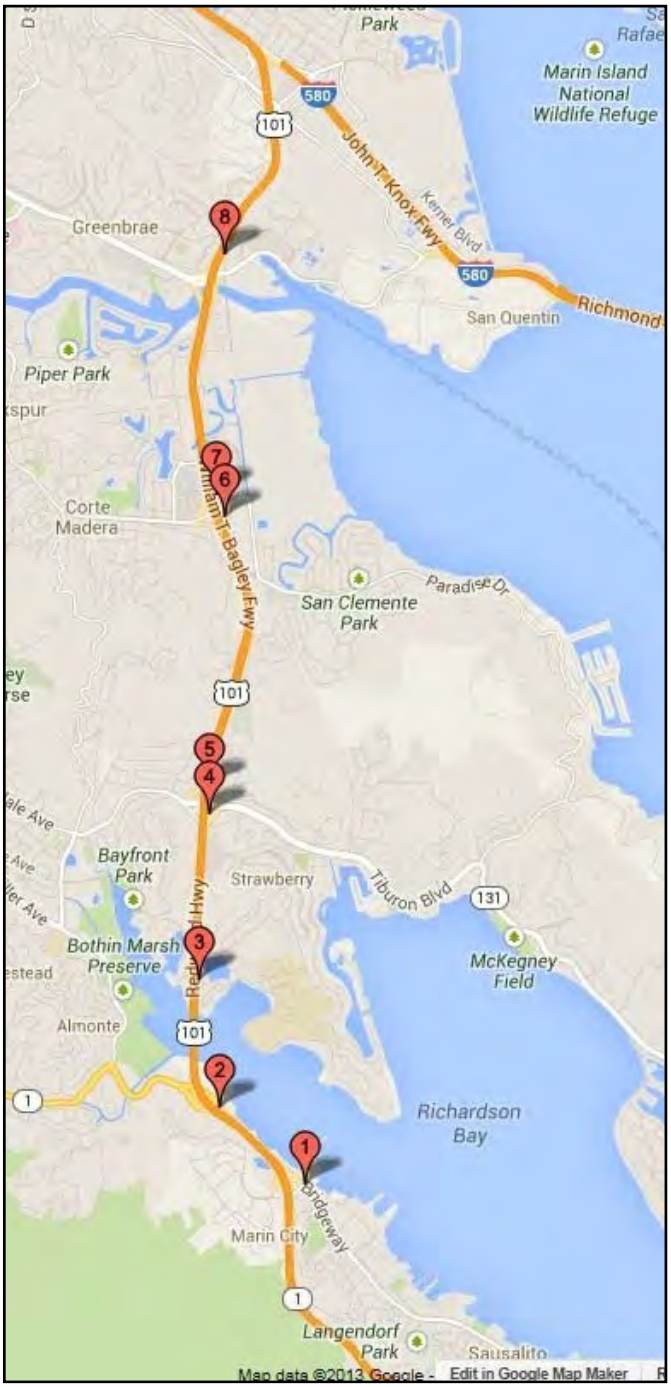


Figure 2: Study Area Showing Ramp Locations

- The FREQ model boundaries were modified to reflect the smaller study area. The modified model spans from the Marin City interchange to the I-580 interchange in San Rafael, whereas, the March 2013 Feasibility Study covered from the Golden Gate Bridge to the Marin-Sonoma County line.

- The length of the FREQ time intervals was revised from half-hour to one-hour intervals. The number of time intervals also changed in response to a shorter study period (4 PM to 6 PM, compared to the 3 PM to 7 PM time frame of the March 2013 Feasibility Study).

- Traffic volumes were updated. There were two sources for the traffic counts: Caltrans traffic counts compiled as part of the March 2013 Feasibility Study and the recent freeway ramp traffic volumes collected by the Transportation Authority of Marin (TAM) on Tuesday, September 10, 2013. In an effort to be conservative, the higher of the two counts was used at locations where both data sources were available. Table 4 shows the volumes used for this assessment.

- HOV operations were assumed to be in place from 4 PM to 6 PM due to the hourly simulation time slice in the FREQ model (HOV operations on the freeway actually begin at 4:30 PM). Modeling HOV operations a half hour earlier than the beginning of actual HOV operations could result in development of traffic congestion earlier than may occur on the freeway and may result in a conservative assessment of traffic congestion along the study corridor. However, this effect may be offset by starting the model without the build-up of congestion that actually begins at 3:30 PM.

- On-ramp storage lengths in the FREQ model were set based on existing conditions, adding space provided by the proposed widening of several on-ramps planned by Caltrans. Information on ramp storage lengths can be found in the Ramp Storage section of this document.

- Capacity was increased on the bottleneck section (between the Tamalpais Drive diagonal on-ramp and the Industrial Way off-ramp) by 2.5 percent in the ramp metering scenario. The Capacity Adjustments section of this document expands on this item.

The combined Priority Lane (PL) and Priority Entry (PE) module (i.e., PL+PE) was used in the FREQ modeling effort to account for the HOV operations and the proposed ramp metering strategy at the eight on-ramps.

MODELING INPUTS

O-D Traffic Volume

The freeway mainline entering traffic volumes (i.e., Origin #1) were obtained from the March 2013 Feasibility Study and from ramp traffic volumes provided by TAM. The freeway mainline exiting traffic volumes (i.e., Destination #7) were calculated by adding on-ramp volumes, subtracting off-ramp volumes, and balancing mainline traffic.

The FREQ model for the March 2013 Feasibility Study had been calibrated and validated based on the field observations conducted at the time, including a survey of travel time, and queue locations and durations. Use of the higher on-ramp traffic volumes entered into the FREQ model for this preliminary assessment resulted in 1,200 (4-5 PM) and 1,300 (5-6 PM) more vehicles using the freeway mainline than in the March 2013 Feasibility Study.

Traffic volume adjustments were made to produce travel times consistent with those observed in the field while retaining the most conservative on-ramp volumes discussed previously. Traffic volumes at some of the off-ramps were adjusted to cap the mainline demand for the freeway bottleneck subsection to the calibrated value used in the March 2013 Feasibility Study. No traffic volumes were reduced at any of the ramps. A review of INRIX travel times showed that travel times produced by the re-calibrated FREQ model were consistent with travel times in the fall season of 2013.

Table 4 shows the traffic volumes in the March 2013 Feasibility Study alongside the volumes recorded in this preliminary study. The last two columns show the change between March 2013 volumes and those recorded in this preliminary study, and the balanced mainline volumes between each ramp, respectively. Appendix A presents the volumes used for freeway modeling in this study in relation to the freeway geometry. Appendix B presents the recent TAM counts and Appendix C includes the March 2013 volumes for reference purposes.

Ramp Storage

Ramp storage assumptions were made in accordance with the Caltrans Ramp Meter Design Manual (RMDM), published in January, 2000. Namely, the limit line was assumed to be located 23 meters upstream from the point where the shortest distance between the freeway mainline and the ramp edges equals seven meters. The numbers presented in this section also assume the completion of added lanes at five on-ramps, as described in Table 5. As in previous studies, the length of the HOV on-ramp lane is not counted toward ramp storage. As a result, the assessment of delays and queues at the ramp meters provides conservative estimates.

Table 4: Hourly Traffic Volumes

O/D #	Description	Time Period	March 2013 Feasibility Study (veh/hr)	Final Adjusted Volume (veh/hr)	Change (Final – March 2013)	Mainline Balanced Volumes (veh/hr)
O1	US 101 Mainline (South End, Calculated)	4-5 PM	5,420	5,420	0	
		5-6 PM	5,637	5,637	0	
O2	Bridgeway On-Ramp	4-5 PM	1,206	1,238	32	5,420
		5-6 PM	1,275	1,275	0	5,637
D1	Route 1 Off-Ramp	4-5 PM	724	910	186	6,658
		5-6 PM	890	1,094	204	6,912
O3	Route 1 On-Ramp	4-5 PM	609	609	0	5,748
		5-6 PM	652	652	0	5,818
D2	Seminary Dr Off-Ramp	4-5 PM	583	583	0	6,357
		5-6 PM	691	691	0	6,470
O4	Seminary Dr On-Ramp	4-5 PM	389	389	0	5,774
		5-6 PM	405	405	0	5,779
D3	Tiburon Blvd Off-Ramp	4-5 PM	584	584	0	6,163
		5-6 PM	662	662	0	6,184
O5	Blithedale Ave Loop On-Ramp	4-5 PM	935	965	30	5,579
		5-6 PM	859	859	0	5,522
O6	Tiburon Blvd Diagonal On-Ramp	4-5 PM	999	1,243	244	6,544
		5-6 PM	888	1,258	370	6,381
D4	Tamalpais Dr Off-Ramp	4-5 PM	1,215	1,489	274	7,787
		5-6 PM	1,340	1,710	370	7,639
O7	Tamalpais Dr Loop On-Ramp	4-5 PM	668	750	82	6,298
		5-6 PM	670	708	38	5,929
O8	Tamalpais Dr Diagonal On-Ramp	4-5 PM	513	585	72	7,048
		5-6 PM	541	707	166	6,637
D5	Industrial Way Off-Ramp	4-5 PM	248	248	0	7,633
		5-6 PM	224	224	0	7,344
D6	Sir Francis Drake Blvd Off-Ramp	4-5 PM	2,416	2,416	0	7,385
		5-6 PM	2,584	2,584	0	7,120
O9	Sir Francis Drake Blvd On-Ramp	4-5 PM	1,556	1,556	0	4,969
		5-6 PM	1,629	1,629	0	4,536
D7	US 101 Mainline (North End, Calculated)	4-5 PM	6,525	6,525	0	6,525
		5-6 PM	6,165	6,165	0	6,165

Table 5: Proposed On-Ramp Number of Lanes

On-Ramp Description	Existing # of Lanes	Proposed # of Lanes
Bridgeway On-Ramp	1	2 Mixed-flow
Blithedale Ave Loop On-Ramp	1	2 Mixed-flow
Tiburon Blvd Diagonal On-Ramp	1	1 HOV; 2 Mixed-flow
Tamalpais Dr Diagonal On-Ramp	1	1 HOV; 1 Mixed-flow
Sir Francis Drake Blvd On-Ramp	2	1 HOV; 2 Mixed-flow

Table 6 summarizes the ramp storage used in FREQ, both in measured length and estimated number of vehicles (the standard ramp metering assumption 30 feet per vehicle was used). Figure 3 illustrates the ramps and their associated storage length. The calculations are included in Appendix D.

Table 6: Ramp Storage Assumptions

Origin #	On-Ramp Description	Storage with Proposed Number of Lanes * (vehicles | ft.)
2	Bridgeway On-Ramp	46 vehicles | 1,400 ft.
3	Route 1 On-Ramp	22 vehicles | 660 ft.
4	Seminary Dr On-Ramp	3 vehicles | 100 ft.
5	Blithedale Ave Loop On-Ramp	22 vehicles | 660 ft.
6	Tiburon Blvd Diagonal On-Ramp	44 vehicles | 1,320 ft.
7	Tamalpais Dr Loop On-Ramp	14 vehicles | 440 ft.
8	Tamalpais Dr Diagonal On-Ramp	25 vehicles | 770 ft.
9	Sir Francis Drake Blvd On-Ramp	38 vehicles | 1,140 ft.

* Note: Storage assumptions are based on available information at the start of this Assessment in September 2013. Ramp storage lengths may be modified as the project design is refined. Ramp metering rates will be refined to account for changes in ramp storage lengths and other changes that may occur prior to ramp metering.

Capacity Adjustments

Consistent with improvements to traffic flows observed on previous ramp metering projects, capacities at the bottlenecks were increased by 2.5 percent on FREQ runs that included a ramp metering strategy. In this study corridor, the only recurring bottleneck develops just downstream of the Tamalpais Drive diagonal on-ramp (with queues that extend as far as State Route 1). To account for the expected increase in capacity at the bottleneck, capacity was increased at this segment only (i.e., subsection 13 in the FREQ file).

Without ramp metering, the capacity in the March 2013 Feasibility Study (5,850 vehicles per hour) was used at the bottleneck section. On the ramp metering FREQ run performed for this study, capacity was increased to 6,000 vehicles per hour to account for improvements in traffic flow expected to result from ramp metering. A change in capacity of this magnitude can result in a significant reduction in travel times along the corridor.

RAMP METERING FEASIBILITY

Freeway operations with and without the ramp metering strategy were modeled through FREQ's PL and PE runs. The preliminary metering rates were developed to fully utilize the available storage on each of the on-ramps, except Sir Francis Drake Boulevard, in order to maximize travel time savings on the freeway. The Sir Francis Drake Boulevard on-ramp is downstream of congestion and would be metered "at demand"; therefore, minimal delay is anticipated at this location. Comparisons of the results are presented in the following sections. Appendix E presents a summary table with details on freeway operations at the subsection level of the base scenario (without ramp metering). Appendix F presents a summary table of the ramp metering scenario in details. Comparisons between the two scenarios (with and without ramp metering strategy) are summarized in the Potential Benefits section.

On-Ramp Queuing

The FREQ analysis indicates that the proposed on-ramp storage would be sufficient to accommodate all on-ramp vehicle demand. Table 7 presents the preliminary ramp metering rates and queue lengths. Figure 4 provides a bar chart showing the maximum ramp metering rate vs. preliminary ramp metering rate. The Seminary Drive on-ramp is a short ramp with storage available for three vehicles. As shown on Figure 4, the metering rate at this on-ramp could be increased to serve the hourly demand at this location should queues begin to spill back onto the local street.

