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Memorandum

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CC	Wendy Goodfriend (BCDC), Dick Fahey (Caltrans), Norman Wong (BART), Clair Bonham-Carter (AECOM)		
Subject	Oakland Coliseum – Damon Slough/Arroyo Viejo Creek		
From	Michael Mak, PE; Kris May, PhD PE; and Vince Geronimo, PE		
Date	July 29, 2014		

1. INTRODUCTION

The Oakland Coliseum area was selected as a focus area for more detailed exposure analysis and adaptation strategy development as part of the current Metropolitan Transportation Commission (MTC) Climate Adaptation Pilot Study. Under the precursor MTC Vulnerability and Risk Assessment Project[1], this area was vulnerable to inundation by sea level rise and coastal storm surge that could impact core transportation assets that support the region: Interstate-880 (I-880), the Coliseum Amtrak Station, the Coliseum/Oakland Airport BART Station, and the new Oakland Airport BART Connector Station. The current Pilot Study includes a more detailed analysis of potential inundation by sea level rise and storm surge, and the parking lots adjacent to the Oakland Coliseum are inundated with 36 inches of sea level rise[2] (or a storm surge scenario that results in a similar level of inundation), and nearly the entire focus area is inundated with 48 inches of sea level rise. However, these results do not consider the additional impact of riverine-induced flooding due to precipitation events. As shown in Figure 1, Damon Slough and its tributaries, Arroyo Viejo Creek and Lion Creek, are located directly adjacent to the core transportation assets. The purpose of this technical memorandum is to explore the potential inundation that could occur due to the combination of sea level rise and riverine flooding, and to identify when and where adaptation strategies may be needed to protect both the core transportation assets, as well as other adjacent assets identified by the project management team (PMT).

This technical memorandum should be considered in tandem with other ongoing work by the San Francisco Bay Conservation and Development Commission (BCDC) and Alameda County Flood Control and Water Conservation District (ACFCWCD) to better understand sea level rise, storm surge, and

[1] Adapting to Rising Tides: Transportation Vulnerability and Risk Assessment Pilot Project, November 2011.

[2] The sea level rise scenario when overtopping first occurs in the focus area has been approximated based on the mapped sea level rise inundation scenarios (e.g., 12”, 24”, 36”, 48”) for the current Pilot Study. The actual sea level rise scenario which results in overtopping of shoreline features may be less than this amount (i.e., if the SLR scenario of first overtopping is 36 inches, overtopping is first observed in this mapped scenario, but overtopping may occur as early as 25 inches). Refined shoreline tools have been developed for this area that can estimate the overtopping threshold within 6 inch increments, and these tools can be used for future updates to this assessment.

shoreline vulnerabilities in Alameda County. The following sections provide a description of the Oakland Coliseum focus area, an overview of the analysis approach, and a discussion of the results.

2. FOCUS AREA DESCRIPTION

The Oakland Coliseum focus area is located inland of the Martin Luther King, Jr. Regional Shoreline of San Leandro Bay in Alameda County, California (see Figure 1). The shoreline is characterized by intermittent salt marshes and mudflats, rip-rap, and vegetated banks. Damon Slough drains directly into San Leandro Bay, and is fed by its upstream tributaries Arroyo Viejo Creek and Lion Creek. The tributaries drain portions of the vast Oakland hills through a complex storm drain system comprised of engineered channels and hydraulic conveyance structures. Arroyo Viejo Creek daylights just upstream of the Amtrak rail crossing and Lion Creek daylights north of Lucille Street near Greenman Field. Damon Slough, Arroyo Viejo Creek, and Lion Creek are all channelized and surrounded with highly urbanized and paved areas. Figure 2 shows a delineation map of the surrounding watersheds and the contributing watersheds to the focus area.

During rainfall-driven storm events, the channels convey stormwater and urban runoff from the contributing watersheds to San Leandro Bay. The flows in Damon Slough must pass through a series of channel constrictions associated with the Oakport Street, I-880, Coliseum Industrial, and Coliseum Way overpasses. Each channel constriction can result in backed-up flows and overbank flooding if flows are high enough. Under existing conditions (i.e., in the absence of sea level rise), flooding occurs at discrete areas along Damon Slough during a 100-year rainfall event coupled with a 10-year storm surge event (e.g., a downstream Bay water level consistent with moderate El Niño conditions). As sea levels rise, smaller rainfall events combined with lower downstream Bay water levels may result in similar and/or more severe flooding and inundation.

The primary core assets and key vulnerabilities defined for this focus area include:

- I-880/Damon Slough Bridge
    - Potential scour at abutments from increasing wind, wave, or tidal energy
    - Potential increase in channel erosion
    - Overtopping of roadway
- Oakland Coliseum Complex
    - Vulnerable infrastructure at existing ground elevations
    - Disruptions in service during periods of flooding
- Oakland Coliseum Amtrak Station
    - Vulnerable utilities below existing ground elevations
    - Disruptions in Amtrak service if service corridor (rail track) is exposed to flooding
    - No alternative rail transit if service is disrupted
- Oakland Coliseum BART Station
    - Elevated transit facility, but no alternative station if service is disrupted
    - Vulnerable access points at and below existing ground elevations
    - Vulnerable facilities at existing ground elevations
    - Disruption in alternative AC Transit service from localized flooding of roadways
- Oakland Airport Connector
    - Elevated transit facility, but no alternative station if service is disrupted
    - Vulnerable power stations and utilities located at existing ground elevations
    - Disruption of access if Coliseum or surrounding access points are flooded

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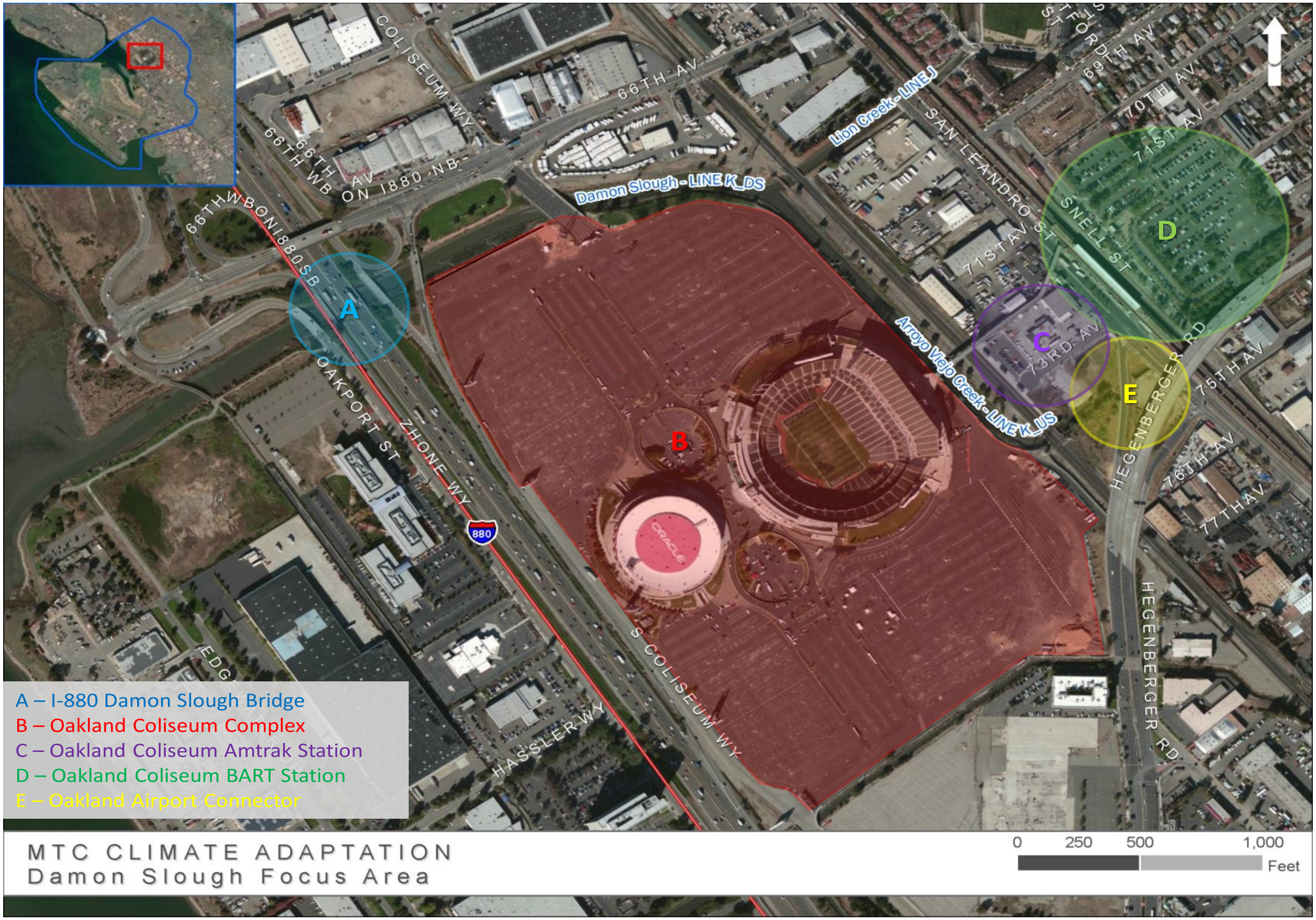