It should be noted that field observations conducted for the March 2013 Feasibility Study indicated queues on the Blithedale Avenue loop on-ramp extended beyond the loop ramp onto Tiburon Boulevard due to existing congestion on the freeway mainline. This condition is a result of the inability of the freeway to absorb the demand from the on-ramp, and the on-ramp's lack of sufficient storage. The proposed widening to two mixed-flow lanes at this location, along with the potential added freeway capacity realized through ramp metering may help to mitigate this. As depicted on Figure 4, there is potential to increase the metering rate at the Blithedale Avenue loop on-ramp to a

maximum rate of 1,800 vehicles per hour, effectively serving the total on-ramp demand. Therefore, it is not expected that metering would result in additional ramp queuing.[2]

[2] Examples of where ramp widening has been used to accommodate ramp metering and reduce queuing on local streets are:

- Northbound SCL101/Bernal Road Loop on-ramp
- Northbound SCL101/Blossom Hill Road Loop on-ramp
- Northbound SCL880/Tasman Drive Loop on-ramp
- Westbound SCL237/Zanker Road on-ramp
- Southbound SM101/Hillsdale Boulevard Loop on-ramp

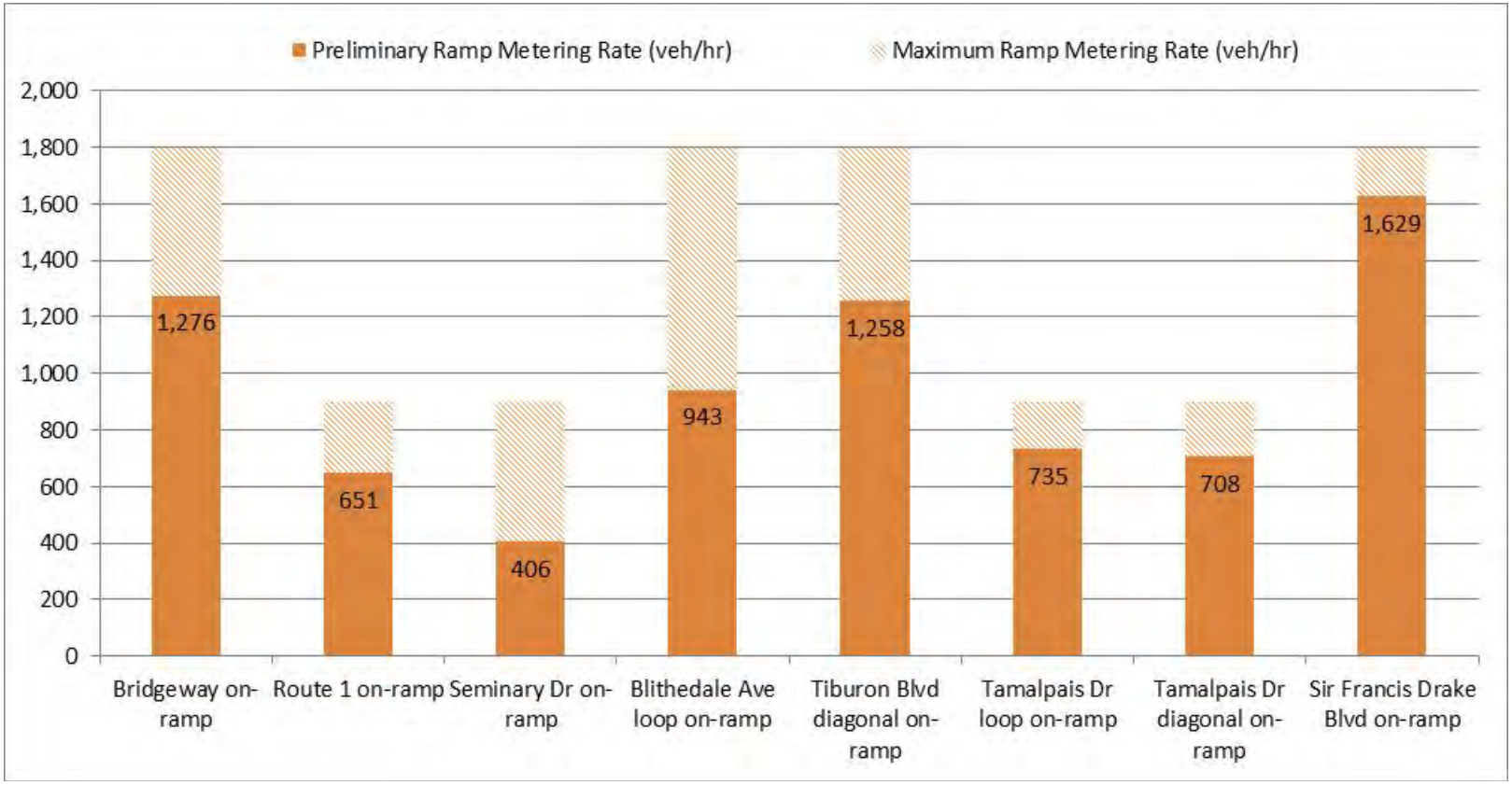
Figure 3: Ramp Locations and Storage

Table 7: Preliminary Metering Rates and Queue Lengths

Input Variables		Bridgeway on-ramp	Route 1 on-ramp	Seminary Dr on-ramp	Blithedale Ave loop on-ramp	Tiburon Blvd diagonal on-ramp	Tamalpais Dr loop on-ramp	Tamalpais Dr diagonal on-ramp	Sir Francis Drake Blvd on-ramp
FREQ Origin #		2	3	4	5	6	7	8	9
Number of MF Lanes at Limit Line		2	1	1	2	2	1	1	2
HOV Bypass at Limit Line		0	0	0	0	1	0	1	1
Maximum Metering Rate (veh/hr)		1,800	900	900	1,800	1,800	900	900	1,800
Ramp Storage (ft)		1,400	660	100	660	1,320	440	770	1,140
Ramp Storage (veh)		46	22	3	22	44	14	25	38
Time Start	Time End	Demands - Hourly Flow for the Entire On-ramp (Vehicles per Hour)							
4:00:00 PM	5:00:00 PM	1,238	609	389	965	1,243	750	585	1,556
5:00:00 PM	6:00:00 PM	1,275	652	405	859	1,258	708	707	1,629
Time Start	Time End	Preliminary Ramp Metering Rate Per Ramp (Vehicles per Hour)							
4:00:00 PM	5:00:00 PM	1,192	587	384	943	1,198	735	560	1,556
5:00:00 PM	6:00:00 PM	1,276	651	406	859	1,258	708	708	1,629
Time Start	Time End	Ramp Queue Length (Vehicles)							
4:00:00 PM	5:00:00 PM	46	22	3	22	44	14	25	1
5:00:00 PM	6:00:00 PM	46	22	3	22	44	14	25	1
Time Start	Time End	Average Metering Delays (Minutes)							
4:00:00 PM	5:00:00 PM	1.11	1.18	0.26	0.82	1.27	0.56	1.28	*
5:00:00 PM	6:00:00 PM	2.09	2.13	0.48	1.76	2.38	1.16	2.05	*

* Minimal delay anticipated at Sir Francis Drake Blvd.

Figure 4: Maximum Ramp Metering Rate (veh/hr) vs. Preliminary Ramp Metering Rate (veh/hr)



The maximum ramp metering rates (900 veh/hr for one lane on-ramp, and 1,800 veh/hr for two-lane on-ramp) are based on a 4-second cycle length and the number of lanes at the limit line. Figure 4 illustrates the difference between the maximum ramp metering rates and preliminary ramp metering rates during the entire simulation time slices from 4:00 PM to 6:00 PM. As shown on Figure 4, there is still potential at all on-ramps to increase the metering rates above the preliminary rates set by FREQ both to prevent queues from spilling back onto the local arterials and to accommodate future traffic growth on the ramps.

POTENTIAL BENEFITS

As noted previously, implementation of ramp metering in other parts of the Bay Area has resulted in significant mobility improvements. Freeway throughput increased by 2-5% in corridors where ramp meters have been activated in Santa Clara, Alameda, and San Mateo Counties, translating into travel time reductions of 5-57%. The potential benefits resulting from implementation of ramp metering along the initial segment of northbound US 101 is presented below.

Travel Time Savings

Table 8 provides travel time comparisons for the 4:00 - 5:00 PM and 5:00 - 6:00 PM hours. The implementation of ramp metering is expected to result in less travel time for motorists traveling along the entire length of the study segment, particularly during the 5:00-6:00 PM hour. However, there would be less travel time savings for motorists entering the freeway midway through the segment.

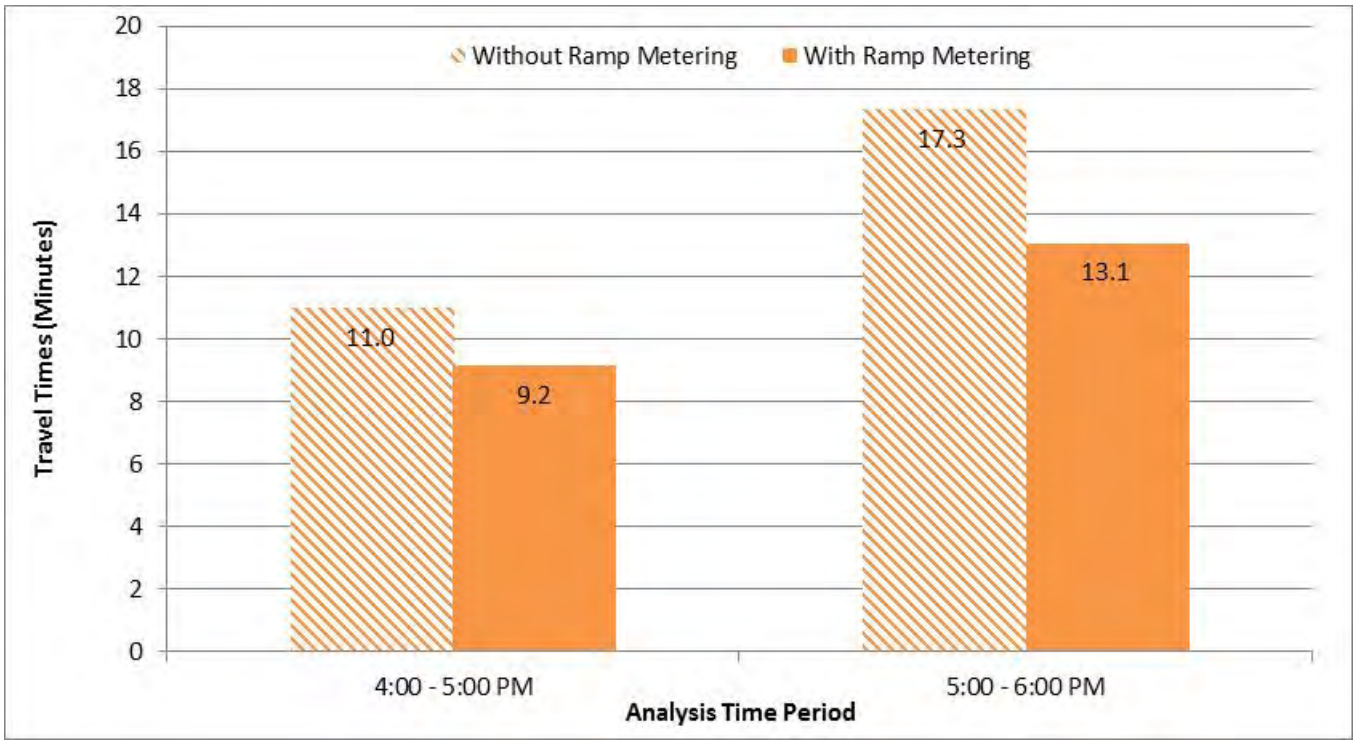
Table 8: Travel Time Comparison

	Without Ramp Metering	With Ramp Metering	Difference	
Analysis Time Period	Minutes	Minutes	Minutes	Percent
4:00 – 5:00 PM	11.0	9.2	-1.8	-16%
5:00 – 6:00 PM	17.3	13.1	-4.2	-24%

From Marin City off-ramp to Bellam Blvd/I-580 off-ramp (6.44 miles)

Source: FREQ model

Figure 5: Travel Time Comparison



Vehicle Throughput Increases

The simulated throughputs at the freeway segment downstream of the Sir Francis Drake on-ramp are presented in Table 9. The throughput of the first and the second time slices indicate the increase of about 100 vehicles.

Table 9: Throughput Comparison at the Last Freeway Subsection

Time Slice	Without Ramp Metering (veh/hr)	With Ramp Metering (veh/hr)	Difference (veh/hr)
4-5 PM	5,365	5,463	98
5-6 PM	5,241	5,338	97

Table 10 shows the comparison of freeway system performances. FREQ analysis indicates that there would be total travel time savings during the PM peak period. It also indicates an overall increase in average travel speed (3 mph).

Table 10: Freeway System Performance Comparison

Measures of Effectiveness	Scenarios	4-5 PM	5-6 PM
Total Travel Time (veh-hr)*	Without RM	987	1,498
	With RM	933	1,348
	Difference	-54	-150
Average Speed (mi/hr)	Without RM	35	23
	With RM	38	26
	Difference	3	3

Note: * On-ramp travel delay due to ramp metering was not included in the total travel time.

OTHER CONSIDERATIONS

Ramp Delays

As with any ramp metering implementation, it is expected that motorists would experience delay at the on-ramps in exchange for travel time savings on the freeway mainline. Table 7 shows that under preliminary metering rates, the average delay would be less than 2.4 minutes at the on-ramp with the strictest metering rate (Tiburon Boulevard's diagonal on-ramp). Ramp metering delays below 2.4 minutes compare favorably with the expected freeway travel time savings (see Table 8 and Figure 5).

Travelers using the Bridgeway and Route 1 on-ramps would also experience slightly more than 2 minutes of delay. But, because these on-ramps are at the beginning of the study segment, these motorists would ultimately save time with ramp metering. However, the same cannot be said for motorists using the Tamalpais Drive on-ramps, for example, as they enter the freeway toward the end of the segment.

Diversion

Currently, during congested periods, drivers seek alternative routes that would save them travel time, and traffic exits the freeway earlier to avoid freeway congestion. Ramp metering will reduce this by improving traffic flow on the freeway mainline, discouraging diversion, and by requiring that traffic exiting the freeway stop at a ramp meter to re-enter the freeway. Note that all ramps in the demand area will be metered.

Downstream Impacts

Based on the FREQ model's estimates, the vehicle throughput would increase at the metered freeway segments. These additional vehicle throughputs might add to congestion and delay of the freeway segments further downstream. Further investigation would be needed should a ramp metering implementation study be conducted.

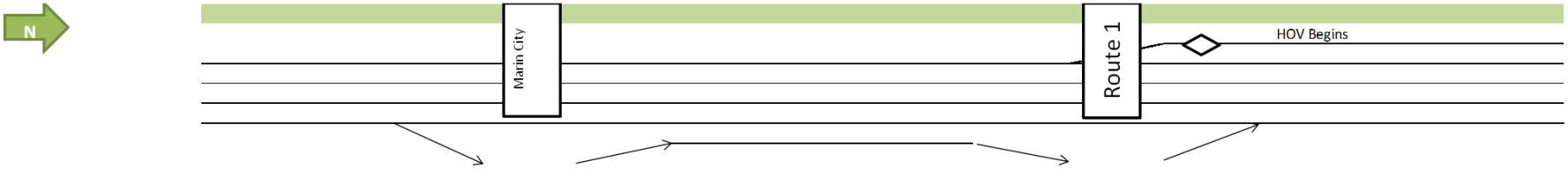
CONCLUSIONS/ NEXT STEPS

The main conclusions from this preliminary assessment include:

- A ramp metering strategy is feasible with the proposed ramp widenings
- The assumed on-ramp storage is sufficient to accommodate all vehicle queues
- Travel times would decrease through the study segment during the most congested period
- All on-ramps in the demand area will be metered, reducing any advantage for early exiting drivers
- Ramp metering rates will be refined before implementation

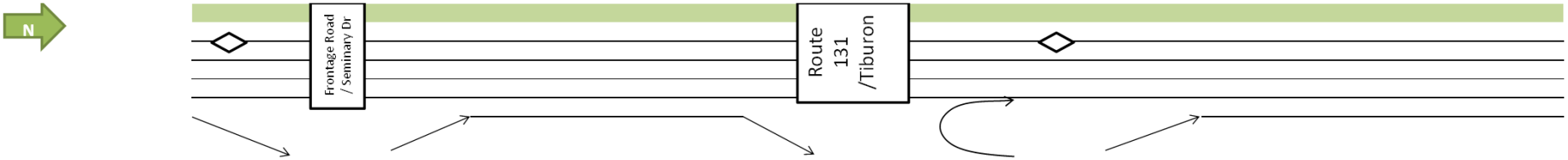
FREQ model results indicate travel time benefits without negatively impacting spillback onto local streets. The preliminary ramp metering rates will be determined based on the occupancy data from the detectors on the freeway mainline. These refined ramp metering rates will also include the balancing of on-ramp delay across all on-ramps in the system to reduce the potential for diversion of traffic from an on-ramp to another one nearby.

Appendix 1 Traffic Volumes and Geometry



Legend
FREQ Input
Red: Volume, March 2013
Black: Volume, September 2013

Hours	Mainline (Calc)	Marin City off-ramp	Mainline (Calc)	Marin City on-ramp	Mainline (Calc)	Route 1 off-ramp	Mainline (Calc)	Route 1 on-ramp	Mainline (Calc)
16:00-17:00	5,594	174	5,420	1,238	6,658	910	5,748	609	6,357
17:00-18:00	5,837	200	5,637	1,275	6,912	1,094	5,818	652	6,470
4-6 PM Total	**11,431**	**374**	**11,057**	**2,513**	**13,570**	**2,004**	**11,566**	**1,261**	**12,827**



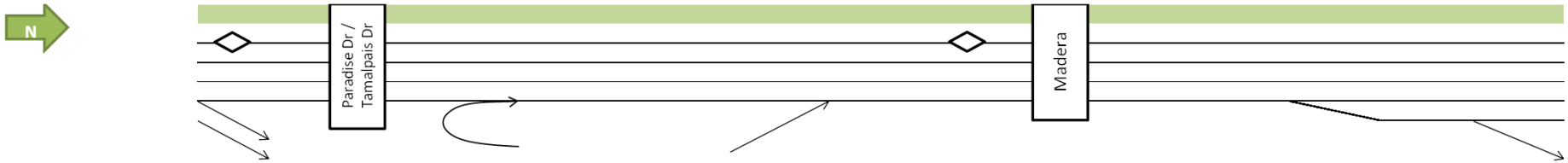
Legend

FREQ Input

Red: Volume, March 2013

Black: Volume, September 2013

Hours	Seminary Dr off-ramp	Mainline (Calc)	Seminary Dr on-ramp	Mainline (Calc)	Rt 131/Tiburon off-ramp	Mainline (Calc)	Rt 131/Tiburon loop on-ramp	Mainline (Calc)	Rt 131/Tiburon diagonal on-ramp	Mainline (Calc)
16:00-17:00	583	5,774	389	6,163	584	5,579	965	6,544	1,243	7,787
17:00-18:00	691	5,779	405	6,184	662	5,522	859	6,381	1,258	7,639
4-6 PM Total	**1,274**	**11,553**	**794**	**12,347**	**1,246**	**11,101**	**1,824**	**12,925**	**2,501**	**15,426**



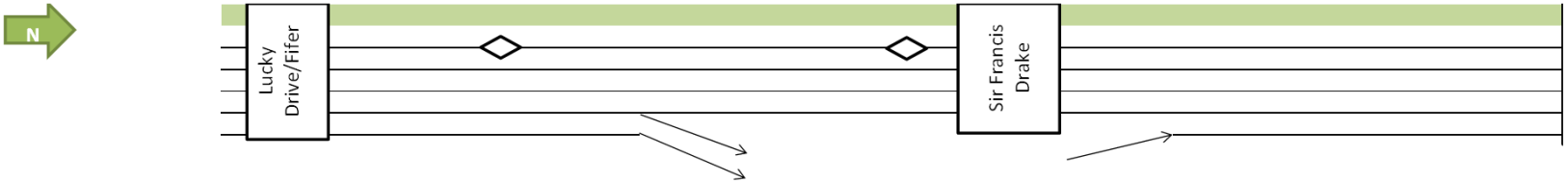
Legend

FREQ Input

Red: Volume, March 2013

Black: Volume, September 2013

Hours	Tamalpais off-ramp	Mainline (Calc)	Tamalpais loop on-ramp	Mainline (Calc)	Tamalpais diagonal on-ramp	Mainline (Calc)	Industrial off-ramp
16:00-17:00	1,489	6,298	750	7,048	585	7,633	248
17:00-18:00	1,710	5,929	708	6,637	707	7,344	224
4-6 PM Total	**3,199**	**12,227**	**1,458**	**13,685**	**1,292**	**14,977**	**472**



Legend
FREQ Input
Red: Volume, March 2013
Black: Volume, September 2013

Hours	Mainline (Calc)	Industrial on-ramp	Sir Francis Drake off-ramp	Mainline (Calc)	Sir Francis Drake on-ramp	Mainline (Calc)
16:00-17:00	7,385	802	2,416	4,969	1,556	6,525
17:00-18:00	7,120	772	2,584	4,536	1,629	6,165
4-6 PM Total	**14,505**		**5,000**	**9,505**	**3,185**	**12,690**

Appendix 2 Traffic Data from Transportation Authority of Marin

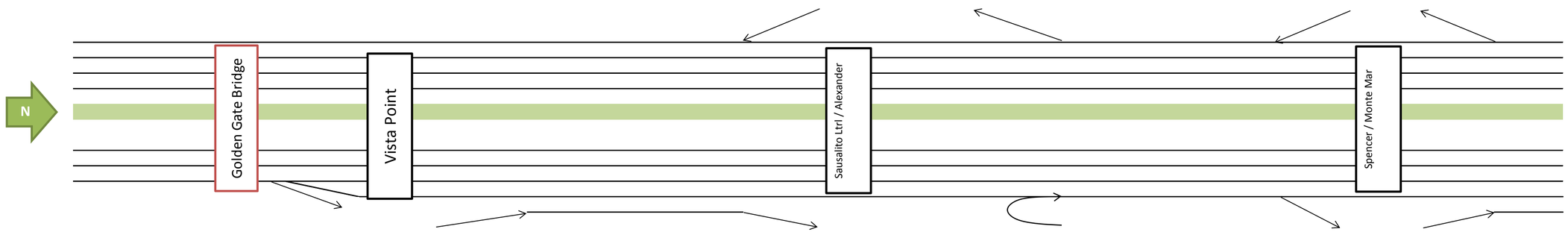
Northbund 101 Ramp Counts for September 10
Collected Data September 10, 2013

	3:45-4:00	4:00-4:15	4:15-4:30	4:30-4:45	4:45-5:00		5:00-5:15	5:15-5:30	5:30-5:45	5:45-6:00		6:00-6:15
Bridgeway / Gate 6		373	311	252	302	**1238**	306	303	276	297	**1182**	
Highway 1/Pohono		140	144	168	132	**584**	108	116	112	112	**448**	
Redwood Highway / Seminary	106	80	78	88	84	**330**	91	66	75	74	**306**	
Blithedale Loop	225	240	229	267	229	**965**	227	201	184	197	**809**	
Tiburon Diagonal		331	313	306	293	**1243**	332	341	314	271	**1258**	
Tamalpais Loop	184	196	181	187	186	**750**	187	171	175	175	**708**	142
Tamalpais Diagonal		139	133	169	144	**585**	210	170	158	169	**707**	
Industrial	216	221	216	212	153	**802**	213	204	174	181	**772**	

Appendix 3 Full Feasibility Study Volume And Geometry Diagram (For Reference Only)

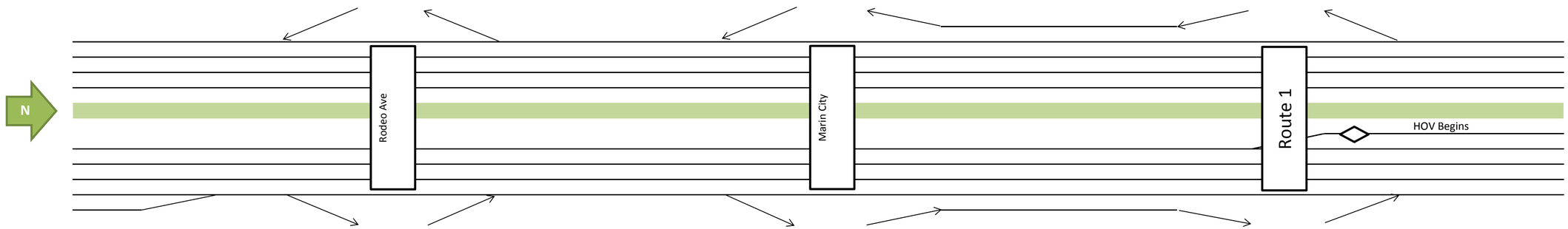
Marin 101 Ramp Metering Feasibility Study - Existing 2011/2012 Mainline Traffic Volumes

Hours	Mainline (Calc)	Sausalito on-ramp	Mainline (Calc)	Sausalito off-ramp	Mainline (Calc)	Mont Mar on-ramp	Mainline (Calc)	Mont Mar off-ramp
05:00-06:00	2,019	43	1,976	45	2,021	17	2,004	16
06:00-07:00	3,868	106	3,762	109	3,871	39	3,832	53
07:00-08:00	6,398	219	6,179	118	6,297	83	6,214	137
08:00-09:00	5,039	268	4,771	158	4,929	93	4,836	136
09:00-10:00	3,316	218	3,098	204	3,302	72	3,230	123
10:00-11:00	3,303	220	3,083	221	3,304	62	3,242	119
6-10 AM Total	**18,621**	**811**	**17,810**	**589**	**18,399**	**287**	**18,112**	**449**



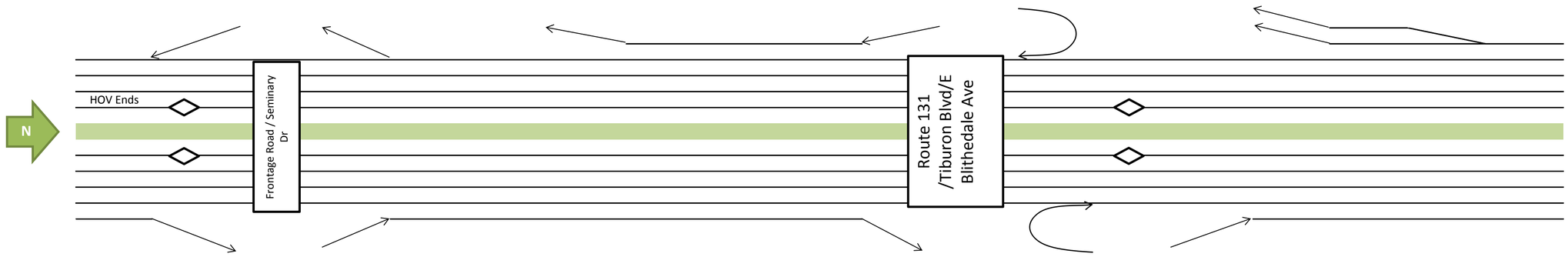
Hours	Mainline (Calc)	Vista Point off-ramp	Mainline (Calc)	Vista Point on-ramp	Mainline (Calc)	Sausalito off-ramp	Mainline (Calc)	**Mainline Control Station (PeMS Counts)**	Sausalito on-ramp	Mainline (Calc)	Mont Mar off-ramp	Mainline (Calc)	Mont Mar on-ramp
14:00-15:00	4,425	143	4,282	198	4,480	242	4,238	**3,862**	133	4,371	59	4,312	134
15:00-16:00	5,204	131	5,073	187	5,260	240	5,020	**4,594**	166	5,186	68	5,118	135
16:00-17:00	5,552	121	5,431	177	5,608	249	5,359	**4,925**	173	5,532	75	5,457	162
17:00-18:00	5,878	79	5,799	138	5,937	269	5,668	**5,196**	144	5,812	89	5,723	154
18:00-19:00	5,878	65	5,813	97	5,910	219	5,691	**5,276**	93	5,784	126	5,658	140
19:00-20:00	4,051	49	4,002	72	4,074	166	3,908	**3,629**	48	3,956	75	3,881	75
3-7 PM Total	**22,512**	**396**	**22,116**	**599**	**22,715**	**977**	**21,738**	**19,991**	**576**	**22,314**	**358**	**21,956**	**591**

Hours	Mainline (Calc)	Rodeo on-ramp	Mainline (Calc)	Rodeo off-ramp	Mainline (Calc)	Marin City on-ramp	Mainline (Calc)	Marin City off-ramp	Mainline (Calc)	Route 1 on-ramp	Mainline (Calc)	Route 1 off-ramp	Mainline (Calc)
05:00-06:00	2,020	0	2,020	0	2,020	32	1,988	154	2,142	129	2,013	50	2,063
06:00-07:00	3,885	0	3,885	1	3,886	89	3,797	383	4,180	338	3,842	201	4,043
07:00-08:00	6,351	2	6,349	2	6,351	175	6,176	806	6,982	780	6,202	475	6,677
08:00-09:00	4,972	3	4,969	3	4,972	226	4,746	1,277	6,023	1,035	4,988	571	5,559
09:00-10:00	3,353	8	3,345	7	3,352	160	3,192	1,151	4,343	688	3,655	507	4,162
10:00-11:00	3,361	4	3,357	5	3,362	161	3,201	1,081	4,282	538	3,744	426	4,170
6-10 AM Total	**18,561**	**13**	**18,548**	**13**	**18,561**	**650**	**17,911**	**3,617**	**21,528**	**2,841**	**18,687**	**1,754**	**20,441**



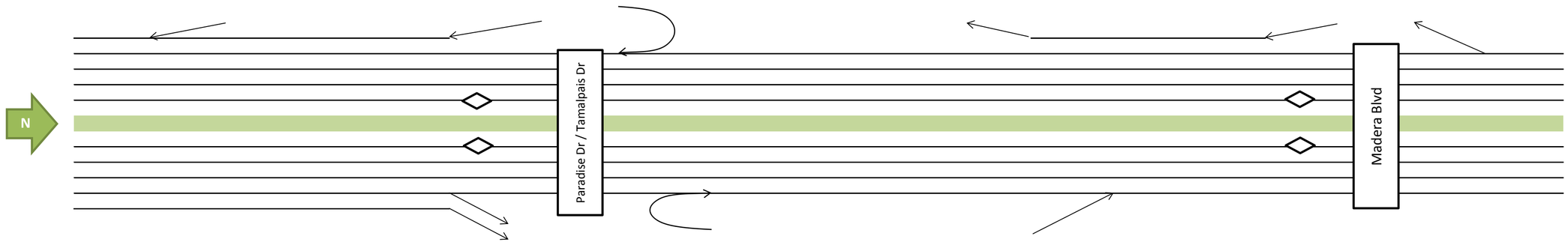
Hours	Mainline (Calc)	Rodeo off-ramp	Mainline (Calc)	Rodeo on-ramp	Mainline (Calc)	Marin City off-ramp	Mainline (Calc)	Marin City on-ramp	Mainline (Calc)	Route 1 off-ramp	Mainline (Calc)	Route 1 on-ramp	Mainline (Calc)
14:00-15:00	4,446	48	4,398	31	4,429	151	4,278	1,209	5,487	575	4,912	554	5,466
15:00-16:00	5,253	55	5,198	40	5,238	158	5,080	1,214	6,294	631	5,663	678	6,341
16:00-17:00	5,619	54	5,565	29	5,594	174	5,420	1,206	6,626	724	5,902	609	6,511
17:00-18:00	5,877	70	5,807	30	5,837	200	5,637	1,275	6,912	890	6,022	652	6,674
18:00-19:00	5,798	75	5,723	29	5,752	201	5,551	1,090	6,641	945	5,696	532	6,228
19:00-20:00	3,956	44	3,912	20	3,932	127	3,805	693	4,498	562	3,936	306	4,242
3-7 PM Total	**22,547**	**254**	**22,293**	**128**	**22,421**	**733**	**21,688**	**4,785**	**26,473**	**3,190**	**23,283**	**2,471**	**25,754**