Figure 1 – Overview of Oakland Coliseum Focus Area

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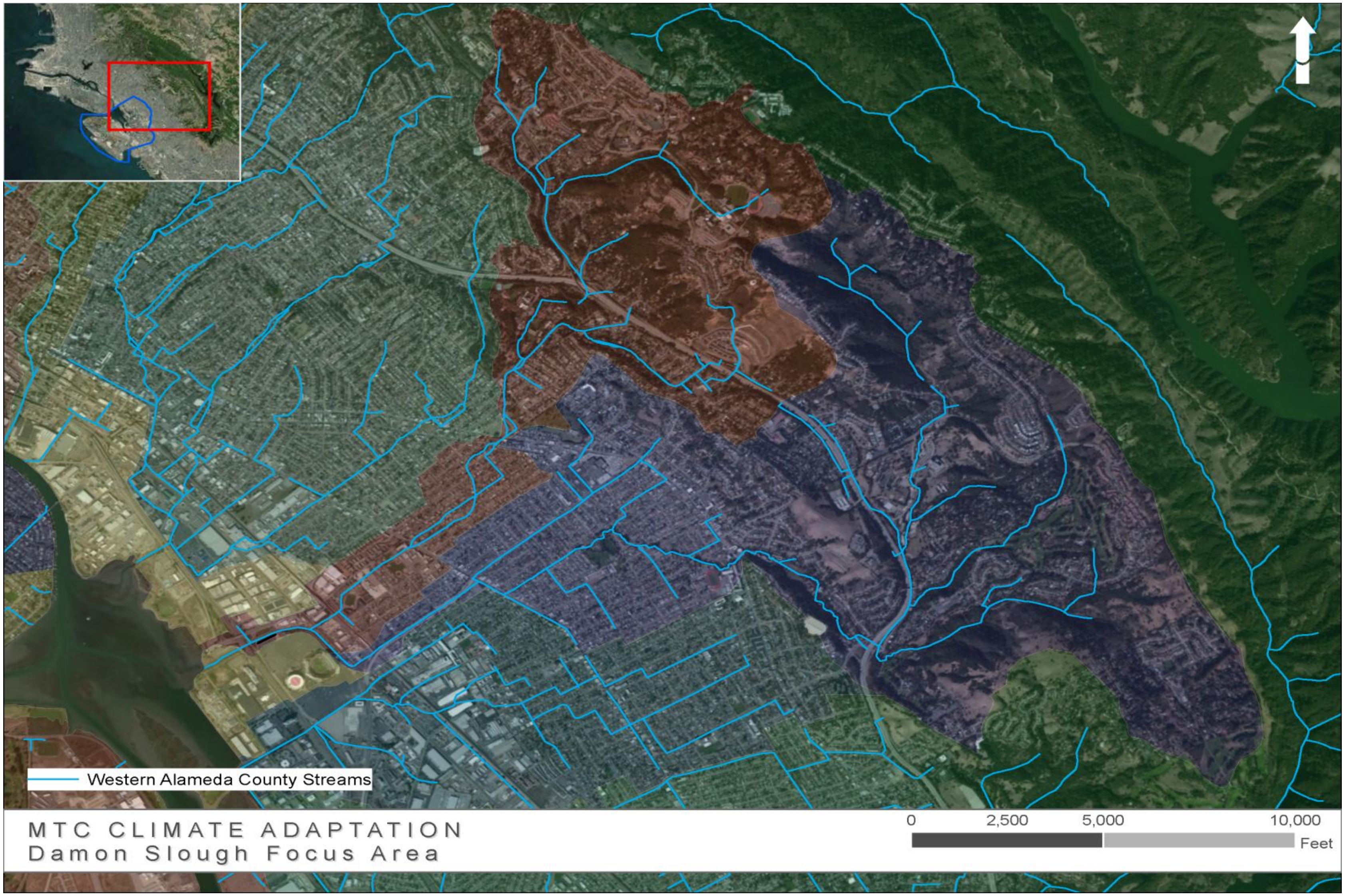

Figure 2 – Watershed Map for Oakland Coliseum Focus Area[3]

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[3] Source: Sowers, J.M., Richard, C., Dulberg, R. and Holmberg, J.F., 2010, Creek & watershed map of the Western Alameda County: a digital database, version 1.0: Fugro William Lettis and Associates, Inc., Walnut Creek, CA, 1:24,000 scale.

3. ANALYSIS APPROACH

Assessing the combined impact of riverine flooding, sea level rise, and coastal storm surge scenarios requires the use of a numerical model that has been developed and calibrated for the specific system of interest. AECOM leveraged an existing steady-state HEC-RAS hydraulic and hydrologic model of Damon Slough, Arroyo Viejo Creek, and Lion Creek from ACFCWCD. The HEC-RAS model was used to evaluate various combinations of downstream Bay water levels, sea level rise, and peak flow events in the slough and creek channels to help understand the key thresholds that can result in overbank flow and inundation within the Oakland Coliseum focus area.

The following sections describe the leveraged HEC-RAS model, the modeled scenarios, and the boundary conditions applied within the model.

3.1. Steady State HEC-RAS Model

An existing steady-state HEC-RAS model of Damon Slough and its tributaries can be used to calculate extreme event water levels along the modeled reaches of the slough and creeks by adjusting the downstream tidal boundary and/or the upstream peak discharge boundary. The HEC-RAS model leveraged for this analysis was initially developed by the ACFCWCD in 2003, and subsequently modified by Philip Williams and Associates (PWA) in 2005, to include additional surveyed cross section data and other model refinements. The steady-state model does not consider the timing of peak flows in the channels generated from different watershed characteristics. Peak flows occurring in the channels at different times can lead to lower flood levels.

Although the HEC-RAS model provides adequate hydraulic and hydrologic data (e.g., channel cross section data, discharge boundary information, overbank mannings n values) for a high-level assessment of potential flooding, it should be noted that this model has not been updated since 2005 to account for channel modifications or changes in land use that may have occurred after 2005.

It should be noted that several existing bridge and culvert structures are not included in the HEC-RAS model, most notably, the Coliseum Way, Oakport Street and I-880 overpasses. This could result in an under-estimation of the potential for flooding in these reaches. In addition, a recent channel diversion at Lion Creek that was designed to attenuate peak flows through a restored area upstream of the confluence with Arroyo Viejo Creek is not included in the HEC-RAS model. This absence of this modification in the model could result in an overestimation of potential flooding in this reach.

AECOM leveraged the model as is and made minor modifications to support the analysis[4], but significant effort was not invested to add additional cross sections or to account for any potential updates needed to more accurately represent the current system. ACFCWCD is currently in the process of updating their hydrologic and hydraulic models in this area (Oakland, ACFCWCD Zone 12), and updated models are expected to be available within a two-year timeframe.

3.2. Scenarios

In the discussion that follows, flooding occurs from two distinct processes. The first is riverine flooding –extreme rainfall runoff driven peak flow events in the stream network during periods of average high tide conditions in the Bay. The second is combined riverine and storm surge flooding –smaller peak flows in the stream network that coincide with periods of episodic, short duration, extreme tide events of greater magnitude than normal tide levels. Inland areas may be temporarily flooded during a

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[4] The leveraged HEC-RAS model was not geo-referenced to an existing horizontal datum. AECOM manipulated the existing model so that the model output could be geo-referenced for inundation mapping purposes.

riverine flood or combined riverine and storm surge event while maintaining at least a portion of their functionality once the floodwaters recede. However, sensitive assets may suffer irreversible damage if exposed to any amount of water, even temporarily. Assets may only be exposed to freshwater from riverine flooding, but can be exposed to saline water during flooding from riverine and storm surge events. The term flooding, as it is used throughout this memorandum, is a temporary inundation condition that results from a storm event rather than the permanent inundation due to daily high tides. Permanent inundation can come with regular tidal inundation, which was not examined in this analysis.

The HEC-RAS model was used to evaluate various combinations of downstream Bay water levels (i.e., MHHW, 10-year storm surge, and 100-year storm surge), sea level rise (i.e., 12 inches and 24 inches), and peak flow events in the slough and creek channels (i.e., 10-year flow and 100-year flow). Although numerous potential combinations of Bay water levels, sea level rise, and peak flow events can be used to evaluate the system, the selected combination of events were designed to help understand the key thresholds that can result in overbank flow and inundation within the Oakland Coliseum focus area.

Average daily tide conditions can be represented by applying the MHHW level at the downstream boundary. The 10-year storm surge elevation is comparable to a typical El Niño winter condition, and the 100-year storm surge elevation is the coastal flood hazard level used by FEMA for developing Flood Insurance Rate Maps for coastal communities. In the absence of riverine flooding, the critical threshold for inundation occurs with 36 inches of sea level rise. However, when riverine flooding is also considered, the threshold is likely lower; therefore two lower sea level rise scenarios were evaluated in combination with the riverine flooding: 12 and 24 inches.

The 10- and 100-year peak flow rates for the Damon Slough, Arroyo Viejo, and Lion Creek reaches are paired with the various downstream tidal boundary conditions. The 10-year peak flow rate can be associated with a precipitation event that occurs during an El Niño winter, and similarly with the coastal storm surge elevations, the 100-year peak flow rate is typically used by FEMA for calculating base flood elevations as shown on the FIRMs for communities adjacent to rivers and creeks.

A summary of the simulations evaluated using the HEC-RAS model is presented in Table 1. The 100-year coastal storm surge elevation was not evaluated in combination with the 100-year riverine peak flow event. This combination would represent an event with a recurrence interval much greater than a 100-year event. The goal of this analysis was to determine the thresholds when inundation begins, and not necessarily to evaluate extreme inundation scenarios.

Table 1: Selected Analysis Scenarios

Tide Condition	Peak Flow	Description
MHHW	**10-year**	10-year peak flow rate during higher high tide conditions.
+ 12" SLR	10-year	10-year peak flow rate during higher high tide conditions with 12" SLR.
+ 24" SLR	10-year	10-year peak flow rate during higher high tide conditions with 24" SLR.
MHHW	**100-year**	100-year peak flow rate during higher high tide conditions. 100-year peak discharge typical for FEMA studies.
+ 12" SLR	100-year	100-year peak flow rate during higher high tide conditions with 12" SLR.
+ 24" SLR	100-year	100-year peak flow rate during higher high tide conditions with 24" SLR.
10-year	**10-year**	10-year peak flow rate during 10-year storm surge levels. Similar to typical event experienced during El Niño winter.
+ 12" SLR	10-year	10-year peak flow rate during 10-year storm surge conditions with 12" SLR.
+ 24" SLR	10-year	10-year peak flow rate during 10-year storm surge conditions with 24" SLR.
10-year	**100-year**	100-year peak flow rate during 10-year storm surge conditions.
+ 12" SLR	100-**year**	100-year peak flow rate during 10-year storm surge conditions with 12" SLR.
+ 24" SLR	100-**year**	100-year peak flow rate during 10-year storm surge conditions with 24" SLR.
100-year	**10-year**	10-yr peak flow rate during 100-year storm surge conditions. 100-year storm surge typical for FEMA studies.
+ 12" SLR	10-**year**	10-year peak flow rate during 100-year storm surge conditions with 12" SLR.
+ 24" SLR	10-**year**	10-year peak flow rate during 100-year storm surge conditions with 24" SLR.

3.3. Boundary Conditions

3.3.1. Upstream Riverine Boundary

The upstream boundary conditions listed within the documentation supplied with the existing HEC-RAS model for Arroyo Viejo Creek and Lion Creek were used this analysis. These peak flow rates were used by PWA in previous modeling efforts, and were taken from the FEMA Flood Insurance Study (FIS) for the City of Oakland (FEMA 1982). On the FEMA Flood Insurance Rate Map (FIRM) for Alameda County, Damon Slough is referred to as Line K_DS, Arroyo Viejo Creek is referred to as Line K_US, and Lion Creek is referred to as Line J (FEMA 2009). Table 2 presents the peak flow rates used for the upstream reach boundary conditions in this study.

Table 2: Reach Boundary Conditions – Peak Flow Rates (10-Year and 100-year)

Reach	FEMA FIS Reach	Peak Flow	
		10-Year	100-Year
Damon Slough	Line K_DS	2,600 cfs	4,000 cfs
Arroyo Viejo Creek	Line K_US	1,600 cfs	2,800 cfs
Lion Creek	Line J	1,200 cfs	1,900 cfs

3.3.2. Downstream Tidal Boundary

The downstream tidal boundary conditions used in this study include MHHW and the10-year and 100-year storm surge (a.k.a. extreme tide) elevations. These elevations were derived from MIKE21 model output from a regional San Francisco Bay modeling study completed as part of the FEMA San Francisco Bay Area Coastal Study [5](DHI 2011). The modeling study spanned a 31-year hindcast period from January 1, 1973 to December 31, 2003 (31 years). The water level data was extracted at a location near San Leandro Bay, and the entire 31-year simulation period was analyzed to determine the 10-year and 100-year storm surge elevations using statistical analysis. The MHHW tidal datum was calculated using the portion of the model output time series corresponding to the most recent National Tidal Datum Epoch (1983 through 2001), which is a specific 19-year period adopted by the National Oceanic and Atmospheric Administration (NOAA) to compute tidal datums. Table 3 presents the daily and extreme tide levels used for Damon Slough tidal boundary conditions.