Hours	Mainline (PeMS Counts)	Seminary Dr on-ramp	Mainline (Calc)	Seminary Dr off-ramp	Mainline (Calc)	Frontage Road off-ramp	Mainline (Calc)	Rt 131/Tiburon diagonal on-ramp	Mainline (Calc)	Rt 131/Tiburon loop on-ramp	Mainline (Calc)	Rt 131/Tiburon off-ramp
05:00-06:00	1,562	114	1,949	31	1,980	96	2,076	67	2,009	103	1,906	211
06:00-07:00	3,526	268	3,775	86	3,861	208	4,069	151	3,918	244	3,674	651
07:00-08:00	5,666	502	6,175	150	6,325	378	6,703	343	6,360	564	5,796	1,763
08:00-09:00	6,168	555	5,004	219	5,223	419	5,642	494	5,148	631	4,517	2,059
09:00-10:00	5,078	510	3,652	182	3,834	419	4,253	368	3,885	485	3,400	1,818
10:00-11:00	4,237	430	3,740	138	3,878	381	4,259	311	3,948	391	3,557	1,605
6-10 AM Total	**20,438**	**1,835**	**18,606**	**637**	**19,243**	**1,424**	**20,667**	**1,356**	**19,311**	**1,924**	**17,387**	**6,291**



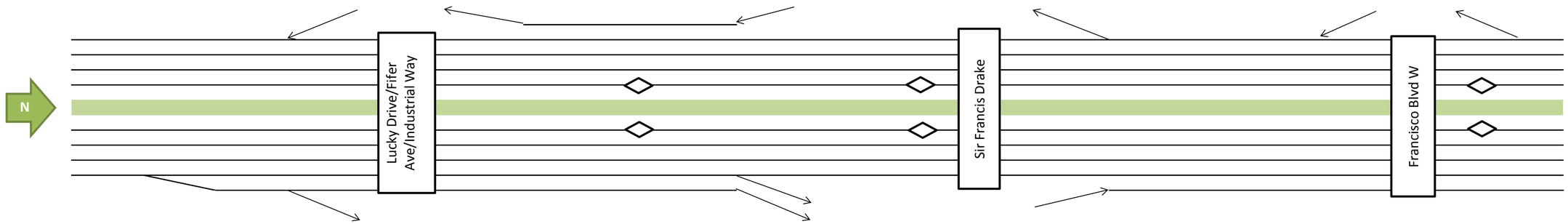
Hours	Seminary Dr off-ramp	Mainline (Calc)	Seminary Dr on-ramp	Mainline (Calc)	Rt 131/Tiburon off-ramp	Mainline (Calc)	Rt 131/Tiburon loop on-ramp	Mainline (Calc)	Rt 131/Tiburon diagonal on-ramp	Mainline (Calc)
14:00-15:00	514	4,952	390	5,342	533	4,809	897	5,706	1,024	6,730
15:00-16:00	575	5,766	391	6,157	547	5,610	984	6,594	1,041	7,635
16:00-17:00	583	5,928	389	6,317	584	5,733	935	6,668	999	7,667
17:00-18:00	691	5,983	405	6,388	662	5,726	859	6,585	888	7,473
18:00-19:00	655	5,573	329	5,902	704	5,198	746	5,944	794	6,738
19:00-20:00	394	3,848	205	4,053	484	3,569	501	4,070	502	4,572
3-7 PM Total	**2,504**	**23,250**	**1,514**	**24,764**	**2,497**	**22,267**	**3,524**	**25,791**	**3,722**	**29,513**

Hours	Mainline (Calc)	Cass Buena on-ramp	Mainline (Calc)	Tamalpais diagonal on-ramp	Mainline (Calc)	Tamalpais loop on-ramp	Mainline (Calc)	Tamalpais off-ramp	Mainline (Calc)	Madera on-ramp	Mainline (Calc)	Madera off-ramp
05:00-06:00	2,117	7	2,110	27	2,083	38	2,045	136	2,181	34	2,147	131
06:00-07:00	4,325	29	4,296	89	4,207	92	4,115	319	4,434	98	4,336	212
07:00-08:00	7,559	77	7,482	255	7,227	252	6,975	811	7,786	232	7,554	392
08:00-09:00	6,576	67	6,509	529	5,980	419	5,561	1,126	6,687	421	6,266	404
09:00-10:00	5,218	60	5,158	436	4,722	295	4,427	858	5,285	399	4,886	407
10:00-11:00	5,162	38	5,124	382	4,742	255	4,487	827	5,314	402	4,912	431
6-10 AM Total	**23,678**	**233**	**23,445**	**1,309**	**22,136**	**1,058**	**21,078**	**3,114**	**24,192**	**1,150**	**23,042**	**1,415**



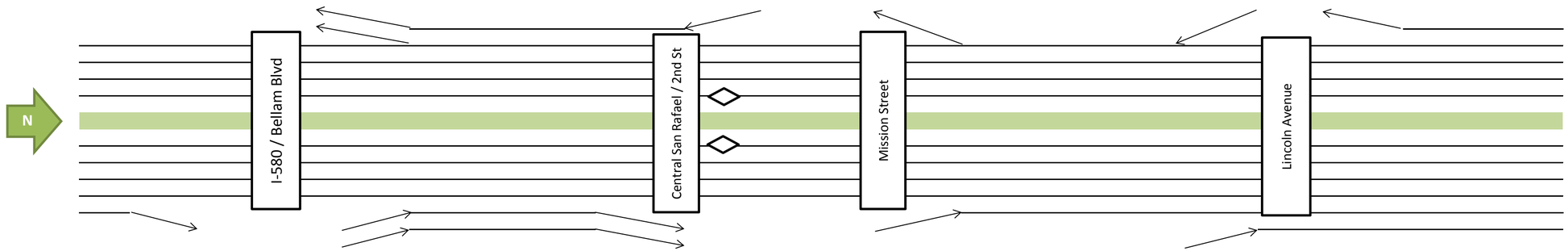
Hours	Tamalpais off-ramp	Mainline (Calc)	Tamalpais loop on-ramp	Mainline (Calc)	Tamalpais diagonal on-ramp	Mainline (Calc)
14:00-15:00	1,051	5,679	668	6,347	452	6,799
15:00-16:00	1,122	6,513	769	7,282	548	7,830
16:00-17:00	1,215	6,452	668	7,120	513	7,633
17:00-18:00	1,340	6,133	670	6,803	541	7,344
18:00-19:00	1,183	5,555	582	6,137	424	6,561
19:00-20:00	704	3,868	459	4,327	257	4,584
3-7 PM Total	**4,860**	**24,653**	**2,689**	**27,342**	**2,026**	**29,368**

Hours	Mainline (Calc)	Lucky Dr/Fifer on-ramp	Mainline (Calc)	Lucky Dr/Fifer off-ramp	Mainline (Calc)	Sir Francis Drake on-ramp	Mainline (Calc)	Sir Francis Drake off-ramp	Mainline	Francisco Boulevard on-ramp	Mainline	Francisco Boulevard off-ramp
05:00-06:00	2,278	29	2,249	163	2,412	366	2,046	337	2,383	144	2,239	137
06:00-07:00	4,548	97	4,451	339	4,790	968	3,822	837	4,659	433	4,226	339
07:00-08:00	7,946	301	7,645	593	8,238	2,144	6,094	1,284	7,378	1,174	6,204	368
08:00-09:00	6,670	312	6,358	567	6,925	1,915	5,010	1,273	6,283	1,367	4,916	298
09:00-10:00	5,293	240	5,053	538	5,591	2,086	3,505	1,220	4,725	984	3,741	308
10:00-11:00	5,343	213	5,130	613	5,743	1,831	3,912	980	4,892	748	4,144	285
6-10 AM Total	**24,457**	**950**	**23,507**	**2,037**	**25,544**	**7,113**	**18,431**	**4,614**	**23,045**	**3,958**	**19,087**	**1,313**



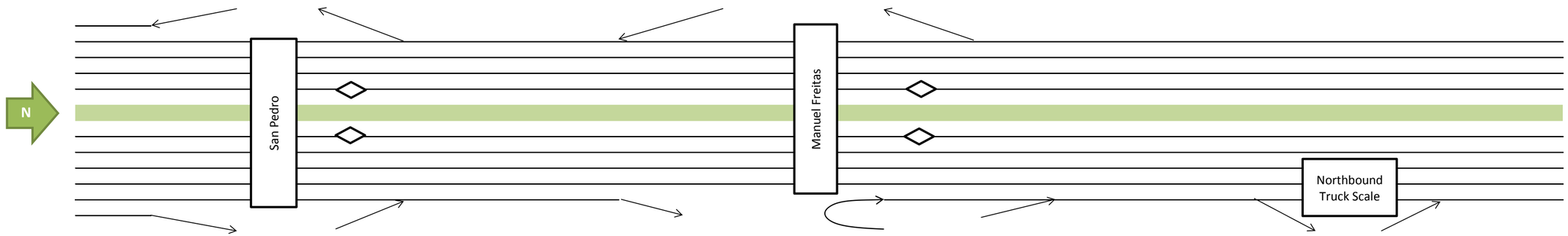
Hours	Industrial off-ramp	Mainline (Calc)	Mainline (Calc)	Sir Francis Drake off-ramp	Mainline (Calc)	Sir Francis Drake on-ramp	Mainline (Calc)
14:00-15:00	281	6,518	4,361	2,157	4,361	1,485	5,846
15:00-16:00	283	7,547	5,132	2,415	5,132	1,610	6,742
16:00-17:00	248	7,385	4,969	2,416	4,969	1,556	6,525
17:00-18:00	224	7,120	4,536	2,584	4,536	1,629	6,165
18:00-19:00	238	6,323	4,012	2,311	4,012	1,523	5,535
19:00-20:00	175	4,409	2,839	1,570	2,839	1,092	3,931
3-7 PM Total	**993**	**28,375**	**18,649**	**9,726**	**18,649**	**6,318**	**24,967**

Hours	Mainline (Calc)	I-580/Bellam off-ramp	Mainline (Calc)	2nd St/San Rafael on-ramp	Mainline (Calc)	Mission/San Rafael off-ramp	Mainline (Calc)	Lincoln on-ramp	Mainline (Calc)	Lincoln off-ramp	Mainline (Calc)
05:00-06:00	2,376	1,089	3,465	397	3,068	347	3,415	36	3,379	39	3,418
06:00-07:00	4,565	1,669	6,234	1,024	5,210	967	6,177	114	6,063	133	6,196
07:00-08:00	6,572	1,854	8,426	2,093	6,333	1,648	7,981	310	7,671	303	7,974
08:00-09:00	5,214	1,888	7,102	2,127	4,975	1,949	6,924	313	6,611	414	7,025
09:00-10:00	4,049	1,806	5,855	1,825	4,030	1,767	5,797	186	5,611	334	5,945
10:00-11:00	4,429	1,539	5,968	1,618	4,350	1,502	5,852	142	5,710	241	5,951
6-10 AM Total	**20,400**	**7,217**	**27,617**	**7,069**	**20,548**	**6,331**	**26,879**	**923**	**25,956**	**1,184**	**27,140**



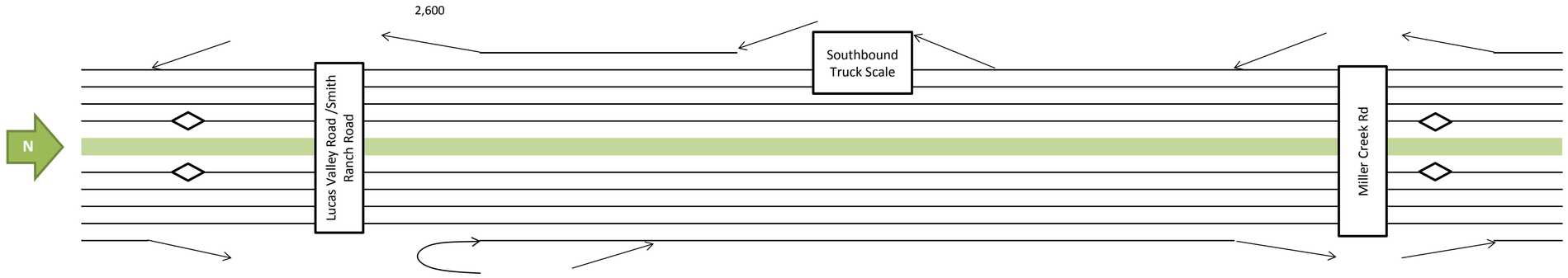
Hours	I-580/Bellam off-ramp	Mainline (Calc)	I-580 on-ramp	Mainline (Calc)	2nd St/Central San Rafael off-ramp	Mainline (Calc)	Mission on-ramp	Mainline (Calc)	Lincoln on-ramp	Mainline (Calc)
14:00-15:00	862	4,984	2,022	7,006	1,668	5,338	1,934	7,272	324	7,596
15:00-16:00	926	5,816	2,195	8,011	1,822	6,189	1,989	8,178	409	8,587
16:00-17:00	913	5,612	2,294	7,906	1,801	6,105	1,965	8,070	404	8,474
17:00-18:00	818	5,347	2,265	7,612	1,940	5,672	2,053	7,725	414	8,139
18:00-19:00	650	4,885	1,796	6,681	1,997	4,684	1,703	6,387	258	6,645
19:00-20:00	413	3,518	1,327	4,845	1,450	3,395	1,057	4,452	164	4,616
3-7 PM Total	**3,307**	**21,660**	**8,550**	**30,210**	**7,560**	**22,650**	**7,710**	**30,360**	**1,485**	**31,845**

Hours	San Pedro on-ramp	Mainline (Calc)	San Pedro off-ramp	Mainline (Calc)	Manuel Freitas on-ramp	Mainline (Calc)	Manuel Freitas off-ramp	Mainline (Calc)
05:00-06:00	124	3,294	78	3,372	185	3,187	196	3,383
06:00-07:00	352	5,844	193	6,037	438	5,599	549	6,148
07:00-08:00	796	7,178	282	7,460	952	6,508	836	7,344
08:00-09:00	905	6,120	354	6,474	1,049	5,425	986	6,411
09:00-10:00	767	5,178	349	5,527	967	4,560	773	5,333
10:00-11:00	679	5,272	286	5,558	944	4,614	720	5,334
6-10 AM Total	**2,820**	**24,320**	**1,178**	**25,498**	**3,406**	**22,092**	**3,144**	**25,236**



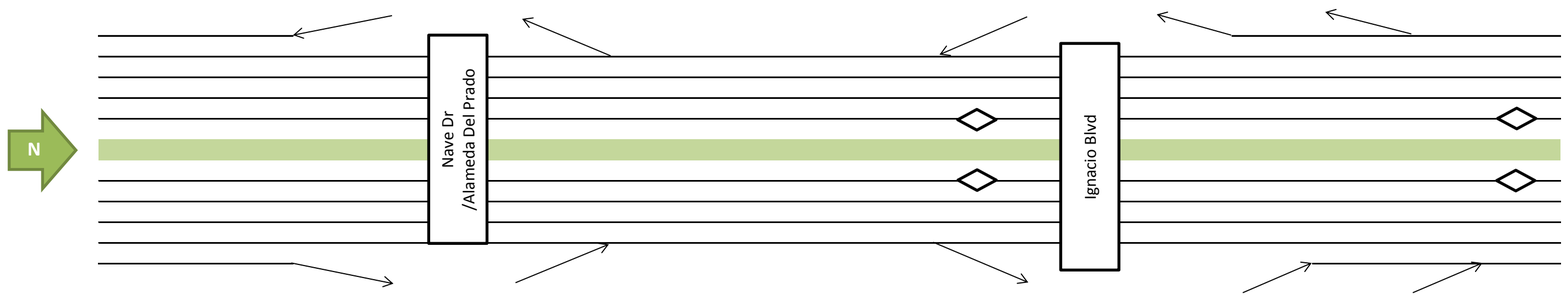
Hours	San Pedro off-ramp	Mainline (Calc)	San Pedro on-ramp	Mainline (Calc)	Manuel Freitas off-ramp	Mainline (Calc)	Manuel Freitas loop on-ramp	Mainline (Calc)	Redwood Hwy on-ramp	Mainline (Calc)	Truck Scale off-ramp	Mainline (Calc)	Truck Scale on-ramp	Mainline (Calc)
14:00-15:00	824	6,772	417	7,189	1,392	5,797	630	6,427	221	6,648	10	6,638	25	6,663
15:00-16:00	871	7,716	481	8,197	1,380	6,817	757	7,574	298	7,872	5	7,867	6	7,873
16:00-17:00	836	7,638	517	8,155	1,324	6,831	725	7,556	361	7,917	5	7,912	12	7,924
17:00-18:00	861	7,278	394	7,672	1,451	6,221	679	6,900	370	7,270	3	7,267	36	7,303
18:00-19:00	791	5,854	308	6,162	1,311	4,851	508	5,359	235	5,594	4	5,590	39	5,629
19:00-20:00	501	4,115	0	4,115	872	3,243	372	3,615	130	3,745	6	3,739	37	3,776
3-7 PM Total	**3,359**	**28,486**	**1,700**	**30,186**	**5,466**	**24,720**	**2,669**	**27,389**	**1,264**	**28,653**				