Table 3: Tidal Boundary Conditions

Reach	FEMA FIS Reach	Elevation (FT-NAVD88)		
		MHHW	10-Year	100-Year
Damon Slough	Line K_DS	6.61	8.84	10.01

[5] www.r9coastal.org

4. FLOOD EXTENT MAPPING

The inundation mapping for this focus area relied on two primary data sources:

- 2-meter digital elevation model (DEM) developed from the 2010 Light Detection and Ranging (LiDAR) data collected by the USGS and NOAA as part of the California Coastal Mapping Program (CCMP)
- HEC-RAS model output water surface elevations at each channel cross section

After spatially adjusting the existing HEC-RAS model to the correct horizontal datum, the flood extent mapping for the Oakland Coliseum focus area was completed using AECOM's proprietary Hydraulic Analyst toolbox for Esri's ArcMap software. The Hydraulic Analyst tool was created for mapping water surface elevations for riverine studies, including the creation of FEMA FIRMs. The Hydraulic Analyst toolbox assists the user in mapping backwater conditions, employing a modified bathtub approach similar to the NOAA Coastal Services Center approach for mapping sea level rise inundation. In this study, potential low-lying disconnected areas were not removed in order to be conservative, as these areas may be flooded if a hydraulic connection (i.e., culverts, storm drains, or other hydraulic features) exists between the low-lying area and the flooding source.

It is important to note that the DEM used for the inundation mapping is associated with 2010 topographic conditions, and the HEC-RAS model is associated with 2005 conditions surveyed at specific cross sections. There are likely differences and discrepancies between the DEM and the HEC-RAS cross sections in areas where significant changes have occurred over time. These differences, and their potential impact on the modeled results, were not fully investigated as part of this modeling effort due in part to the limited level of documentation that accompanied the leveraged HEC-RAS model.

Although fifteen combinations of Bay water levels, sea level rise, and riverine peak flows were analyzed, as shown in Table 1, only eight scenarios were mapped for illustrative purposes, as presented in Table 4. There were limited differences observed on the maps between 12- and 24-inches of sea level rise, therefore only the existing conditions and 24 inches of sea level rise scenarios were mapped to compare the differences in flooding extent. It should be emphasized that flooding can occur under existing conditions, and flooding is expected to worsen with 12 inches of sea level rise. The identification, development and implementation of adaption strategies is required in the near term to protect existing assets. With 12 inches of sea level rise, smaller peak riverine flow events can result in flooding than currently observed under existing conditions. With 24 inches of sea level rise, extensive flooding can occur throughout the focus area. Both the 12 inch and 24 inch sea level rise scenarios should be considered in the adaptation strategy planning process -- the flooding extent and water surface elevations (presented in Section 5) with 24 inches of sea level rise are only slightly greater than expected with 12 inches of sea level rise. The flood extent maps are presented in Attachment A. The maps can be used to enhance the overall understanding of the flooding vulnerabilities at the core transportation assets within the Oakland Coliseum focus area.

Table 4: Mapped HEC-RAS Simulations

Mapping Scenario	Modeled Scenario
Mapping Scenario 1	MHHW + 100-year Peak Flow
	MHHW + 24” SLR + 100-year Peak Flow
Mapping Scenario 2	10-year Extreme Tide + 10-year Peak Flow
	10-year Extreme Tide + 24” SLR + 10-year Peak Flow
Mapping Scenario 3	10-year Extreme Tide + 100-year Peak Flow
	10-year Extreme Tide + 24” SLR + 100-year Peak Flow
Mapping Scenario 4	100-year Extreme Tide + 10-year Peak Flow
	100-year Extreme Tide + 24” SLR + 10-year Peak Flow

5. RESULTS

The following section provides an evaluation of the potential inundation throughout the focus area under various storm surge and peak flow conditions. The results are evaluated for Damon Slough (FEMA Line K_DS), Arroyo Viejo Creek (FEMA Line K_US), and Lion Creek (FEMA Line J). The results for Lion Creek are only presented downstream of the San Leandro Street crossing, since the configuration of the channel upstream of this location represents conditions prior to upstream improvements implemented after 2005. The locations of the HEC-RAS cross sections referenced through this section can be viewed in Figure 3.

From the HEC-RAS results, no flooding is expected to occur from Damon Slough during existing conditions until 100-year extreme tide levels are coupled with a 10-year peak flow event. The flows at the Coliseum Way bridge begins to surcharge, or flow at full capacity, once peak flows exceed a 100-year event during MHHW tide levels, but these flows still remain within the existing channel. The channel banks at Damon slough are overtopped during storm surge events with 12 and 24 inches of sea level rise when combined with extreme riverine discharges in the channel.

The tidal influence on flood levels with 12 and 24 inches of sea level rise is lessened with increasing upstream distance in Arroyo Viejo Creek, but any rise in upstream water levels contributes to backwater flooding and expose assets to saline waters. The results show that high peak flows have the greatest impact on flooding in this reach, and flooding occurs with a 50-year peak flow event, even during existing MHHW tide levels with no sea level rise. The greatest impact of sea level rise will be seen during the occurrence of a 100-year extreme tide level with 24 inches of sea level rise, where storm surge will have more impact on water levels upstream in the reach. Flooding at Arroyo Viejo Creek can be attributed to several factors; the reduced downstream conveyance capacity in Damon Slough during higher tide levels, the addition of peak flows discharging from Lion Creek during extreme rainfall events, and the undersized conveyance capacity of the channel itself.

Flooding without elevated tide levels also occurs in Lion Creek, where flows reach out into the floodplains above a 50-year peak flow event during current day MHHW tide levels. During the 12- and 24-inches of sea level rise scenarios, Lion Creek is flooded under most modeled storm events. The most severe flooding will occur during 24 inches of sea level rise and the occurrence of a 100-year extreme tide level. The culverts under the Amtrak rail crossing and adjacent service road crossing flow full during a 10-year peak flow event under current day MHHW tide levels. With the same scenario under 12 or 24 inches of sea level rise, the Amtrak crossing is flooded.

Table 5 presents an example key to interpreting the summary tables of water surface elevations reported at each modeled HEC-RAS section in Damon Slough (Table 6), Arroyo Viejo Creek (Table 7), and Lion Creek (Table 8). Specific details on the layout of the table are as follows:

- The cross section names are simplified from their original HEC-RAS station labels in order to identify the cross sections more easily (see Figure 3 for locations of modeled cross sections).
- For each cross section, the water surface elevation for each scenario is listed.
- Cross sections that are not flooded are shaded in light green.
- Cross sections that are flooded, but by a depth less than 1 foot, are shaded in yellow.
- Cross sections that are flooded by a depth greater than 1 foot, but less than 2 feet, are shaded in red.
- Cross sections that are flooded by a depth greater than 2 feet are shaded in purple.
- The controlling[6] left bank and right bank elevations that can convey channel flow without flooding of adjacent areas are listed. Where applicable, the location of flooding is listed (LB for left bank, and RB for right bank), along with the approximate depth of flooding. For example, if the left bank is flooded by a depth greater than 2 feet, but the right bank is only flooded by a depth lower than 2 feet, the designation *LB2; RB1* is listed.

Table 5: Example Key for HEC-RAS Summary Output Tables.

	Description
9.95 | 10.9	Controlling elevation of left and right bank (in FT-NAVD88); water surface above these elevations will flood adjacent areas outside of main channel.
9.17 -	Water surface elevation (in FT-NAVD88). Flow is contained below defined channel left/right bank, or controlling overbank elevation.
10.27 LB	Flow outside of controlling left channel overbank; flooding expected with depth <1ft
11.17 LB1; RB	Flow outside of controlling left channel overbank; flooding expected with depth between 1-2 feet. Flow outside of controlling right channel overbank; flooding expected with depth <1ft
12.28 LB2; RB1	Flow outside of controlling left channel overbank; flooding expected with depth >2ft. Flow outside of controlling right channel overbank; flooding expected with depth between 1-2 ft

[6] The controlling bank elevations for the purposes of this analysis are the elevations above the defined channel bank elevations when floodwaters will reach extensive portions of the floodplains. These elevations are greater than the bank elevations defined in the HEC-RAS model since flooding of the immediate overbanks does not necessary contribute to critical flooding of the adjacent areas. The channel bank elevations in the HEC-RAS model were defined as the approximate water surface elevation in the channel corresponding to a 10-year peak flow event.

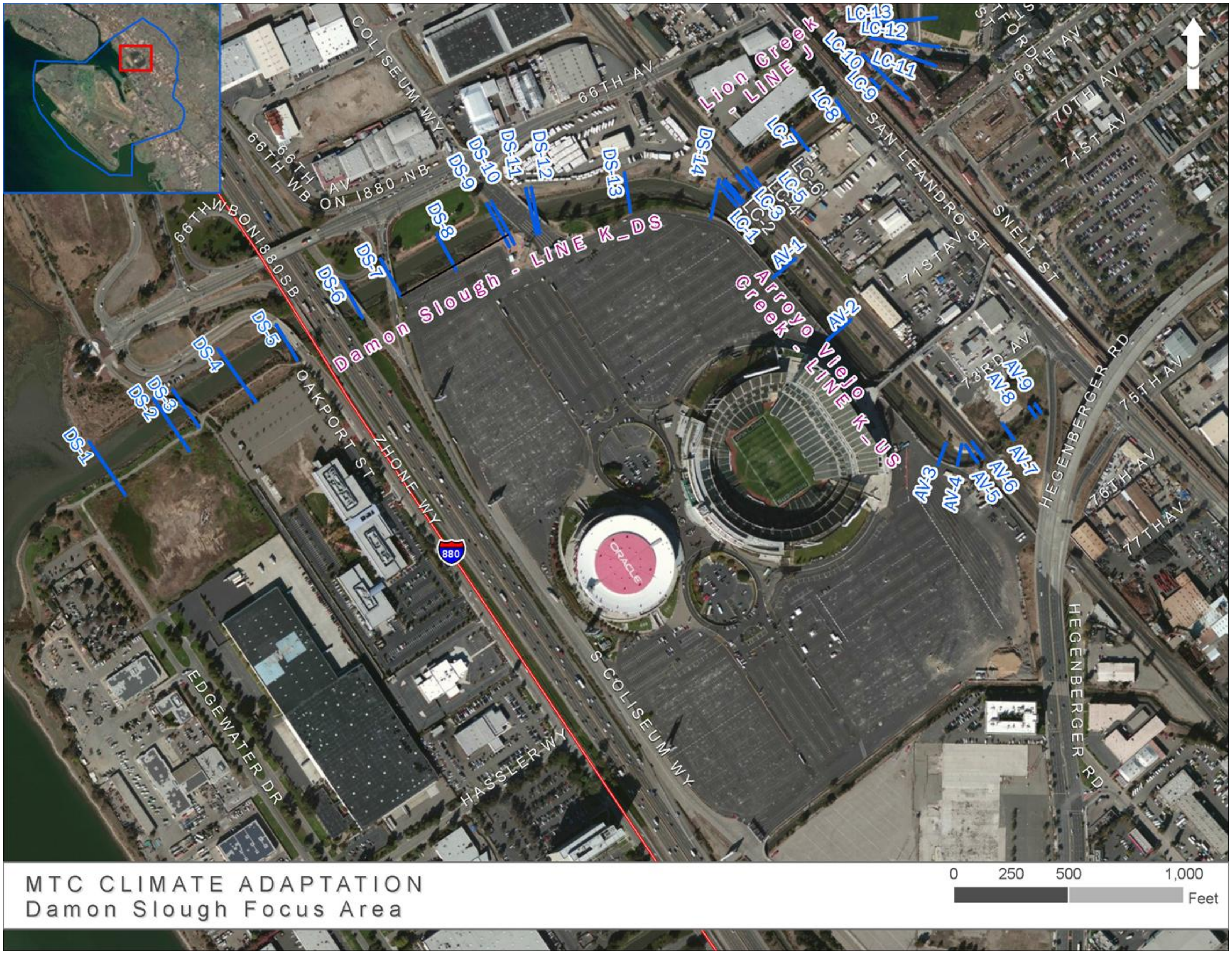

Figure 3: Locations of Modeled HEC-RAS Cross Sections

Table 6: HEC-RAS Results – Damon Slough (LINE K_DS)