Hours	Lucas Valley on-ramp	Mainline (Calc)	Lucas Valley off-ramp	Mainline (Calc)	Truck Scale on-ramp	Mainline (Calc)	Truck Scale off-ramp	Mainline (Calc)	Miller Creek on-ramp	Mainline (Calc)	Miller Creek off-ramp
05:00-06:00	115	3,268	123	3,391	16	3,375	16	3,391	60	3,331	29
06:00-07:00	330	5,818	343	6,161	13	6,148	13	6,161	130	6,031	155
07:00-08:00	706	6,638	558	7,196	13	7,183	13	7,196	951	6,245	1,047
08:00-09:00	692	5,719	684	6,403	7	6,396	7	6,403	1,050	5,353	1,146
09:00-10:00	629	4,704	557	5,261	8	5,253	8	5,261	205	5,056	568
10:00-11:00	632	4,702	335	5,037	4	5,033	4	5,037	188	4,849	166
6-10 AM Total	**2,357**	**22,879**	**2,142**	**25,021**	**41**	**24,980**	**41**	**25,021**	**2,336**	**22,685**	**2,916**



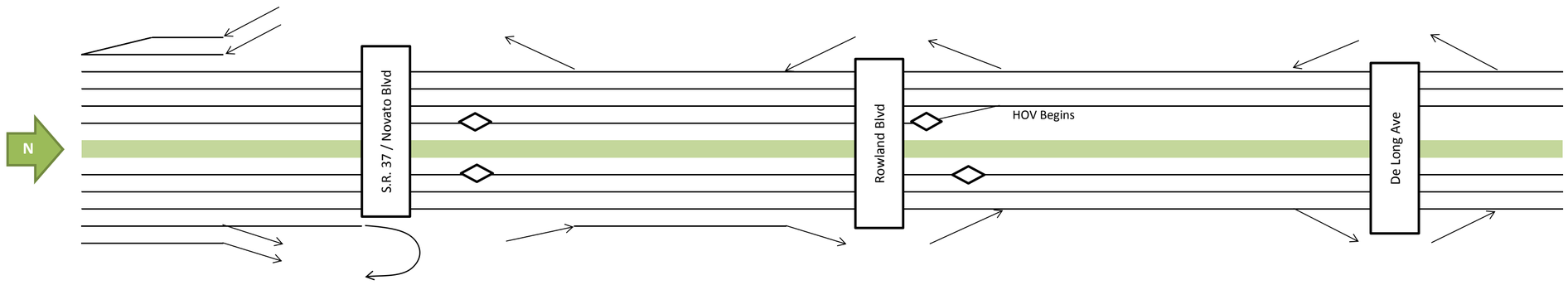
Hours	Lucas Valley off-ramp	Mainline (Calc)	Lucas Valley loop on-ramp	Mainline (Calc)	Lucas Valley diagonal on-ramp	Mainline (Calc)	Miller Creek off-ramp	Mainline (Calc)	Miller Creek on-ramp
14:00-15:00	708	5,955	137	6,092	351	6,443	211	6,232	169
15:00-16:00	745	7,128	175	7,303	424	7,727	264	7,463	210
16:00-17:00	701	7,223	185	7,408	467	7,875	267	7,608	187
17:00-18:00	737	6,566	182	6,748	468	7,216	290	6,926	196
18:00-19:00	646	4,983	166	5,149	255	5,404	256	5,148	160
19:00-20:00	492	3,284	100	3,384	130	3,514	191	3,323	94
3-7 PM Total	**2,829**	**25,900**	**708**	**26,608**	**1,614**	**28,222**	**1,077**	**27,145**	**753**

Hours	Mainline (Calc)	Alameda Del Prado on-ramp	Mainline (Calc)	Alameda Del Prado off-ramp	Mainline (Calc)	Ignacio on-ramp	Mainline (Calc)	Ignacio loop off-ramp	Mainline (Calc)	Ignacio diagonal off-ramp
05:00-06:00	3,360	186	3,174	40	3,214	293	2,921	142	3,063	137
06:00-07:00	6,186	481	5,705	65	5,770	570	5,200	304	5,504	256
07:00-08:00	7,292	1,062	6,230	92	6,322	739	5,583	613	6,196	474
08:00-09:00	6,499	1,112	5,387	135	5,522	677	4,845	833	5,678	670
09:00-10:00	5,624	743	4,881	142	5,023	710	4,313	524	4,837	420
10:00-11:00	5,015	453	4,562	126	4,688	669	4,019	397	4,416	386
6-10 AM Total	**25,601**	**3,398**	**22,203**	**434**	**22,637**	**2,696**	**19,941**	**2,274**	**22,215**	**1,820**



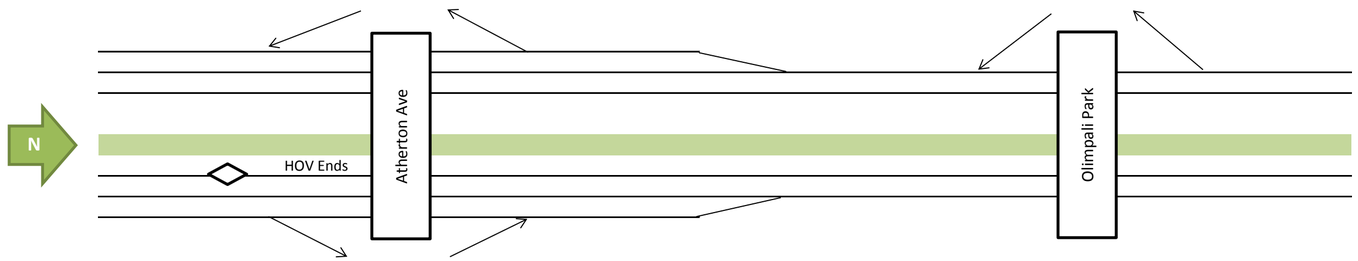
Hours	Mainline (Calc)	Nave Drive off-ramp	Mainline (Calc)	Nave Drive on-ramp (south)	Mainline (Calc)	**Mainline (PeMS Counts)**	Ignacio off-ramp	Mainline (Calc)	Nave Drive on-ramp (north)	Mainline (Calc)	Ignacio on-ramp
14:00-15:00	6,401	541	5,860	161	6,021	5,665	681	5,340	283	5,623	821
15:00-16:00	7,673	655	7,018	171	7,189	6,778	829	6,360	288	6,648	901
16:00-17:00	7,795	762	7,033	170	7,203	6,866	819	6,384	281	6,665	1,057
17:00-18:00	7,122	832	6,290	164	6,454	6,647	845	5,609	257	5,866	1,059
18:00-19:00	5,308	658	4,650	141	4,791	5,662	706	4,085	235	4,320	727
19:00-20:00	3,417	451	2,966	118	3,084	4,196	503	2,581	183	2,764	476
3-7 PM Total	**27,898**	**2,907**	**24,991**	**646**	**25,637**	**25,953**	**3,199**	**22,438**	**1,061**	**23,499**	**3,744**

Hours	Mainline (Calc)	**Mainline (Caltrans Counts)**	Route 37/Novato on-ramp	Mainline (Calc)	Route 37/Novato off-ramp	Mainline (Calc)	Rowland on-ramp	Mainline (Calc)	Rowland off-ramp	Mainline (Calc)	De Long on-ramp	Mainline (Calc)	De Long off-ramp
05:00-06:00	3,200	3,068	738	2,462	26	2,488	156	2,332	227	2,559	263	2,296	69
06:00-07:00	5,760	5,678	1,429	4,331	79	4,410	478	3,932	345	4,277	607	3,670	181
07:00-08:00	6,670	6,456	1,917	4,753	134	4,887	808	4,079	312	4,391	817	3,574	247
08:00-09:00	6,348	5,909	1,883	4,465	214	4,679	860	3,819	311	4,130	826	3,304	270
09:00-10:00	5,257	5,277	1,418	3,839	250	4,089	711	3,378	356	3,734	694	3,040	206
10:00-11:00	4,802	4,577	1,117	3,685	257	3,942	850	3,092	413	3,505	688	2,817	172
6-10 AM Total	**24,035**	**23,320**	**6,647**	**17,388**	**677**	**18,065**	**2,857**	**15,208**	**1,324**	**16,532**	**2,944**	**13,588**	**904**



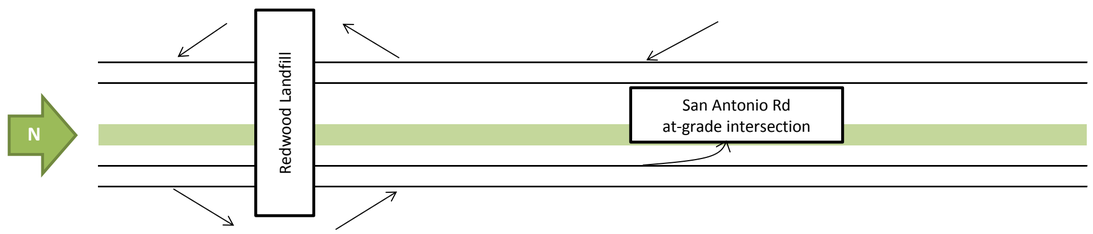
Hours	Mainline (Calc)	**Mainline (Caltrans Counts)**	Route 37 off-ramp	Mainline (Calc)	Novato Boulevard off-ramp	Mainline (Calc)	Route 37/Novato on-ramp	Mainline (Calc)	Rowland off-ramp	Mainline (Calc)	Rowland on-ramp	Mainline (Calc)	De Long off-ramp	Mainline (Calc)	De Long on-ramp
14:00-15:00	6,444	5,645	1,054	5,390	251	5,139	342	5,481	1,278	4,203	518	4,721	1,001	3,720	185
15:00-16:00	7,549	6,857	1,682	5,867	432	5,435	334	5,769	1,250	4,519	516	5,035	1,105	3,930	191
16:00-17:00	7,722	7,189	1,865	5,857	448	5,409	277	5,686	1,332	4,354	530	4,884	1,218	3,666	202
17:00-18:00	6,925	6,990	1,738	5,187	412	4,775	312	5,087	1,330	3,757	551	4,308	1,253	3,055	186
18:00-19:00	5,047	5,380	1,265	3,782	330	3,452	268	3,720	1,095	2,625	525	3,150	970	2,180	161
19:00-20:00	3,240	3,963	855	2,385	229	2,156	220	2,376	742	1,634	434	2,068	701	1,367	123
3-7 PM Total	**27,243**	**26,416**	**6,550**	**20,693**	**1,622**	**19,071**	**1,191**	**20,262**	**5,007**	**15,255**	**2,122**	**17,377**	**4,546**	**12,831**	**740**

Hours	Mainline (Calc)	Atherton on-ramp	Mainline (Calc)	Atherton off-ramp	**Mainline Control Station (PeMS Counts)**	From Olimpali Park	Mainline (Calc)	To Olimpali Park	Mainline
05:00-06:00	2,365	226	2,139	124	2,263	0	2,263	0	2,263
06:00-07:00	3,851	557	3,294	260	3,554	1	3,553	1	3,554
07:00-08:00	3,821	749	3,072	438	3,510	3	3,507	2	3,509
08:00-09:00	3,574	813	2,761	600	3,361	4	3,357	4	3,361
09:00-10:00	3,246	622	2,624	345	2,969	5	2,964	7	2,971
10:00-11:00	2,989	598	2,391	269	2,660	7	2,653	7	2,660
6-10 AM Total	**14,492**	**2,741**	**11,751**	**1,643**	**13,394**	**13**	**13,381**	**14**	**13,395**



Hours	Mainline (Calc)	Atherton off-ramp	Mainline (Calc)	Atherton on-ramp	Mainline (Calc)
14:00-15:00	3,905	680	3,225	367	3,592
15:00-16:00	4,121	738	3,383	468	3,851
16:00-17:00	3,868	795	3,073	644	3,717
17:00-18:00	3,241	905	2,336	723	3,059
18:00-19:00	2,341	727	1,614	390	2,004
19:00-20:00	1,490	544	946	229	1,175
3-7 PM Total	**13,571**	**3,165**	**10,406**	**2,225**	**12,631**

Hours	Redwood Sanitary on-ramp	Mainline (Calc)	Redwood Sanitary off-ramp	Mainline (Calc)	on- From San Antonio	Mainline (Calc)	Hours
05:00-06:00	2	2,261	2	2,263	13	2,250	05:00-06:00
06:00-07:00	10	3,544	11	3,555	71	3,484	06:00-07:00
07:00-08:00	15	3,494	17	3,511	108	3,403	07:00-08:00
08:00-09:00	7	3,354	8	3,362	51	3,311	08:00-09:00
09:00-10:00	4	2,967	4	2,971	26	2,945	09:00-10:00
10:00-11:00	4	2,656	4	2,660	27	2,633	10:00-11:00
6-10 AM Total	**36**	**13,359**	**40**	**13,399**	**256**	**13,143**	**6-10 AM Total**



Hours	Redwood Sanitary off-ramp	Mainline (Calc)	Redwood Sanitary on-ramp	Mainline (Calc)	off- To San Antonio	Mainline (Calc)	Hours
14:00-15:00	7	3,585	8	3,593	22	3,571	14:00-15:00
15:00-16:00	7	3,844	8	3,852	25	3,827	15:00-16:00
16:00-17:00	7	3,710	8	3,718	25	3,693	16:00-17:00
17:00-18:00	9	3,050	10	3,060	31	3,029	17:00-18:00
18:00-19:00	10	1,994	11	2,005	34	1,971	18:00-19:00
19:00-20:00	9	1,166	10	1,176	18	1,158	19:00-20:00
3-7 PM Total	**33**	**12,598**	**37**	**12,635**	**115**	**12,520**	**3-7 PM Total**