RAS XS	0	340	432.89	697.86	961.66	I-880 Crossin g	1303.12	1496.96	1765.08	2020	2043.06	Coliseum Way Crossing	2180.26	2200	2590.03	2981.22
RAS XS	DS-1	DS-2	DS-3	DS-4	DS-5		DS-6	DS-7	DS-8	DS-9	DS-10		DS-11	DS-12	DS-13	DS-14
LB | RB Elev.	10.67 | 9.62	12.14 | 12.44	12.23 | 12.65	11.70 | 11.0	11.06 | 10.54		11.14 | 11.32	11.18 | 16.07	9.95 | 10.9	12.2 | 12.06	12.2 | 12.06		10.95 | 13.07	10.95 | 13.07	12.01 | 12.01	12.00 | 12.00
Scenario	**Water Surface Elevation (FT-NAV88)**															
MHHW + 10-year	6.61 -	6.84 -	6.99 -	7.14 -	7.31 -	-	7.56 -	7.69 -	7.88 -	8.11 -	8.13 -	-	8.27 -	8.28 -	8.48 -	8.87 -
+ 12" SLR	7.61 -	7.73 -	7.82 -	7.91 -	8.02 -	-	8.18 -	8.26 -	8.4 -	8.57 -	8.59 -	-	8.69 -	8.7 -	8.84 -	9.16 -
+ 24" SLR	8.61 -	8.68 -	8.73 -	8.79 -	8 .86 -	-	8.95 -	9.01 -	9.1 -	9.22 -	9.23 -	-	9.44 -	9.44 -	9.52 -	9.74 -
MHHW + 100-year	6.61 -	7.15 -	7.46 -	7.73 -	8.03 -	-	8.4 -	8.59 -	8.85 -	9.2 -	9.21 -	-	9.74 -	9.76 -	9.89 -	10.32 -
+ 12" SLR	7.61 -	7.89 -	8.1 -	8.28 -	8.5 -	-	8.78 -	8.93 -	9.15 -	9.45 -	9.46 -	-	10 -	10.02 -	10.12 -	10.5 -
+ 24" SLR	8.61 -	8.77 -	8.91 -	9.02 -	9.17 -	-	9.37 -	9.47 -	9.64 -	9.88 -	9.89 -	-	10.45 -	10.46 -	10.53 -	10.84 -
10-year Extreme Tide + 10-year	8.84 -	8.9 -	8.95 -	9 -	9.06 -	-	9.15 -	9.2 -	9.28 -	9.39 -	9.4 -	-	9.61 -	9.62 -	9.68 -	9.88 -
+ 12" SLR	9.84 RB	9.87 -	9.91 -	9.94 -	9.98 -	-	10.04 -	10.07 -	10.12 -	10.2 -	10.2 -	-	10.44 -	10.44 -	10.47 -	10.6 -
+ 24" SLR	10.84 LB; RB1	10.86 -	10.89 -	10.91 -	10.93 RB	-	10.97 -	10.99 -	11.02 LB1; RB	11.08 -	11.08 -	-	11.33 LB	11.33 LB	11.34 -	11.43 -
10-year Extreme Tide + 100-year	8.84 -	8.98 -	9.11 -	9.21 -	9.35 -	-	9.53 -	9.62 -	9.78 -	10 -	10.01 -	-	10.58 -	10.59 -	10.65 -	10.94 -
+ 12" SLR	9.84 RB	9.92 -	10.01 -	10.08 -	10.17 -	-	10.29 -	10.36 -	10.46 LB	10.64 -	10.64 -	-	11.23 LB	11.23 LB	11.27 -	11.49 -
+ 24" SLR	10.84 LB; RB1	10.89 -	10.95 -	11 -	11.06 RB	-	11.14 -	11.18 -	11.26 LB1; RB	11.38 -	11.39 -	-	11.99 LB1	12 LB1	12.01 -	12.17 LB; RB
100-year Extreme Tide + 10-year	10.01 -	10.04 -	10.08 -	10.11 -	10.14 -	-	10.19 -	10.22 -	10.27 LB	10.35 -	10.35 -	-	10.58 -	10.59 -	10.61 -	10.74 -
+ 12" SLR	11.01 LB; RB1	11.03 -	11.05 -	11.07 RB	11.1 LB; RB	-	11.13 -	11.15 -	11.18 LB1; RB	11.23 -	11.24 -	-	11.48 LB	11.49 LB	11.5 -	11.58 -
+ 24" SLR	12.01 LB1; RB2	12.02 -	12.04 -	12.05 LB; RB1	12.07 LB; RB1	-	12.09 LB; RB	12.1 LB	12.12 LB2; RB1	12.16 RB	12.16 RB	-	12.42 LB1	12.42 LB1	12.42 LB; RB	12.48 LB; RB

Table 7: HEC-RAS Results – Arroyo Viejo Creek (LINE K_US)

RAS XS	3416.43	3744.86	4473.12	4547.99	4607.95	4639.46	Amtrak Crossing	4790	4921.3	4951.28
RAS XS	AV-1	AV-2	AV-3	AV-4	AV-5	AV-6		AV-7	AV-8	AV-9
LB | RB Elev.	10.4 | 10.65	11.02 | 10.83	11.86 | 10.73	12.09 | 10.67	10.74 | 10.26	11.11 | 10.86		12.53 | 11.27	12.97 | 12.97	17.02 | 12.51
Scenario	Water Surface Elevation (FT-NAV88)									
MHHW + 10--year	9.38 -	9.55 -	9.92 -	10.01 -	10.01 -	9.99 -	-	10.26 -	10.36 -	10.31 -
+ 12" SLR	9.6 -	9.75 -	10.08 -	10.16 -	10.16 -	10.15 -	-	10.39 -	10.48 -	10.42 -
+ 24" SLR	10.07 -	10.19 -	10.44 -	10.51 -	10.5 RB	10.49 -	-	10.69 -	10.76 -	10.7 -
MHHW + 100-year	10.89 LB; RB	11.13 LB; RB	11.59 RB	11.69 RB1	11.67 LB1; RB	11.63 LB; RB	-	12.03 RB	12.02 -	11.76 -
+ 12" SLR	11.02 LB; RB	11.25 LB; RB	11.67 RB	11.77 RB1	11.76 LB1; RB	11.72 LB; RB	-	12.09 RB	12.07 -	11.81 -
+ 24" SLR	11.29 LB; RB	11.48 LB; RB	11.86 RB1	11.94 RB1	11.93 LB1; RB	11.89 LB1; RB	-	12.22 RB	12.19 -	11.93 -
10-year Extreme Tide + 10-year	10.2 -	10.3 -	10.55 -	10.61 -	10.6 RB	10.59 -	-	10.78 -	10.84 -	10.78 -
+ 12" SLR	10.83 LB; RB	10.91 RB	11.08 RB	11.12 RB	11.12 LB; RB	11.1 RB	-	11.26 -	11.29 -	11.23 -
+ 24" SLR	11.59 LB1; RB	11.64 LB; RB	11.75 RB1	11.78 RB1	11.78 RB1	11.77 LB; RB	-	11.87 RB	11.87 -	11.8 -
10-year Extreme Tide + 100-year	11.37 LB; RB	11.56 LB; RB	11.91 LB; RB1	12 RB1	11.99 LB1; RB1	11.95 LB; RB1	-	12.26 RB	12.23 -	11.97 -
+ 12" SLR	11.82 LB1; RB	11.98 LB; RB1	12.26 LB; RB1	12.32 LB; RB1	12.31 LB1; RB2	12.28 LB1; RB1	-	12.53 RB1	12.47 -	12.22 -
+ 24" SLR	12.42 LB2; RB1	12.54 LB1; RB	12.74 LB; RB2	12.79 LB; RB2	12.78 LB2; RB2	12.75 LB1; RB1	-	12.94 LB; RB1	12.86 -	12.62 RB
100-year Extreme Tide + 10-year	10.95 LB; RB	11.03 LB; RB	11.19 RB	11.23 RB	11.22 LB; RB	11.21 LB; RB	-	11.35 RB	11.38 -	11.31 -
+ 12" SLR	11.73 LB1; RB	11.78 LB; RB	11.88 LB; RB1	11.91 RB1	11.9 LB1; RB1	11.89 LB; RB1	-	11.99 RB	11.98 -	11.92 -
+ 24" SLR	12.58 LB2; RB1	12.62 LB1; RB	12.68 LB; RB1	12.7 LB; RB2	12.7 LB1; RB2	12.69 LB1; RB	-	12.74 LB; RB1	12.73 -	12.66 RB

AECOM

Table 8: HEC-RAS Results – Lion Creek (LINE J)