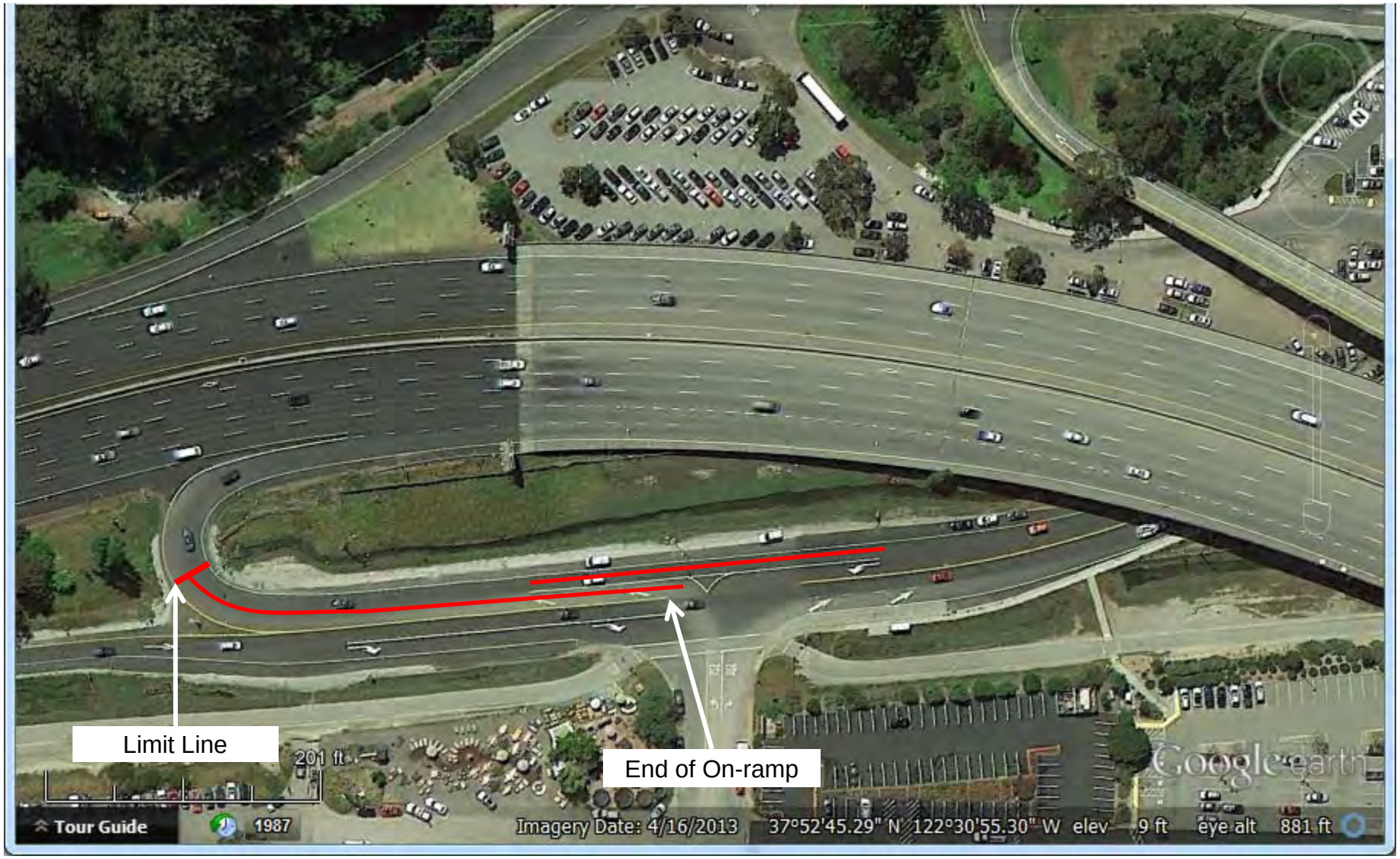
Appendix 4 Ramp Metering Storage Calculations

NB MRN-101 Ramp Metering Bridgeway FREQ Origin/on-ramp #1

On-ramp storage upstream of limit line

Based on Ramp Metering Equipment Drawing
23 vehicles (700 ft) to end of on-ramp
46 vehicles (1400 ft) total storage (2-lane on-ramp)

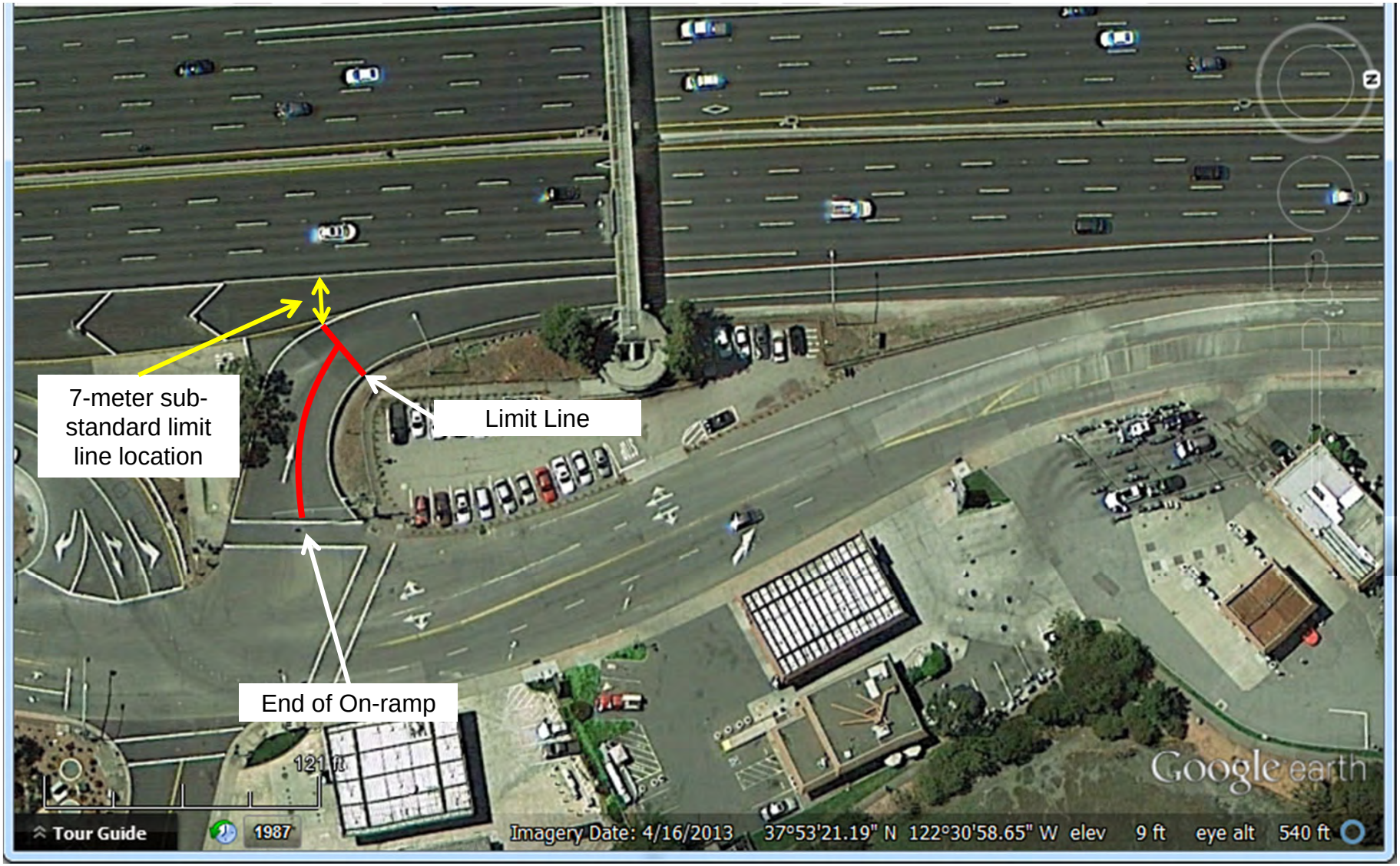
NB MRN-101 Ramp Metering | Highway 1/ Pohono Street | FREQ Origin/on-ramp #2



On-ramp storage upstream of limit line

Based on Caltrans Ramp Metering Design Manual
13 vehicles (390 ft) to end of on-ramp (left)
9 vehicles (270 ft) to end of on-ramp (right)
22 vehicles (660 ft) total storage

NB MRN-101 Ramp Metering | Redwood Highway / Seminary | FREQ Origin/on-ramp #3



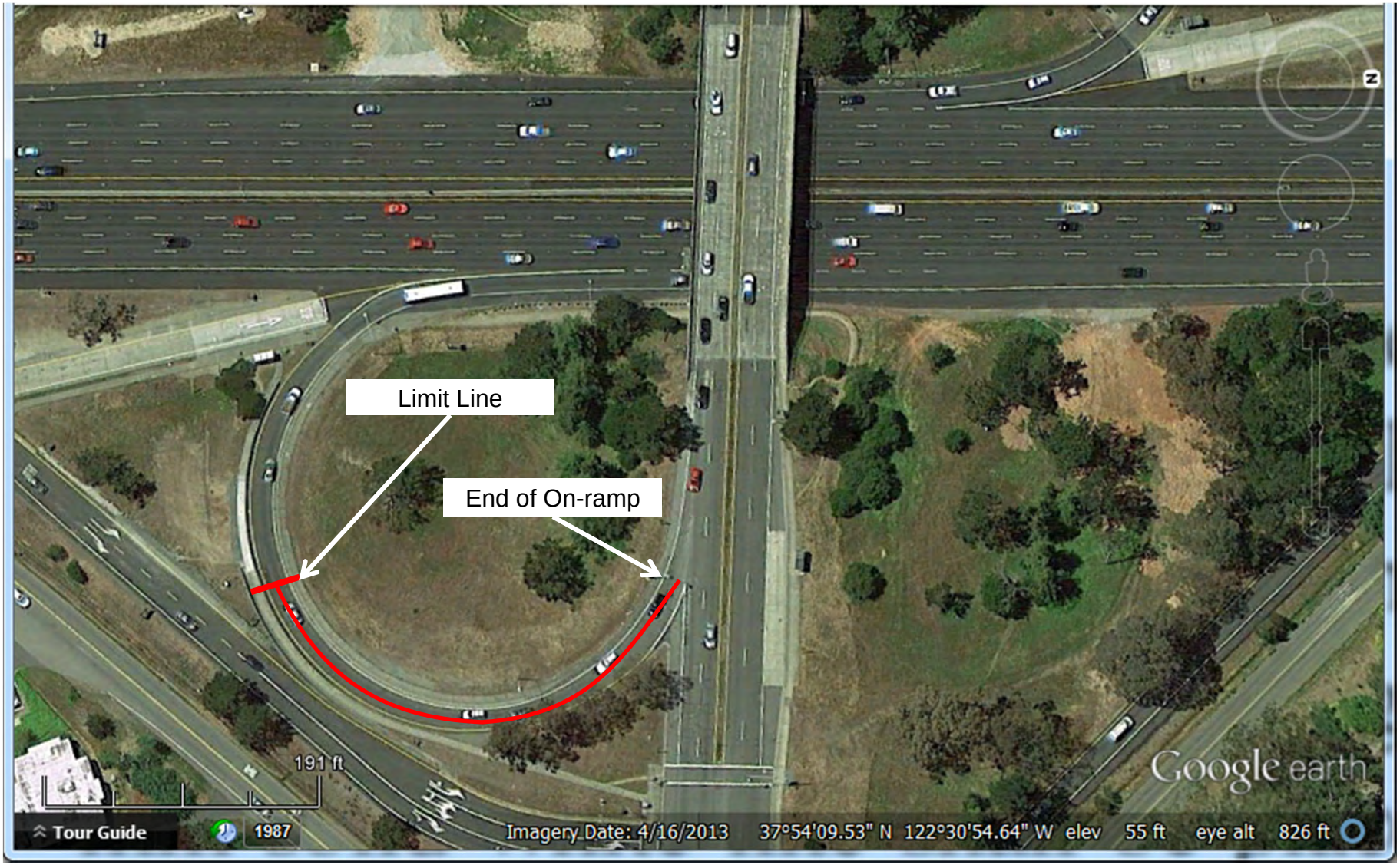
On-ramp storage upstream of limit line

Based on Caltrans Ramp Metering Design Manual
3 vehicles (100 ft) to end of on-ramp

The ramp metering limit line cannot be set up based on Caltrans RMDM.

- A minimum of 23 m u[stream of the 7 m point on the entrance.
- Thus, the limit line is not determined by the Caltrans RMDM

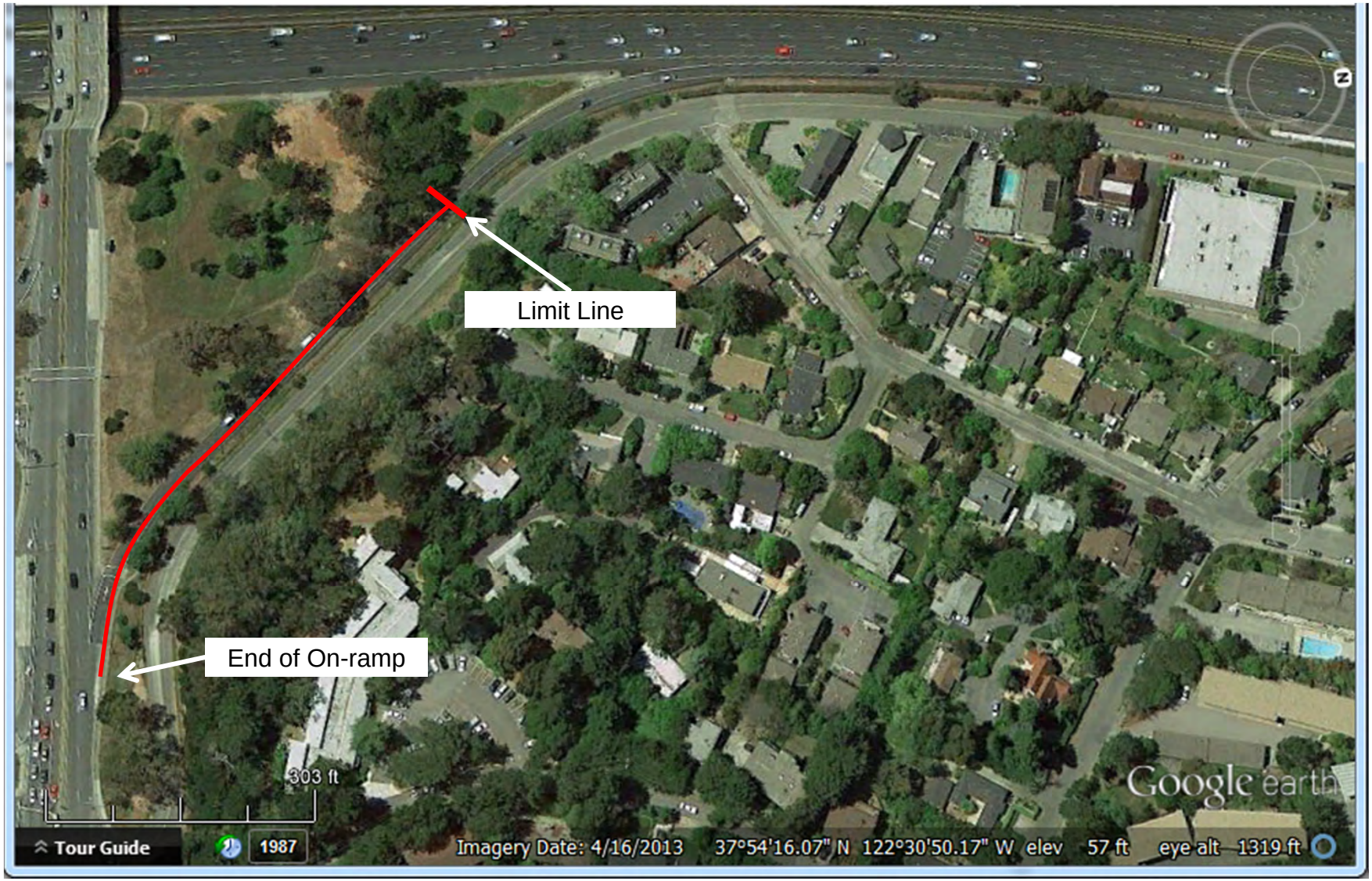
NB MRN-101 Ramp Metering Blithedale Ave / Tiburon Blvd Loop FREQ Origin/on-ramp #4



On-ramp storage upstream of limit line

Based on Ramp Metering Equipment Drawing
11 vehicles (330 ft) to end of on-ramp
22 vehicles (660 ft) total storage (2-lane on-ramp)

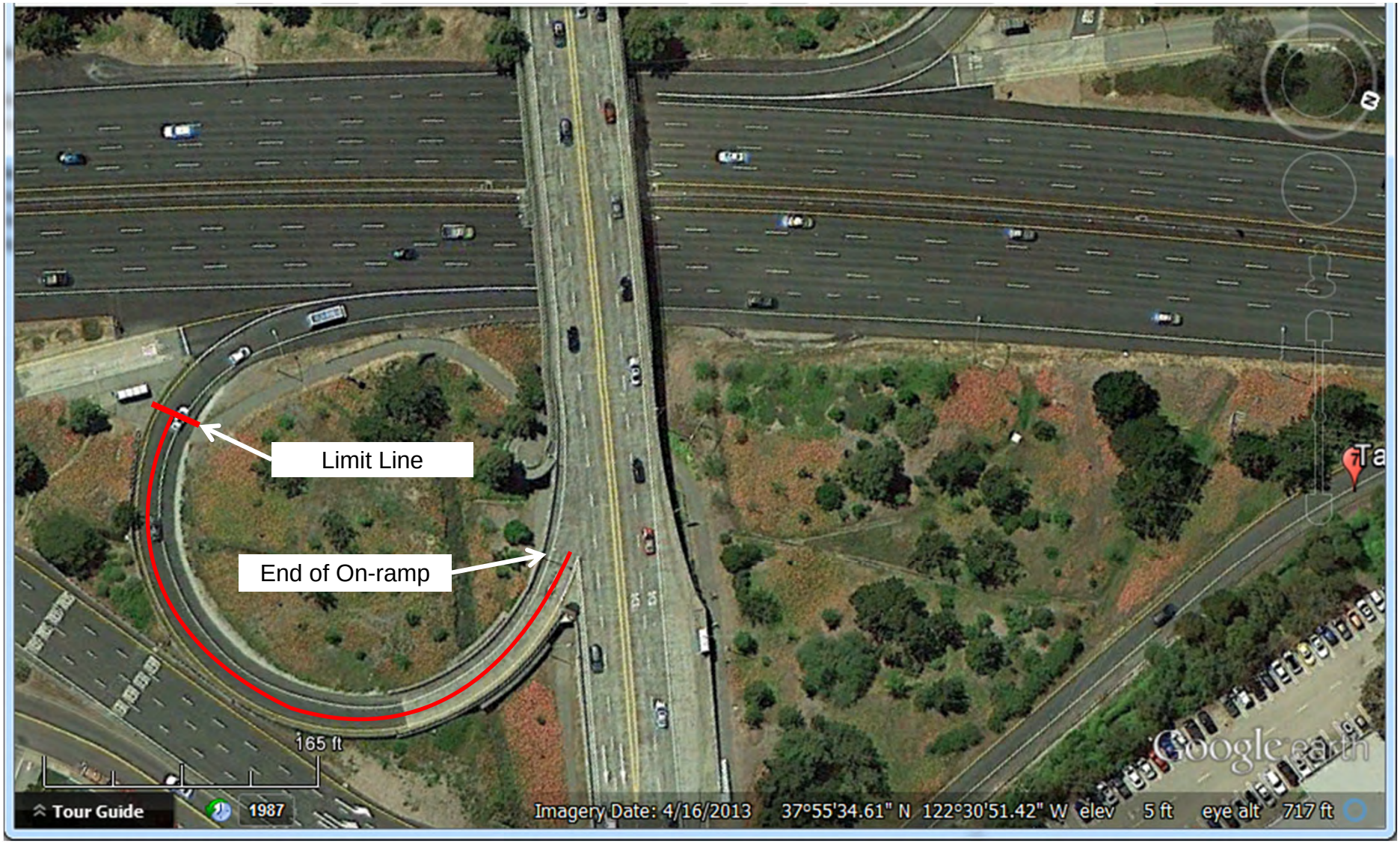
NB MRN-101 Ramp Metering Blithedale Ave / Tiburon Blvd Diagonal FREQ Origin/on-ramp #5



On-ramp storage upstream of limit line

Based on Widening Plan with HOV bypass on-ramp
22 vehicles (660 ft) to end of on-ramp
44 vehicles (1,320 ft) total storage (2-lane on-ramp)

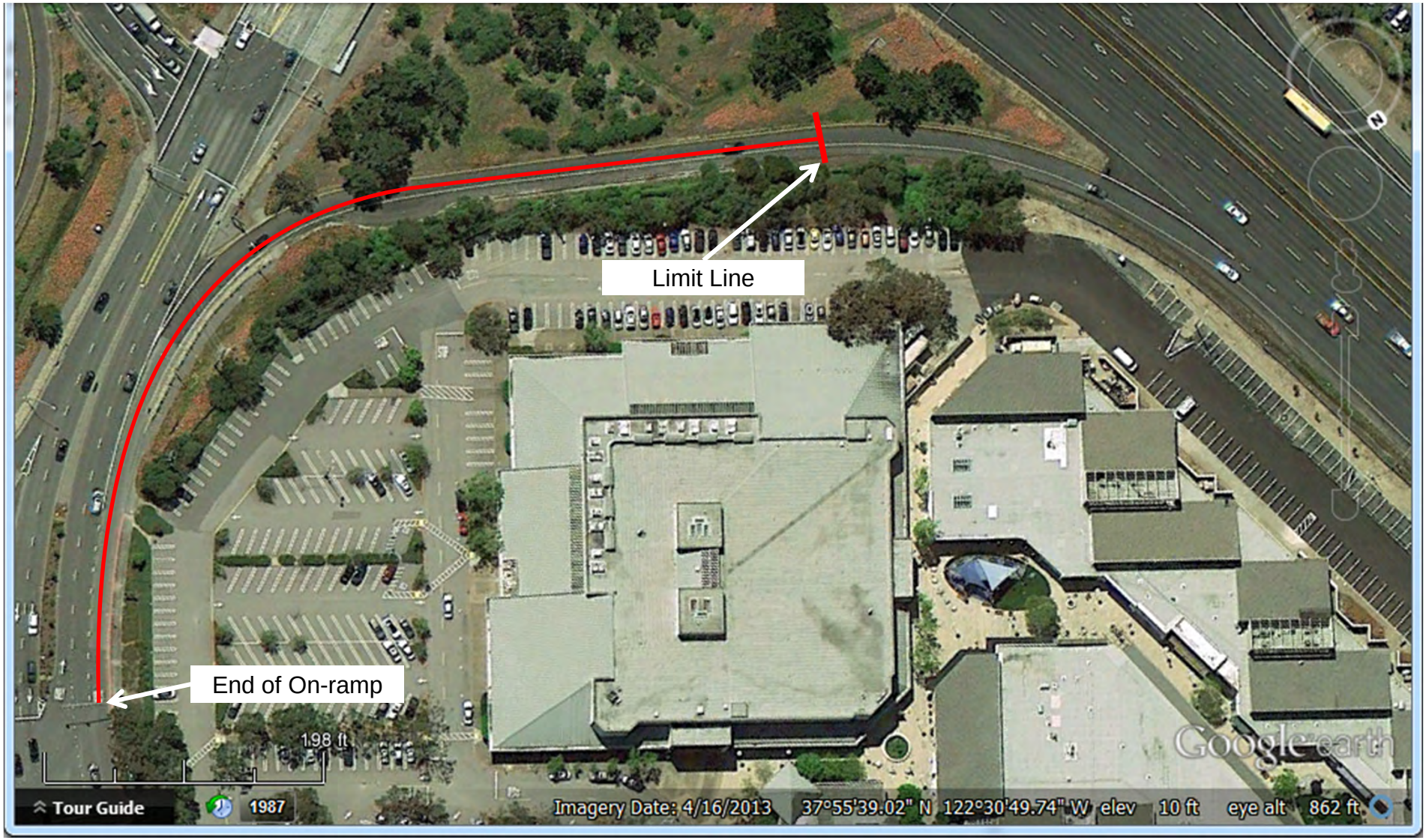
NB MRN-101 Ramp Metering | Tamalpais Dr. Loop | FREQ Origin/on-ramp #6



On-ramp storage upstream of limit line

Based on Caltrans Ramp Metering Design Manual
14 vehicles (440 ft) to end of on-ramp

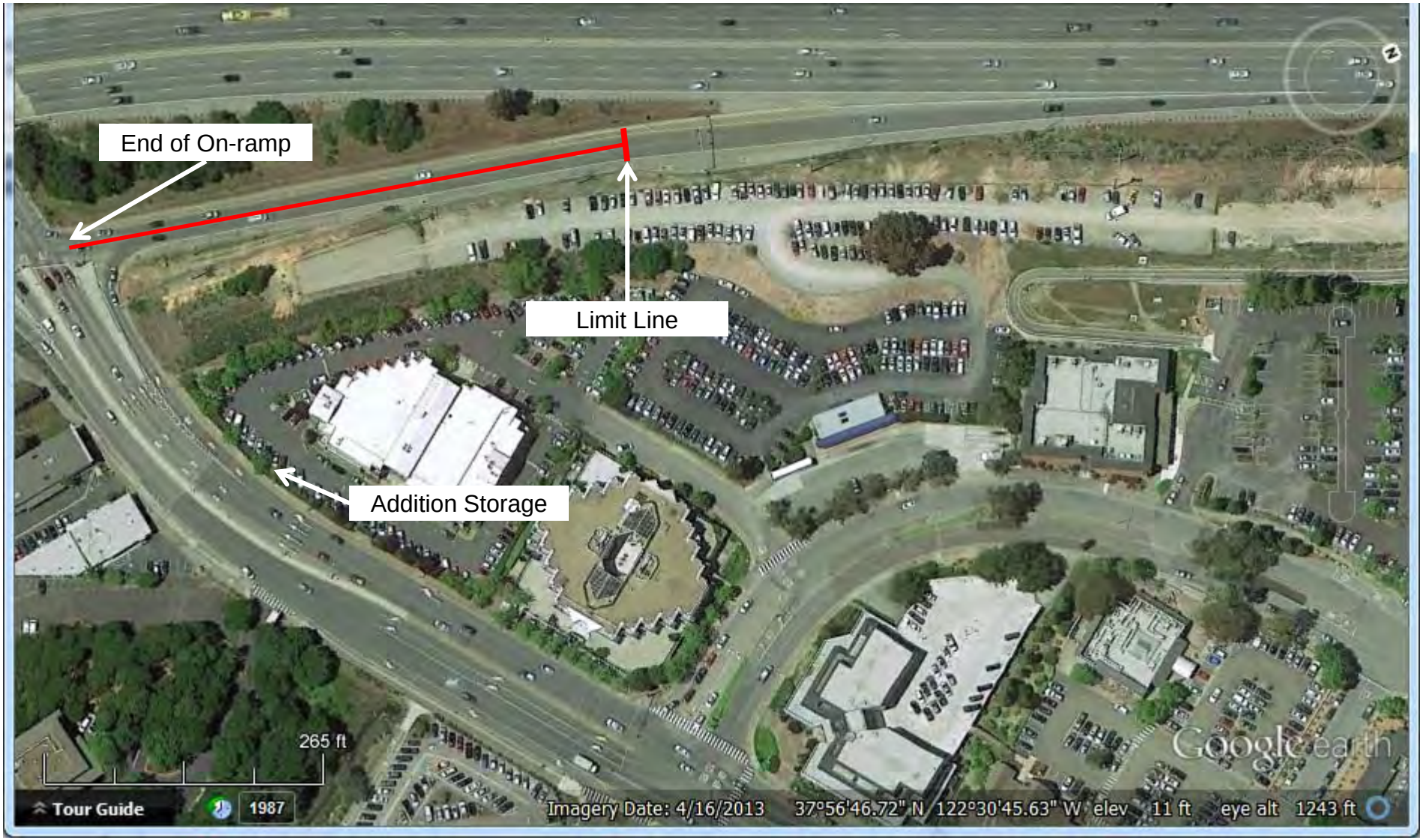
NB MRN-101 Ramp Metering | Tamalpais Dr. Diagonal | FREQ Origin/on-ramp #7



On-ramp storage upstream of limit line

Based on Ramp Metering Equipment Drawing
with HOV bypass on-ramp
25 vehicles (770 ft) to end of on-ramp

NB MRN-101 Ramp Metering Sir Francis Drake Blvd FREQ Origin/on-ramp #8



On-ramp storage upstream of limit line

Based on Detector on the Pavement
38 vehicles (1140 ft) to end of 2-lane on-ramp

Appendix 5 FREQ Output – Without Ramp Metering

US 101 NB - 2013 PM

FREQ SS	LOCATION	Demands (vph)	Sim. Thru-put (vph)	SS Length (ft)	Lanes	Cap	Queue Length (ft)	Time Slice 1 Travel Times (sec)	Delays (sec)	Speed (mph)	Density (vphpl)	V/C	LOS	Cumu TT (mins)	Cumu Delays (mins)
1	Mainline at Marin City Off-Ramp to Bridgeway On-Ramp	5421	5421	1623	4	7880	0	20	3	55	24.6	0.69	C	0.3	0.1
2	Bridgeway On-Ramp to Route 1 Off-Ramp	6659	6659	894	5	8780	0	11	2	55	24.2	0.76	C	0.2	0.0
3	Route 1 Off-Ramp to HOV Lane Start	5749	5749	740	4	7880	0	9	1	55	26.1	0.73	D	0.2	0.0
4	HOV Lane Start to Route 1 On-Ramp	4891	4891	615	4	7880	0	8	2	55	22.2	0.62	C	0.1	0.0
5	Route 1 On-Ramp to Seminary Dr Off-Ramp	5449	5449	3065	4	7829	0	38	6	55	24.8	0.7	C	0.6	0.1
6	Seminary Dr Off-Ramp to Seminary Dr On-Ramp	4866	4206	1165	3	5910	* 80.	14	2	55	25.5	0.71	F	0.2	0.0
7	Seminary Dr On-Ramp to Tiburon Blvd Off-Ramp	5219	4558	3416	4	6375	** 3416.	67	31	35	32.5	0.72	F	1.1	0.5
8	Tiburon Blvd Off-Ramp to Blithedale Avenue Loop On-Ramp	4635	3974	1192	3	5910	** 1192.	39	26	21	61.7	0.67	F	0.7	0.4
9	Blithedale Avenue Loop On-Ramp to Tiburon Blvd Diag On-Ramp	5444	4783	1065	3	5754	** 1065.	27	16	27	59.5	0.83	F	0.5	0.3
10	Tiburon Blvd Diag On-Ramp to Tamalpais Dr Off-Ramp	6486	5825	6667	4	6828	** 6667.	207	137	22	65.3	0.85	F	3.5	2.3
11	Tamalpais Dr Off-Ramp to Tamalpais Dr Loop On-Ramp	5176	4516	894	3	5910	** 894.	44	35	14	109.9	0.76	F	0.7	0.6
12	Tamalpais Dr Loop On-Ramp to Tamalpais Dr Diag On-Ramp	5925	5265	704	3	5910	** 704.	24	17	20	88.2	0.89	F	0.4	0.3
13	Tamalpais Dr Diag On-Ramp to Lane Add	6510	5850	2414	3	5850	0	33	8	50	39	1	E	0.6	0.1
14	Lane Add to Industrial Way Off-Ramp	6510	5850	780	4	7844	0	10	2	55	26.6	0.75	D	0.2	0.0
15	Industrial Way Off-Ramp to Sir Francis Drake Blvd Off-Ramp	6300	5661	1413	4	7525	0	18	3	55	25.7	0.75	C	0.3	0.1
16	Sir Francis Drake Blvd Off-Ramp to Sir Francis Drake Blvd On-Ramp	4239	3809	2975	3	5910	0	37	6	55	23.1	0.64	C	0.6	0.1
17	Sir Francis Drake Blvd On-Ramp to Dummy HOV End	5795	5365	2183	4	6840	0	27	4	55	24.4	0.78	C	0.5	0.1
18	Dummy HOV End to Mainline at Bellam Blvd/I-580	6525	6095	2184	4	8810	0	27	4	55	27.7	0.69	D	0.5	0.1
												Travel Time (min)		11.0	