RAS XS	65	87	90	98	146	160	179	200	453	667
RAS XS	LC-1	LC-2	Bridge	LC-3	LC-4	Bridge	LC-5	LC-6	LC-7	LC-8
LB | RB Elev.	13.12 | 13.24	13.12 | 13.24		13.16 | 13.21	10.24 | 10.97		10.16 | 10.23	12.00 | 12.00	12.78 | 12.49	13.00 | 13.00
Scenario	WSEL (FT-NAV8)									
MHHW + 10--year	9.16 -	9.17 -	-	9.19 -	9.19 -	-	9.3 -	9.31 -	9.39 -	9.48 -
+ 12" SLR	9.42 -	9.42 -	-	9.49 -	9.49 -	-	9.61 -	9.62 -	9.69 -	9.76 -
+ 24" SLR	9.93 -	9.94 -	-	10.03 -	10.02 -	-	10.16 -	10.17 -	10.22 -	10.28 -
MHHW + 100-year	10.72 -	10.73 -	-	10.99 -	10.98 RB	-	11.37 LB1; RB1	11.4 -	11.47 -	11.54 -
+ 12" SLR	10.88 -	10.89 -	-	11.15 -	11.14 LB; RB	-	11.55 LB1; RB1	11.58 -	11.64 -	11.71 -
+ 24" SLR	11.17 -	11.18 -	-	11.46 -	11.45 LB1; RB	-	11.8 LB1; RB1	11.83 -	11.88 -	11.94 -
10-year Extreme Tide + 10-year	10.07 -	10.07 -	-	10.16 -	10.16 -	-	10.30 RB	10.31 -	10.36 -	10.41 -
+ 12" SLR	10.74 -	10.75 -	-	10.86 -	10.86 LB	-	11.01 LB, RB	11.02 -	11.06 -	11.10 -
+ 24" SLR	11.54 -	11.54 -	-	11.67 -	11.66 LB1; RB	-	11.8 LB1; RB1	11.81 -	11.83 -	11.86 -
10-year Extreme Tide + 100-year	11.26 -	11.27 -	-	11.55 -	11.54 LB1; RB	-	11.88 LB1; RB1	11.91 -	11.96 -	12.02 -
+ 12" SLR	11.75 -	11.75 -	-	12.06 -	12.04 LB1; RB1	-	12.31 LB2; RB2	12.35 LB, RB	12.39 -	12.44 -
+ 24" SLR	12.37 -	12.38 -		12.7 -	12.69 LB2; RB1	-	12.89 LB2; RB2	12.92 LB, RB	12.96 RB	12.99 -
100-year Extreme Tide + 10-year	10.87 -	10.88 -	-	10.99 -	10.99 LB; RB	-	11.17 LB1, RB	11.18 -	11.22 -	11.25 -
+ 12" SLR	11.68 -	11.68 -	-	11.81 -	11.81 LB1; RB	-	11.93 LB1, RB1	11.95 -	11.97 -	11.99 -
+ 24" SLR	12.55 -	12.55 -	-	12.70 -	12.69 LB2; RB1	-	12.78 LB2; RB2	12.79 LB; RB	12.81 LB; RB	12.82 -

Although the water surface elevations reported at each HEC-RAS cross section provide valuable information about the interdependencies between the various boundary conditions and channel hydraulics that result in flood levels, it is challenging to directly translate these results to assess the extent of inland flooding. This assessment can be supplemented by reviewing the flood maps presented in Attachment A in detail. Using a combination of the HEC-RAS model summary and the flood mapping, the scenarios when the channels and core assets are first exposed to flooding are presented in Table 9 and Table 10 provide insight into the timing of when the operations of the assets can be impacted. The timing of flooding at the stream channels (Table 9) is presented separately from the timing of flooding at the locations of the key assets (Table 10). This is because assets are not necessarily flooded by a directly adjacent tributary to until a later scenario, so it is helpful to identify these areas and scenarios separately. For example, areas adjacent to Damon Slough (i.e., the Coliseum Complex parking area) can be flooded from upstream sources prior to flooding in the Damon Slough channel itself. The scenario of when the assets are first exposed to flooding from only riverine discharge, and also from the combined effects of riverine and coastal storm surge events, is also presented. Note that peak flow rates between the 10- and 100-year events are listed (including 25- and 50-year events[7]), in an effort to provide more useful scenarios from which to formulate adaptation strategies.

Note that not all of the scenarios presented in Table 9 and Table 10 were mapped. As stated in Section 4, limited differences were observed in the flooding extents between 12 and 24 inches of sea level rise, therefore only the existing conditions and 24 inches of sea level rise scenarios were mapped. The following sections provides a discussion on of the timing of flooding and impacts to the focus area under existing conditions also sea level rise.

Table 9: Timing of Flooding at Stream Channels in Focus Area

Asset	Scenario	Timing of Flooding			
		From Riverine		From Coastal and Riverine	
		Extreme Tide	Peak Flow	Extreme Tide	Peak Flow
Damon Slough	Existing	-	-	100-Year	10-Year*
	12-inch SLR	-	-	10-Year	10-Year*
	24-inch SLR	-	-	10-Year	10-Year*
Arroyo Viejo Creek	Existing	MHHW	50-Year	10-Year	25-Year
	12-inch SLR	MHHW	50-Year	10-Year	10-Year
	24-inch SLR	MHHW	25-Year	10-Year	10-Year
Lion Creek	Existing	MHHW	50-Year	10-Year	25-Year*
	12-inch SLR	MHHW	25-Year*	10-Year	10-Year*
	24-inch SLR	MHHW	25-Year*	10-Year	10-Year*

*Flooding occurs at isolated transects, but is not yet extensive.

7 The 25-year flowrate used in the HEC-RAS model is as follows: (Lion Creek - 1,831, Arroyo Viejo Creek - 2,000cfs, Damon Slough - 3,100cfs). The 50-year flowrate used in the HEC-RAS model is as follows: (Lion Creek - 2,400cfs, Arroyo Viejo Creek – 2,800cfs, Damon Slough - 3,600cfs).

Table 10: Timing of Flooding at Key Assets in Focus Area

Asset	Scenario	Timing of Flooding			
		From Riverine		From Coastal and Riverine	
		Extreme Tide	Peak Flow	Extreme Tide	Peak Flow
I-880 Crossing[1]	Existing	-	-	-	-
	12-inch	-	-	100-Year	10-Year
	24-inch	MHHW	100-Year	10-Year	10-Year
Coliseum Complex	Existing	MHHW	50-Year	10-Year	10-Year
	12-inch	MHHW	50-Year	10-Year	10-Year
	24-inch	MHHW	25-Year	10-Year	10-Year
Coliseum Amtrak Station / Rail Corridor	Existing	MHHW	50-Year	10-Year	25-Year
	12-inch	MHHW	50-Year	10-Year	25-Year
	24-inch	MHHW	25-Year	10-Year	10-Year
Coliseum BART Station	Existing	MHHW	100-Year	10-Year	100-Year
	12-inch	MHHW	100-Year	10-Year	10-Year
	24-inch	MHHW	100-Year	10-Year	10-Year
OAK Airport Connector	Existing	MHHW	50-Year*	10-Year	25-Year*
	12-inch	MHHW	50-Year*	10-Year	25-Year*
	24-inch	MHHW	50-Year*	10-Year	10-Year*

*Flooding occurs at isolated transects, but is not yet extensive.

[1] Flooding of roadway adjacent to Damon Slough occurs when water levels reach 10.5’ NAVD (approx.).

5.1. Existing Conditions (No Sea Level Rise)

From the HEC-RAS modeling results, flooding occurs throughout the focus area during existing conditions, prior to any increase in daily tide conditions due to sea level rise. The following provides detail on the timing of flooding and the processes that contribute to the flooding during existing conditions.

Stream Channels

Damon Slough

- Under existing MHHW tide conditions in the absence of sea level rise, there is no flooding in the Damon Slough channel even at a 100-year peak flow event. Limited flooding occurs during storm surge conditions when a 10-year peak flow event coincides with a 100-year extreme tide. This scenario was the worst case scenario that was modeled. The most severe flooding in this reach is primarily driven by higher Bay water levels during extreme storm surge conditions, but only when coupled with an extreme peak flow event. Mitigation measures need to consider the combined effects of downstream flooding from storm surge and upstream flooding from rainfall driven runoff events that occur simultaneously.

Arroyo Viejo Creek

- Under existing MHHW tide conditions in the absence of sea level rise, there is limited flooding at one section in the channel during peak flows above the 25-year event, but critical flooding occurs above a 50-year peak flow event. During storm surge conditions at the 10-year extreme tide level, flooding begins at a 25-year peak flow, but extensive flooding occurs during a 50-year peak flow event. The most severe flooding in this reach during existing conditions is primarily driven from rainfall runoff events, but is increased when these events occur during storm surge conditions. Floodwaters in Arroyo Viejo Creek will also travel overland to flood areas adjacent to Damon Slough at the Coliseum park area. Measures to mitigate flooding during existing conditions should first consider strategies in the watershed or directly at the channel banks.

Lion Creek

- Under existing MHHW tide conditions in the absence of sea level rise, flooding occurs at a 50-year peak flow event. During storm surge conditions at or above the 10-year extreme tide level, flooding begins at a 25-year peak flow event, but extensive flooding occurs during a 100-year peak flow event. Flooding is more severe with a 100-year peak flow event during a 10-year extreme tide, than a 10-year peak flow event during a 100-year extreme tide, meaning that the most severe flooding occurs from heavy rainfall events, but flooding is also intensified during storm surge events.

Key Assets

I-880 Crossing

- No flooding over the I-880 crossing over Damon Slough or adjacent roadway areas is expected to occur during existing conditions. However, further modeling is necessary to verify these findings, since the I-880 crossing was not modeled in HEC-RAS.

Coliseum Complex

- Flooding occurs throughout the Coliseum Complex during MHHW tide conditions with a 50- to 100-year peak flow rate. Under coastal storm surge, flooding can also occur with a 10-year extreme tide combined with a 25-year peak flow event. Flooding at low-lying areas at the parking lot is not expected to occur directly from Damon Slough, but via overland flow pathways from Arroyo Viejo Creek during these peak flow events. The most extensive flooding in the parking lot area is expected during a 100-year extreme tide level combined with a 10-year peak flow event. Protection of this asset should consider both higher water levels during storm surge conditions and watershed flooding.

Coliseum Amtrak Station / Rail Corridor

- In the absence of storm surge, the Coliseum Amtrak Station and adjacent rail corridor is vulnerable to flooding beginning at a 50-year peak flow event. During coastal storm surge, flooding can also occur with a 100-year extreme tide combined with a 25-year peak flow event. Although the Amtrak Station passenger platform may not be flooded during all scenarios, the operations of this asset are sensitive to flooding of the surrounding railway and any exposure of the electrical components to floodwaters. The rail crossings over Arroyo Viejo and Lion Creek are especially vulnerable to flooding during all scenarios, but the crossing over Arroyo Viejo creek was not modeled in HEC-RAS, and this constriction should be included if more detailed modeling work is conducted. Protection of this asset should consider both higher water levels during storm surge conditions and watershed flooding.

Coliseum BART Station

- The Coliseum BART station is the most vulnerable during rainfall runoff events, and is exposed to flooding from Lion Creek via an overland flow pathway along San Leandro Street and also just north of San Leandro Street. Although the passenger platform and service corridor is elevated, there are existing power utilities and pedestrian access points located at existing ground elevations, which are vulnerable to exposure prior to the BART station itself. Under existing MHHW tide conditions, flooding can occur during 100-year peak flow event. During coastal storm surge, more severe flooding can occur with a 10-year extreme tide combined with a 100-year peak flow event. Storm surge conditions in the Bay have less of an impact in this area than flooding from watershed runoff. Flooding of the adjacent roadways and parking lot can occur during scenarios earlier than a 100-year peak flow event without storm surge, and may cause disruptions that will impact the overall level of service of the system. Watershed flooding should be addressed to mitigate impacts to this asset.