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FREQ SS	LOCATION	Demands (vph)	Sim. Thru-put (vph)	SS Length (ft)	Lanes	Queue Length (ft)	Travel Times (sec)	Delays (sec)	Speed (mph)	Density (vphpl)	V/C	LOS	Cumu TT (mins)	Cumu Delays (mins)
		Time Slice 2												
1	Mainline at Marin City Off-Ramp to Bridgeway On-Ramp	5637	5637	1623	4	0	20	3	55	25.6	0.72	C	0.3	0.1
2	Bridgeway On-Ramp to Route 1 Off-Ramp	6913	6913	894	5	0	11	2	55	25.1	0.79	C	0.2	0.0
3	Route 1 Off-Ramp to HOV Lane Start	5819	5376	740	4	** 740.	12	4	42	31.7	0.68	F	0.2	0.1
4	HOV Lane Start to Route 1 On-Ramp	4976	4533	615	4	** 615.	17	11	24	47.2	0.58	F	0.3	0.2
5	Route 1 On-Ramp to Seminary Dr Off-Ramp	5574	5132	3065	4	** 3065.	139	107	15	87.7	0.66	F	2.3	1.8
6	Seminary Dr Off-Ramp to Seminary Dr On-Ramp	4882	4440	1165	3	** 1165.	61	49	13	113.2	0.75	F	1.0	0.8
7	Seminary Dr On-Ramp to Tiburon Blvd Off-Ramp	5251	4808	3416	4	** 3416.	179	143	13	95.7	0.75	F	3.0	2.4
8	Tiburon Blvd Off-Ramp to Blithedale Avenue Loop On-Ramp	4589	4146	1192	3	** 1192.	74	61	11	129.7	0.7	F	1.2	1.0
9	Blithedale Avenue Loop On-Ramp to Tiburon Blvd Diag On-Ramp	5314	4872	1065	3	** 1065.	43	32	17	97	0.84	F	0.7	0.5
10	Tiburon Blvd Diag On-Ramp to Tamalpais Dr Off-Ramp	6378	5935	6667	4	** 6667.	253	183	18	80.4	0.87	F	4.2	3.1
11	Tamalpais Dr Off-Ramp to Tamalpais Dr Loop On-Ramp	4877	4434	894	3	** 894.	51	42	12	119.3	0.75	F	0.9	0.7
12	Tamalpais Dr Loop On-Ramp to Tamalpais Dr Diag On-Ramp	5585	5142	704	3	** 704.	27	20	18	93.6	0.87	F	0.5	0.3
13	Tamalpais Dr Diag On-Ramp to Lane Add	6293	5850	2414	3	0	33	8	50	39	1	E	0.6	0.1
14	Lane Add to Industrial Way Off-Ramp	6293	5850	780	4	0	10	2	55	26.6	0.75	D	0.2	0.0
15	Industrial Way Off-Ramp to Sir Francis Drake Blvd Off-Ramp	6100	5671	1413	4	0	18	3	55	25.8	0.76	C	0.3	0.1
16	Sir Francis Drake Blvd Off-Ramp to Sir Francis Drake Blvd On-Ramp	3885	3612	2975	3	0	37	6	55	21.9	0.61	C	0.6	0.1
17	Sir Francis Drake Blvd On-Ramp to Dummy HOV End	5514	5241	2183	4	0	27	4	55	23.8	0.77	C	0.5	0.1
18	Dummy HOV End to Mainline at Bellam Blvd/I-580	6164	5891	2184	4	0	27	4	55	26.8	0.67	D	0.5	0.1
											Travel Time (min)		17.3	

Appendix 6 FREQ Output – With Ramp Metering

US 101 NB - 2013 PM

FREQ SS	LOCATION	Demands (vph)	Sim. Thru-put (vph)	SS Length (ft)	Lanes	Cap	Queue Length (ft)	Time Slice 1 Travel Times (sec)	Delays (sec)	Speed (mph)	Density (vphpl)	V/C	LOS	Cumu TT (mins)	Cumu Delays (mins)
1	Mainline at Marin City Off-Ramp to Bridgeway On-Ramp	5422	5422	1623	4	7880	0	20	3	55	24.6	0.69	C	0.3	0.1
2	Bridgeway On-Ramp to Route 1 Off-Ramp	6660	6614	894	5	8780	0	11	2	55	24.1	0.75	C	0.2	0.0
3	Route 1 Off-Ramp to HOV Lane Start	5750	5710	740	4	7880	0	9	1	55	26	0.72	C	0.2	0.0
4	HOV Lane Start to Route 1 On-Ramp	4891	4855	615	4	7880	0	8	2	55	22.1	0.62	C	0.1	0.0
5	Route 1 On-Ramp to Seminary Dr Off-Ramp	5449	5391	3065	4	7829	0	38	6	55	24.5	0.69	C	0.6	0.1
6	Seminary Dr Off-Ramp to Seminary Dr On-Ramp	4866	4813	1165	3	5910	0	14	2	55	29.2	0.81	D	0.2	0.0
7	Seminary Dr On-Ramp to Tiburon Blvd Off-Ramp	5218	5162	3416	4	6375	0	42	6	55	23.5	0.81	C	0.7	0.1
8	Tiburon Blvd Off-Ramp to Blithedale Avenue Loop On-Ramp	4634	4205	1192	3	5910	* 521.	16	3	52	27.1	0.71	F	0.3	0.1
9	Blithedale Avenue Loop On-Ramp to Tiburon Blvd Diag On-Ramp	5443	4992	1065	3	5754	** 1065.	17	6	43	38.4	0.87	F	0.3	0.1
10	Tiburon Blvd Diag On-Ramp to Tamalpais Dr Off-Ramp	6484	5989	6667	4	6828	** 6667.	162	92	28	53.1	0.88	F	2.7	1.5
11	Tamalpais Dr Off-Ramp to Tamalpais Dr Loop On-Ramp	5175	4705	894	3	5910	** 894.	38	29	16	100.8	0.8	F	0.6	0.5
12	Tamalpais Dr Loop On-Ramp to Tamalpais Dr Diag On-Ramp	5924	5440	704	3	5910	** 704.	22	15	22	81.5	0.92	F	0.4	0.3
13	Tamalpais Dr Diag On-Ramp to Lane Add	6509	6000	2414	3	6000	0	33	8	50	40	1	E	0.6	0.1
14	Lane Add to Industrial Way Off-Ramp	6509	6000	780	4	7844	0	10	2	55	27.3	0.76	D	0.2	0.0
15	Industrial Way Off-Ramp to Sir Francis Drake Blvd Off-Ramp	6298	5806	1413	4	7525	0	18	3	55	26.4	0.77	D	0.3	0.1
16	Sir Francis Drake Blvd Off-Ramp to Sir Francis Drake Blvd On-Ramp	4238	3907	2975	3	5910	0	37	6	55	23.7	0.66	C	0.6	0.1
17	Sir Francis Drake Blvd On-Ramp to Dummy HOV End	5794	5463	2183	4	6840	0	27	4	55	24.8	0.8	C	0.5	0.1
18	Dummy HOV End to Mainline at Bellam Blvd/I-580	6524	6193	2184	4	8810	0	27	4	55	28.1	0.7	D	0.5	0.1
												Travel Time (min)		9.2	

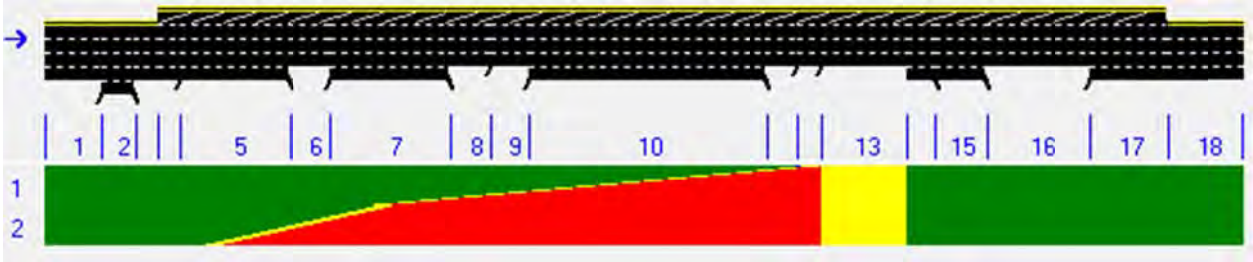
US 101 NB - 2013 PM

FREQ SS	LOCATION	Time Slice 2 Demands (vph)	Sim. Thru-put (vph)	SS Length (ft)	Lanes	Queue Length (ft)	Travel Times (sec)	Delays (sec)	Speed (mph)	Density (vphpl)	V/C	LOS	Cumu TT (mins)	Cumu Delays (mins)
1	Mainline at Marin City Off-Ramp to Bridgeway On-Ramp	5637	5637	1623	4	0	20	3	55	25.6	0.72	C	0.3	0.1
2	Bridgeway On-Ramp to Route 1 Off-Ramp	6913	6913	894	5	0	11	2	55	25.1	0.79	C	0.2	0.0
3	Route 1 Off-Ramp to HOV Lane Start	5819	5820	740	4	0	9	1	55	26.5	0.74	D	0.2	0.0
4	HOV Lane Start to Route 1 On-Ramp	4976	4977	615	4	0	8	2	55	22.6	0.63	C	0.1	0.0
5	Route 1 On-Ramp to Seminary Dr Off-Ramp	5575	5277	3065	4	* 368.	39	7	54	24.6	0.67	F	0.7	0.1
6	Seminary Dr Off-Ramp to Seminary Dr On-Ramp	4883	4586	1165	3	** 1165.	23	11	35	43.8	0.78	F	0.4	0.2
7	Seminary Dr On-Ramp to Tiburon Blvd Off-Ramp	5252	4955	3416	4	** 3416.	116	80	20	61.9	0.78	F	1.9	1.3
8	Tiburon Blvd Off-Ramp to Blithedale Avenue Loop On-Ramp	4590	4294	1192	3	** 1192.	68	55	12	120.7	0.73	F	1.1	0.9
9	Blithedale Avenue Loop On-Ramp to Tiburon Blvd Diag On-Ramp	5316	5020	1065	3	** 1065.	40	29	18	91.7	0.87	F	0.7	0.5
10	Tiburon Blvd Diag On-Ramp to Tamalpais Dr Off-Ramp	6379	6083	6667	4	** 6667.	227	157	20	76.4	0.89	F	3.8	2.6
11	Tamalpais Dr Off-Ramp to Tamalpais Dr Loop On-Ramp	4877	4584	894	3	** 894.	47	38	13	113.8	0.78	F	0.8	0.6
12	Tamalpais Dr Loop On-Ramp to Tamalpais Dr Diag On-Ramp	5585	5292	704	3	** 704.	24	17	20	88.1	0.9	F	0.4	0.3
13	Tamalpais Dr Diag On-Ramp to Lane Add	6293	6000	2414	3	0	33	8	50	40	1	E	0.6	0.1
14	Lane Add to Industrial Way Off-Ramp	6293	6000	780	4	0	10	2	55	27.3	0.76	D	0.2	0.0
15	Industrial Way Off-Ramp to Sir Francis Drake Blvd Off-Ramp	6100	5816	1413	4	0	18	3	55	26.4	0.77	D	0.3	0.1
16	Sir Francis Drake Blvd Off-Ramp to Sir Francis Drake Blvd On-Ramp	3886	3709	2975	3	0	37	6	55	22.5	0.63	C	0.6	0.1
17	Sir Francis Drake Blvd On-Ramp to Dummy HOV End	5515	5338	2183	4	0	27	4	55	24.3	0.78	C	0.5	0.1
18	Dummy HOV End to Mainline at Bellam Blvd/I-580	6165	5988	2184	4	0	27	4	55	27.2	0.68	D	0.5	0.1
											Travel Time (min)		13.1	

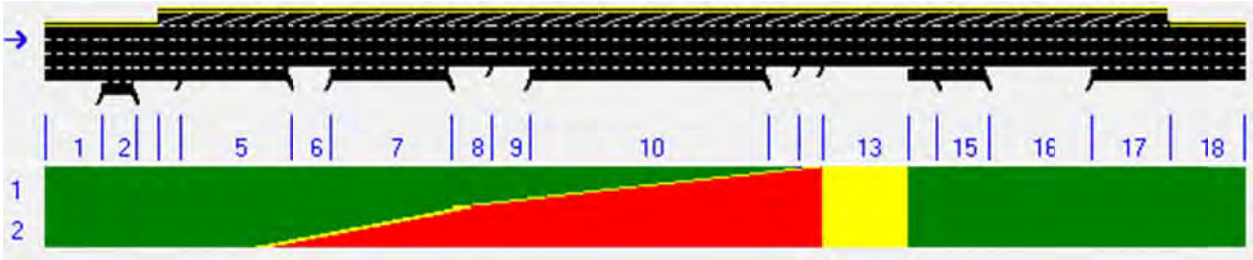
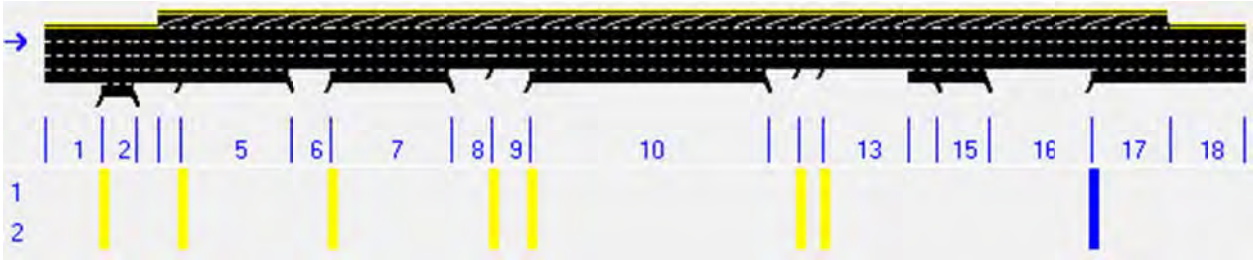
Appendix 7 FREQ Diagrams

APPENDIX G: FREQ DIAGRAMS

Appendix Figure 1: FREQ Operations Contour - Without Ramp Metering



Appendix Figure 2: FREQ Operations Contour - With Ramp Metering



Appendix Figure 3: FREQ Ramp Metering Queuing Diagram – With Ramp Metering