Oakland Airport Connector

- Although the pedestrian area of the new Oakland Airport Connecter is elevated, there are vulnerable power facilities and utilities located at ground elevations. The location of the new Oakland Airport Connector is vulnerable to flooding during a 50-year peak flow event in the surrounding channels, even in the absence of storm surge conditions. During coastal storm surge, overland flooding can also occur with a 10-year extreme tide combined with a 25-year peak flow event. The Airport Connector railway eventually enters ground elevations outside of this focus area boundary, and flooding at this location will cause disruptions in service to the overall transit system in this area and should be investigated.

5.2. Future Conditions (12-inches of Sea Level Rise)

With 12 inches of sea level rise at the downstream tidal boundary, flooding will be increased in all areas. In some areas, flooding will occur more frequently with smaller peak flow events under the same coastal storm surge conditions with sea level rise. The areas that are the farthest upstream from the tidal influence will see the least impact from rising tides, but will still experience worsened flooding due to the rising baseflow elevation in the stream channels.

Stream Channels

Damon Slough

- Damon Slough is still able to convey the 100-year peak flow event within the channel in the absence of storm surge conditions in the Bay with 12 inches of sea level rise. However, flooding now occurs during smaller and more frequent storm surge events – a 10-year extreme tide when combined with a 10-year peak flow event. The greatest influence on downstream water levels is storm surge, so the addition of 12 inches of sea level rise on the 100-year extreme tide level can flood these areas by a depth greater than 1-foot. The upstream portions of Damon Slough are flooded by less than 1-foot with either a 10-year peak flow during a 100-year extreme tide or a 100-year peak flow during a 10-year extreme tide, meaning that any combination of riverine and storm surge can now cause flooding during the 12 inch sea level rise scenario. This was not the case with no sea level rise. The primary driver for flooding in the downstream reaches are extreme tide levels during storm surge conditions, and the primary driver for flooding in the upstream reaches are peak flows during rainfall runoff events.

Arroyo Viejo Creek

- In Arroyo Viejo Creek, flooding first occurs during a 50-year peak flow event during MHHW tide conditions with 12 inches of sea level rise. Flooding also occurs during a 50-year peak flow event with MHHW tide conditions with no sea level rise, but with 12 inches of sea level rise, the downstream portions will experience greater depths of flooding. Under coastal storm surge with 12 inches of sea level rise, Arroyo Viejo Creek floods during a 10-year extreme tide level combined with a 10-year peak flow event, compared to flooding during existing conditions from a 10-year extreme tide combined with a 25-year peak flow event. Although adding 12 inches of sea level rise at the downstream boundary does not translate to an increase of 12 inches in the upstream baseflow elevation in this reach, the tidal influence is strong enough to create additional flooding in upstream areas during storm surge conditions.

Lion Creek

- In Lion Creek, 12 inches of sea level rise allows flooding to occur more frequently with smaller peak flow events. During MHHW tide conditions, areas adjacent to Lion Creek now flood at a 25-year peak flow event, and with coastal storm surge, flooding now occurs at a 10-year extreme tide level combined with a 10-year peak flow event. Although adding 12 inches of sea level rise at the downstream boundary does not translate to an increase of 12 inches in the upstream baseflow elevation in this reach, the tidal influence is strong enough to create additional flooding in upstream areas during storm surge conditions.

Key Assets

I-880 Crossing

- With 12 inches of sea level rise, no flooding over the I-880 roadway is expected to occur unless there are elevated Bay water levels during storm surge conditions. Flooding at I-880 due to 12 inches of sea level rise is expected to occur when a 100-year extreme tide level is combined with a 10-year peak flow rate. The deck of the bridge crossing over Damon Slough and portions of the adjacent roadways are vulnerable to flooding during this scenario.

Coliseum Complex

- Flooding occurs throughout the Coliseum Complex during MHHW tide conditions with 12 inches of sea level rise and a 50-year peak flow rate, the same as existing conditions with no sea level rise. Flooding at low-lying areas at the parking lot is from overland flow pathways from Arroyo

Viejo Creek during these peak flow events. With 12 inches of sea level rise flooding also comes directly from overtopping over Damon Slough starting from a 10-year extreme tide combined with a 25-year peak flow event. The most extensive flooding in the parking lot area is expected during a 100-year storm surge combined with a 10-year peak flow event.

Coliseum Amtrak Station / Rail Corridor

- With 12 inches of sea level rise, the Coliseum Amtrak Station and adjacent rail corridor is exposed to flooding starting at a 50-year peak flow event during MHHW tide conditions, the same as with no sea level rise. With coastal storm surge, flooding can also first occur during a 10-year extreme tide when combined with a 25-year peak flow event, the same as with no sea level rise.

Coliseum BART Station

- Flooding can occur during peak flows of a 100-year event under MHHW tide conditions with 12 inches of sea level rise, the same as with no sea level rise. With coastal storm surge, flooding can also first occur during a 10-year extreme tide when combined with a 10-year peak flow event. This is a smaller peak flow than the 25-year peak flow required to cause flooding with a 10-year extreme tide with no sea level rise.

Oakland Airport Connector

- Under 12 inches of sea level rise, the new Oakland Airport Connector can be exposed to flooding at the same scenarios with no sea level rise, but at a greater depth.

5.3. Future Conditions (24-inches of Sea Level Rise)

With 24 inches of sea level rise at the downstream tidal boundary, extensive flooding is expected throughout most of the focus areas during coincident peak flows in the stream channels. Flooding is expected to occur more frequently than with 12 inches of sea level rise from both smaller peak flow events and lower levels of extreme tides. The areas that are the farthest upstream from the tidal influence will see the least impact from rising tides, but additional flooding in new areas is now expected. Greater than 2 feet of flooding can be expected in many areas with a 10-year peak flow during a 100-year extreme tide or a 100-year peak flow during a 10-year extreme tide.

Stream Channels

Damon Slough

- Damon Slough is still able to convey the 100-year peak flow event within the channel in the absence of storm surge conditions in the Bay during 24 inches of sea level rise. However, during storm surge conditions (10- and 100-year extreme tide), additional portions of the channel now begin to flood at a 10-year peak flow rate. The greatest influence on downstream water levels is storm surge, so the addition of 24 inches of sea level rise on the 100-year extreme tide level can flood these areas by a depth greater than 2-feet. The upstream portions of Damon Slough are flooded by more than 1-foot with either a 10-year peak flow during a 100-year extreme tide or a 100-year peak flow during a 10-year extreme tide, meaning that any combination of the most extreme tide or peak flow event can now cause extensive flooding during 24 inches of sea level rise. Flooding will increase significantly compared to that expected during 12 inches of sea level rise.

Arroyo Viejo Creek

- With 24 inches of sea level rise flooding is now expected to occur with a 25-year peak flow event during MHHW tide conditions, whereas the channel can still convey this scenario under 12 inches of sea level rise. Flooding still occurs with a 10-year peak flow during a 10-year storm surge. Portions of the channel are also flooded by greater than 2 feet during 24 inches of sea level rise, with a 10-year peak flow during a 100-year extreme tide or a 100-year peak flow during a 10-year extreme tide. At these scenarios, additional areas upstream of Hegenberger Road are now flooded. Although adding 24 inches of sea level rise at the downstream boundary does not translate to an increase of 24 inches in the upstream baseflow elevation in this reach, the tidal influence is strong enough to create additional flooding in upstream areas during storm surge conditions.

Lion Creek

- In Lion Creek, flooding during 24 inches of sea level rise is now more severe and additional areas will be flooded upstream of the Amtrak crossing. The critical scenario of flooding is still the 10-year peak flow combined with a 10-year extreme tide. Although adding 24 inches of sea level rise at the downstream boundary does not translate to an increase of 24 inches in the upstream baseflow elevation in this reach, the tidal influence is strong enough to create additional flooding in upstream areas during storm surge conditions.

Key Assets

I-880 Crossing

- With 24 inches of sea level rise, flooding at I-880 is still only vulnerable to flooding during storm surge conditions, at a greater frequency than during 12 inches of sea level rise. The critical scenario of flooding is now the 10-year extreme tide level combined with a 10-year peak flow. Further modeling is necessary to verify these findings.

Coliseum Complex

- With 24 inches of sea level rise, portions of the parking lot are flooded with a 25-year peak flow event under MHHW tide conditions, compared to a 50-year peak flow event with 12 inches sea level rise. Direct flooding comes directly from overtopping over Damon Slough starting from a 10-year peak flow during a 10-year extreme tide event. Up to 2-feet of flooding is expected with a 10-year peak flow during a 100-year extreme tide or a 100-year peak flow during a 10-year extreme tide. The most extensive flooding in the parking lot area is expected during a 100-year storm surge coupled with a 10-year peak flow event.

Coliseum Amtrak Station / Rail Corridor

- With 24 inches of sea level rise, the Coliseum Amtrak Station and adjacent rail corridor is exposed to flooding starting at a 25-year peak flow event during MHHW tide conditions. Flooding can also first occur with a 10-year extreme tide combined with a 10-year peak flow event, compared to a 10-year extreme tide with a 25-year peak flow during 12 inches of sea level rise. Flooding is expected at all combinations of extreme tide levels coupled with peak flow events under this sea level rise scenario.

Coliseum BART Station

- Flooding at the BART station and adjacent areas can occur during peak flows at a 100-year event under MHHW tide conditions with 24 inches of sea level rise, the same as with 12 inches of sea level rise. With coastal storm surge, flooding can occur with a 10-year extreme tide combined with a 10-year peak flow event, the same as with 12 inches of sea level rise.

Oakland Airport Connector

- With 24 inches of sea level rise, the new Oakland Airport Connector is vulnerable to flooding during a 50-year peak flow event in the surrounding channels, even in the absence of storm surge conditions. This is same as 0 and 12 inches of sea level rise. Flooding can also first occur with a 10-year extreme tide combined with a 10-year peak flow event, compared to a 10-year extreme tide with a 25-year peak flow during 12 inches of sea level rise.

6. SUMMARY

This analysis builds upon the work completed during the previous MTC Vulnerability and Risk Assessment Project, by providing a more detailed analysis of potential inundation by sea level rise and storm surge coupled with riverine flood conditions in the selected focus area. The current Pilot Study shows inundation of several areas during 36 inches of sea level rise (or a storm surge scenario that results in a similar level of inundatio*n)*, and nearly the entire focus area is inundated with 48 inches of sea level rise. These results do not consider the additional impact of riverine-induced flooding due to precipitation events. To evaluate these impacts, the existing HEC-RAS model provided by ACFCWCD was used to simulate a variety of storm surge and peak flow scenarios, and flood extent maps were created to supplement the analysis.

Flooding does not occur in the Damon Slough channel unless peak flow events from rainfall driven runoff occur during periods of coastal storm surge. Under existing conditions with no sea level rise, flooding can occur during storm surge conditions when a 100-year extreme tide level is combined with a 10-year peak flow event. With sea level rise of 12 or 24 inches, a similar level of flooding can occur more frequently with a lower (10-year) extreme tide combined with the same 10-year peak flow event. Flooding at I-880 will being to occur during storm surge conditions at 12 inches of sea level rise when a 100-year extreme tide is combined with a 10-year peak flow, and will occur more frequently during 24 inches of sea level rise at a lower (10-year) extreme tide level combined with the same 10-year peak flow rate. The most severe flooding at Damon Slough and the adjacent assets is primarily driven by coastal storm surge.

Flooding in Arroyo Viejo Creek is expected to occur from a 50-year peak flow event occurring during current day MHHW tide conditions, which exposes the Coliseum Complex, Coliseum BART Station, Coliseum Amtrak Station, and the Oakland Airport Connector Station to flooding. A similar level of flooding is expected during 12 inches of sea level rise, but with 24 inches of sea level rise, the channel can flood with only a 25-year peak flow event during MHHW tide conditions. With elevated tide levels (during an El Niño winter, for example), all of the core assets could be exposed to flooding during smaller peak flow events that occur more frequently. During existing conditions, Arroyo Viejo Creek can flood from a 10-year extreme tide combined with a 25-year peak flow event. With 12 inches of sea level rise, Arroyo Viejo Creek will flood more frequently with a 10-year extreme tide combined with a 10-year peak flow event. With 24 inches, this timing of flooding will remain the same, but the depth of flooding will increase. The most severe flooding in Arroyo Creek is primarily driven from watershed runoff, but is increased by higher Bay water levels.

Lion Creek also experiences flooding during existing conditions, and will also experience more frequent flooding with sea level rise. With 12 and 24 inches of sea level rise, Lion Creek will flood with a smaller (25-year) peak flow event during MHHW tide conditions, compared to a 50-year peak flow event during MHHW tide conditions with no sea level rise. Lion Creek will also flood more frequently from coastal storm surge events with 12 and 24 inches of sea level rise, with a 10-extreme tide combined with a 10-year peak flow event, compared to a 10-year extreme tide with no sea level rise combined with a 25-year peak flow event. The most severe flooding in Lion Creek is primarily driven from watershed flooding, but is increased by higher Bay water levels.

From this analysis, it is clear that the timing for implementing adaptation strategies to protect the core assets from exposure to flooding is now, during existing conditions, prior to any increases in sea level. Sea level rise of 12 and 24 inches will increase the severity of flooding in areas already flooded during existing conditions, regardless if the frequency of flooding increases or not. It will be important for adaptation strategies to consider the impacts of riverine discharges on flood levels, since similar levels to permanent inundation during 48 inches of sea level rise and above can already be experienced during existing conditions with certain occurrences of storm surge and peak flow events. Sea level rise alone may not immediately impact the assets in this focus area, but the rising tidal boundary will allow flooding to occur at more frequent intervals from smaller magnitudes of storm surge and peak flow events.

Understanding the flood dynamics with the modeling of extreme events and developing more detailed flood maps will provide valuable information for developing adaptation strategies for the vulnerable assets in this focus area. Some of the next steps that can be taken to further inform the planning process are provided in the following section.

7. POTENTIAL ADAPTATION MEASURES

The Damon Slough focus area will require multiple adaptation measures to prevent current and future flooding and inundation from both riverine and coastal extreme events. The combined effects of riverine and coastal flooding pose a greater impact on the system than only considering permanent inundation from sea level rise. As a part of the overall MTC Climate Adaptation Pilot Project, several adaptation strategies have been outlined to address the vulnerabilities identified within the Damon Slough focus area. The strategies are designed to protect the current location of key assets, and implementing policy changes to prevent future development in areas that are vulnerable to future sea level rise should be considered. The strategies outlined below could be implemented to help reduce existing and future flood risks.

7.1. Tide Gate (Damon Slough)

To provide protection for the Coliseum area from rising sea levels, a tide gate can be installed in the Damon Slough channel just downstream of the I-880 crossing. A tide gate can be used to control the maximum tide levels in the channel, while allowing for drainage during flood events. Because of sea level rise and a net positive deposition of sediment that would occur behind the barrier, the tide gate would need to be raised periodically, but maintenance costs will be minimal. This concept is similar in design to the Thames Flood Barrier (on a much smaller scale), and provides some transient storage. At more advanced levels of sea level rise where gravity flow is lost, provision for pumping stormwater to a point just downstream of I-880 will need to be considered.

7.2. Levee/Floodwall (Damon Slough)

Constructing levees adjacent to either edge of Damon Slough from upstream of I-880 to San Leandro Street can protect adjacent facilities and properties from future high tide levels. Because the footprint of walls, levees and berms would be relatively large, mitigation for loss of habitat and recreation may be required for this strategy. A traditional levee with steeper slopes, or a floodwall with vertical slopes, could be designed and potentially constrained within the existing banks of the slough. This strategy does not include flood protection for I-880. Flooding at I-880 will occur from overland flow from either side of the crossing, in addition to flooding from below in the Damon Slough channel, which is not addressed with this strategy.

7.3. Living Levee (Damon Slough)

Using a combination of natural restoration and aesthetic levees/walls/berms along the length of Damon Slough, the same protection of adjacent assets from flooding can be achieved over using strictly engineered measures. A living levee typically has a flatter waterside slope to allow for the creation of habitat, which results in a wider footprint. A living levee provides additional benefits above flood protection, including increased marsh and riparian habitat which enhances the natural aesthetics of the slough. Because of its larger cross-sectional area, a living levee will also have sufficient accommodation space to allow for future modifications that could support higher rates of sea level rise in the future. However, the footprint of walls, levees and berms would be relatively large, and mitigation for loss of existing habitat and recreation may be required for this strategy. This strategy will also require land acquisition to be effective. This strategy does not include flood protection for I-880, but implementing a wider floodplain in Damon Slough will accommodate higher peak flows and potentially relive some constriction at the I-880 crossing during extreme storm events.

7.4. Fill (Damon Slough)

To prevent high tide overflow in the Coliseum Area and to prevent overtopping of I-880, Damon Slough can be filled to a point just downstream of the I-880 bridges. This would allow the I-880 crossing to be converted to an enclosed culverted battery or similar system that provides adequate drainage from upland flooding. Habitat loss in Damon Slough could be mitigated offsite. Current stormwater runoff entering upstream would need to be diverted to a point just downstream of I-880. Any diversion would need to consider future water levels and its impact on maintaining gravity flow. Where gravity flow is not possible, pumping systems may need to be considered. Maintenance of the drainage system in response to sediment deposition will need to be considered as part of this strategy.

8. POTENTIAL NEXT STEPS

Several next steps can be taken to refine the understanding of the flood dynamics and critical overland flow pathways within this focus area during existing and future conditions. The results from these additional analyses can provide more detail on the level of exposure that assets in this focus area may experience, and may include the following:

- *Update the existing HEC-RAS model* - incorporate the most up to date channel conditions by modeling critical channel structures such as bridges and culverts, and modifying cross section data to include any channel modifications implemented or observed since 2005.
- *Understand the timing of peak flows* - the current steady-state model does not consider the timing of peak flows in the channels. Peak flows occurring at different times can lead to lower flood levels. These processes can be evaluated by incorporating time varying reach boundaries in the HEC-RAS model.
- *Revise the existing DEM* - incorporate new changes in topography from the Airport Connector construction, and other recent channel or floodplain modifications into the existing topographic DEM.
- *Revise the inundation maps* - revise the inundation maps using refined HEC-RAS model output to provide a more detailed assessment of the flooding extents in the focus area.
- *2-dimensional flow modeling* - core assets in low-lying areas are also vulnerable to flooding via overland flow pathways connected to flood sources. These processes may be captured in more detail by using a 2-dimensional flow model (HEC-RAS is 1-dimensional) that can simulate flow through these critical pathways.
- *Evaluate sediment transport* - sea level rise may alter the existing morphology of Damon Slough at the mouth of the channel. Changes include scouring of the channel upstream to the abutments at the I-880 crossing from increased tidal energy. However, these changes will be offset by sediment deposition in the channel from upstream sources. Determining the equilibrium between the two processes as sea levels rise will provide insight to future changes in the morphology of the channel. This can be evaluated by conducting a sediment transport study.

9. REFERENCES

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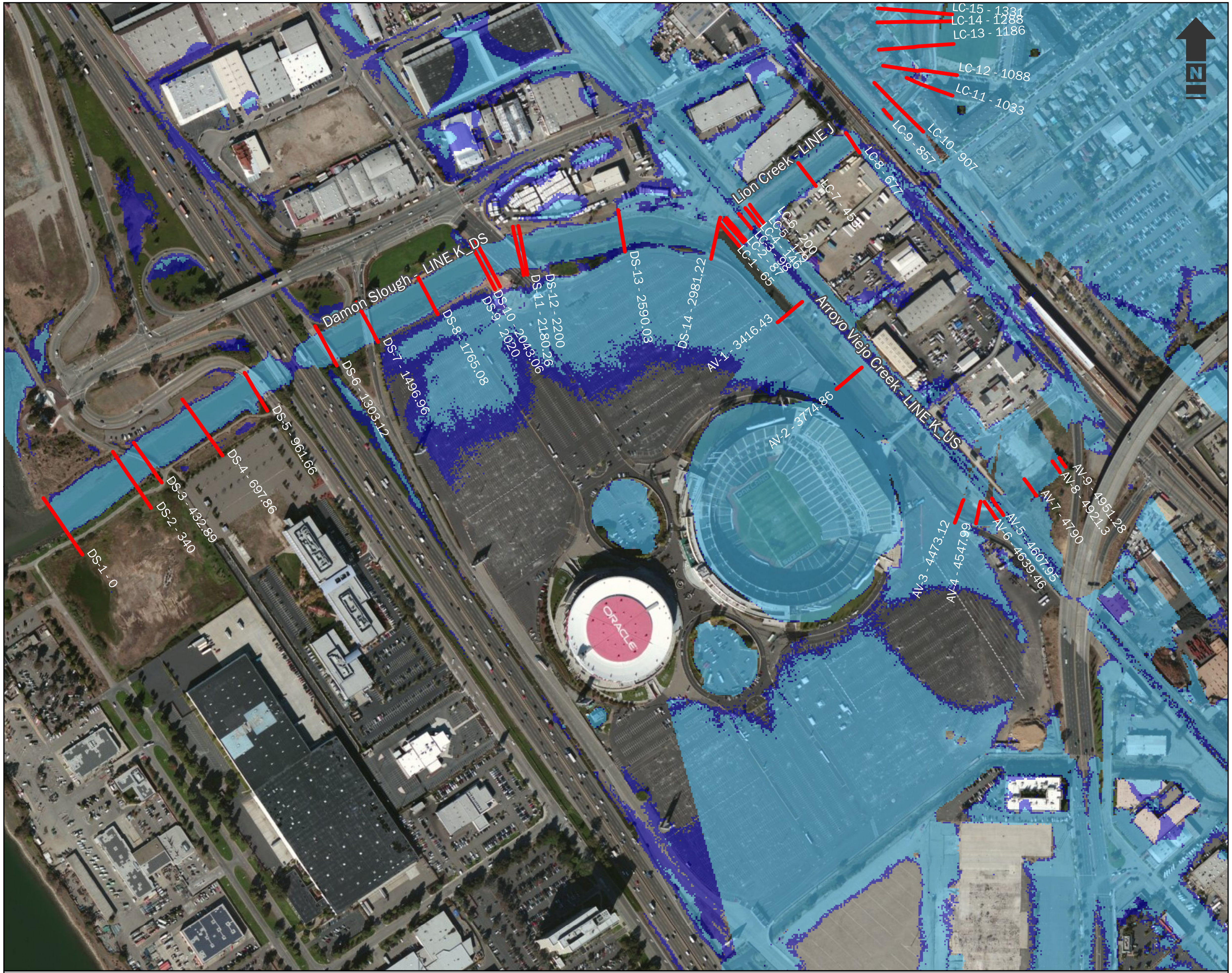
Attachment A – Flooding Extents for Selected Scenarios during Existing MHHW Tide Conditions and 24 inches of Sea Level Rise

Figure 1 – MHHW + 100-Year Peak Flow (Existing Conditions and 24" SLR)

Figure 2 – 10-Year Extreme Tide Level + 10-Year Peak Flow (Existing Conditions and 24" SLR)

Figure 3 – 10-Year Extreme Tide Level + 100-Year Peak Flow (Existing Conditions and 24" SLR)

Figure 4 – 100-Year Extreme Tide Level + 10-Year Peak Flow (Existing Conditions and 24" SLR)



MTC CLIMATE ADAPTATION
Damon Slough Focus Area
Alameda County

FLOODING EXTENTS

MHHW + 100-YR Peak Flow

MHHW (24" SLR) + 100-YR Peak Flow

HEC-RAS XS

0 250 500 1,000 Feet

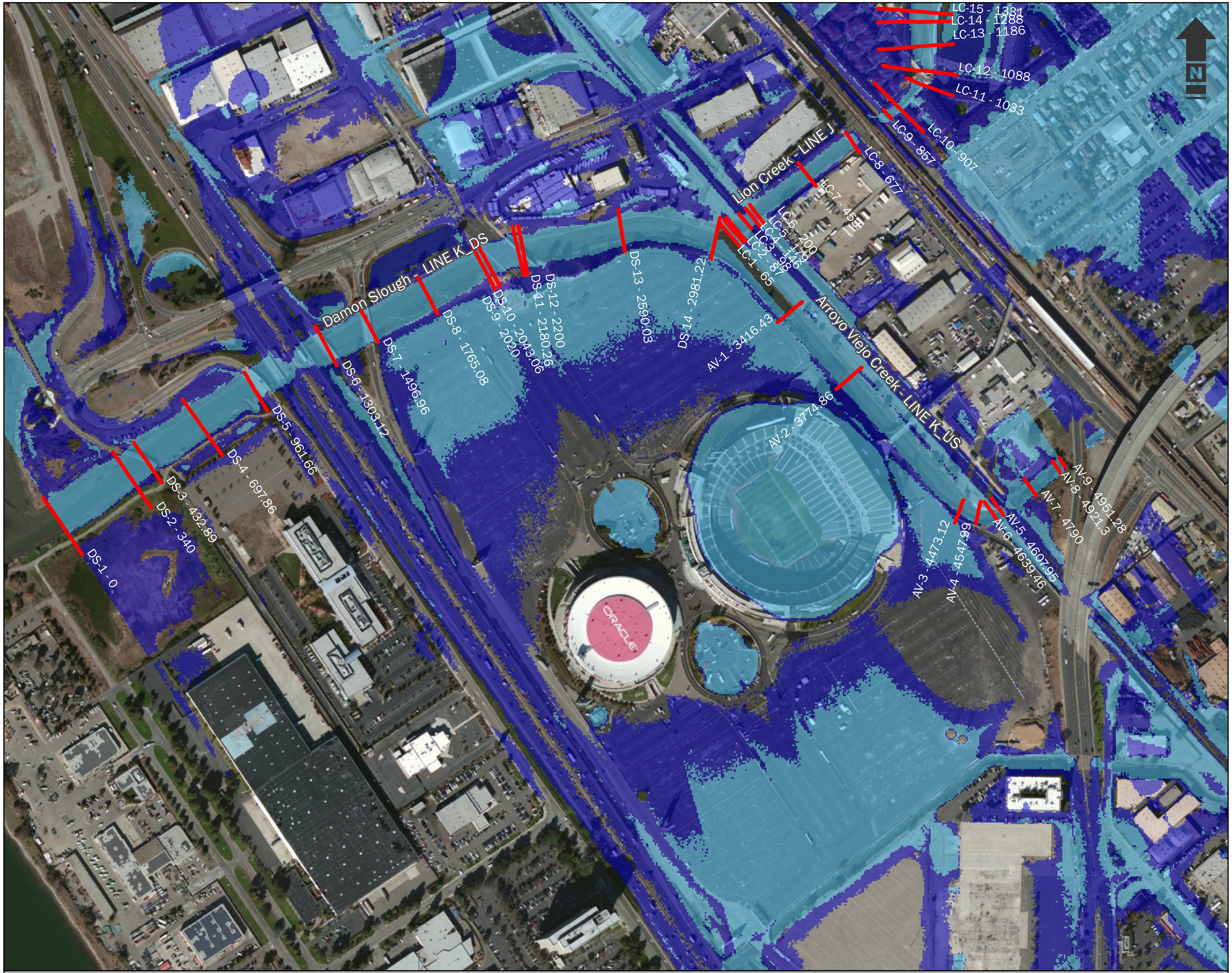
North American Vertical Datum 1988

NAD 1983 StatePlane California III FIPS 0403 Feet

AECOM

4/20/2014

FIGURE 1



MTC CLIMATE ADAPTATION
Damon Slough Focus Area
Alameda County

FLOODING EXTENTS

10-YR Extreme Tide + 10-YR Peak Flow

10-YR Extreme Tide (24" SLR) + 10-YR Peak Flow

HEC-RAS XS

0 250 500 1,000 Feet

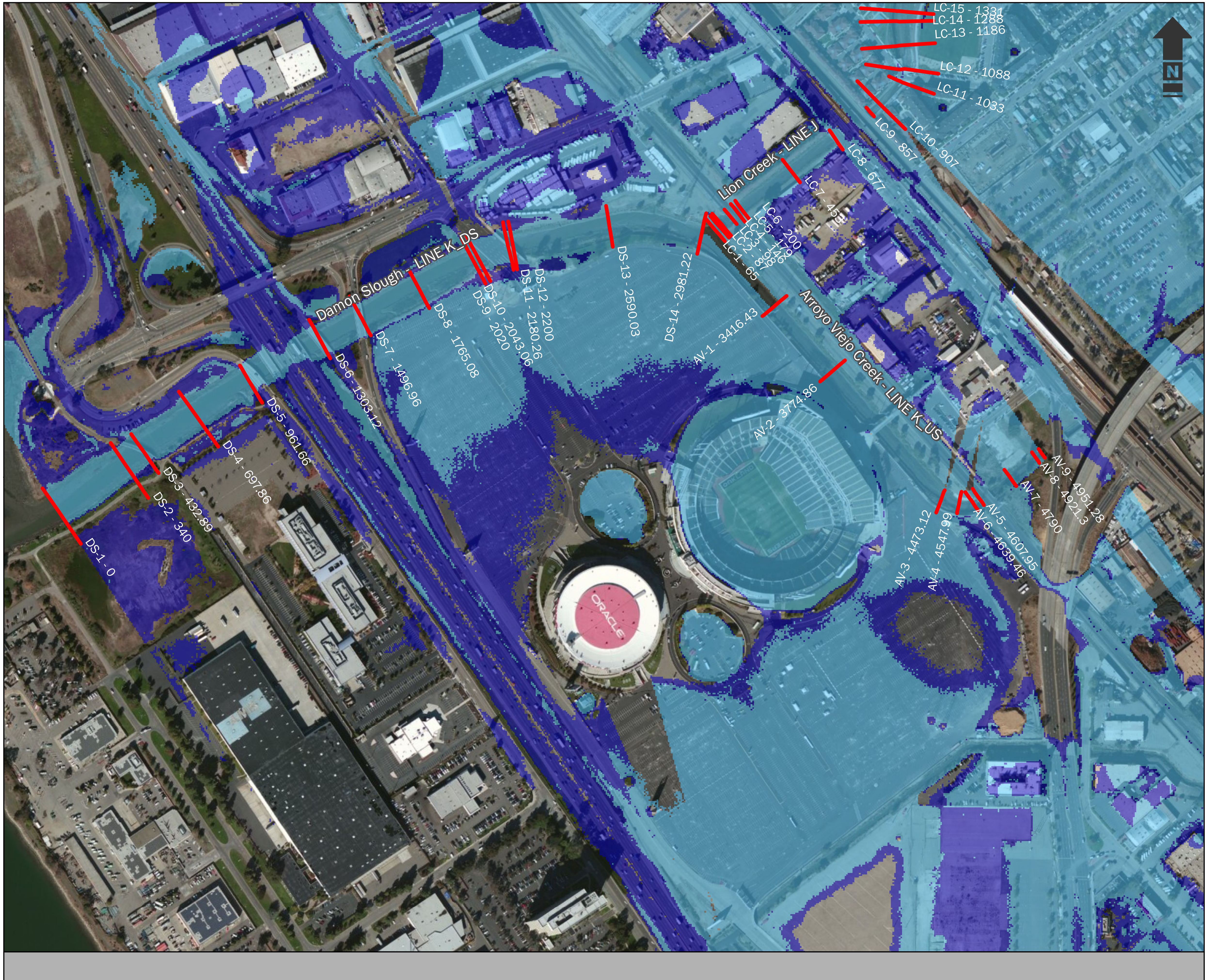
North American Vertical Datum 1988

NAD 1983 StatePlane California III FIPS 0403 Feet

AECOM

4/20/2014

FIGURE 2



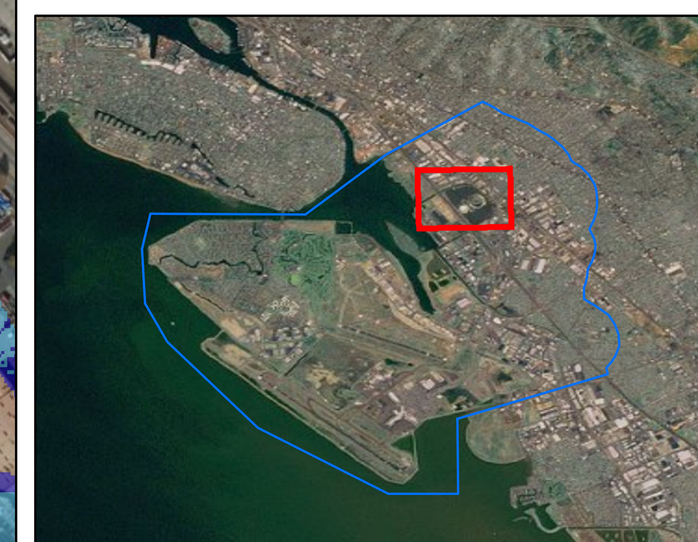
MTC CLIMATE ADAPTATION
Damon Slough Focus Area
Alameda County

FLOODING EXTENTS

10-YR Extreme Tide + 100-YR Peak Flow

10-YR Extreme Tide (24" SLR) + 100-YR Peak Flow

HEC-RAS XS



0 250 500 1,000 Feet

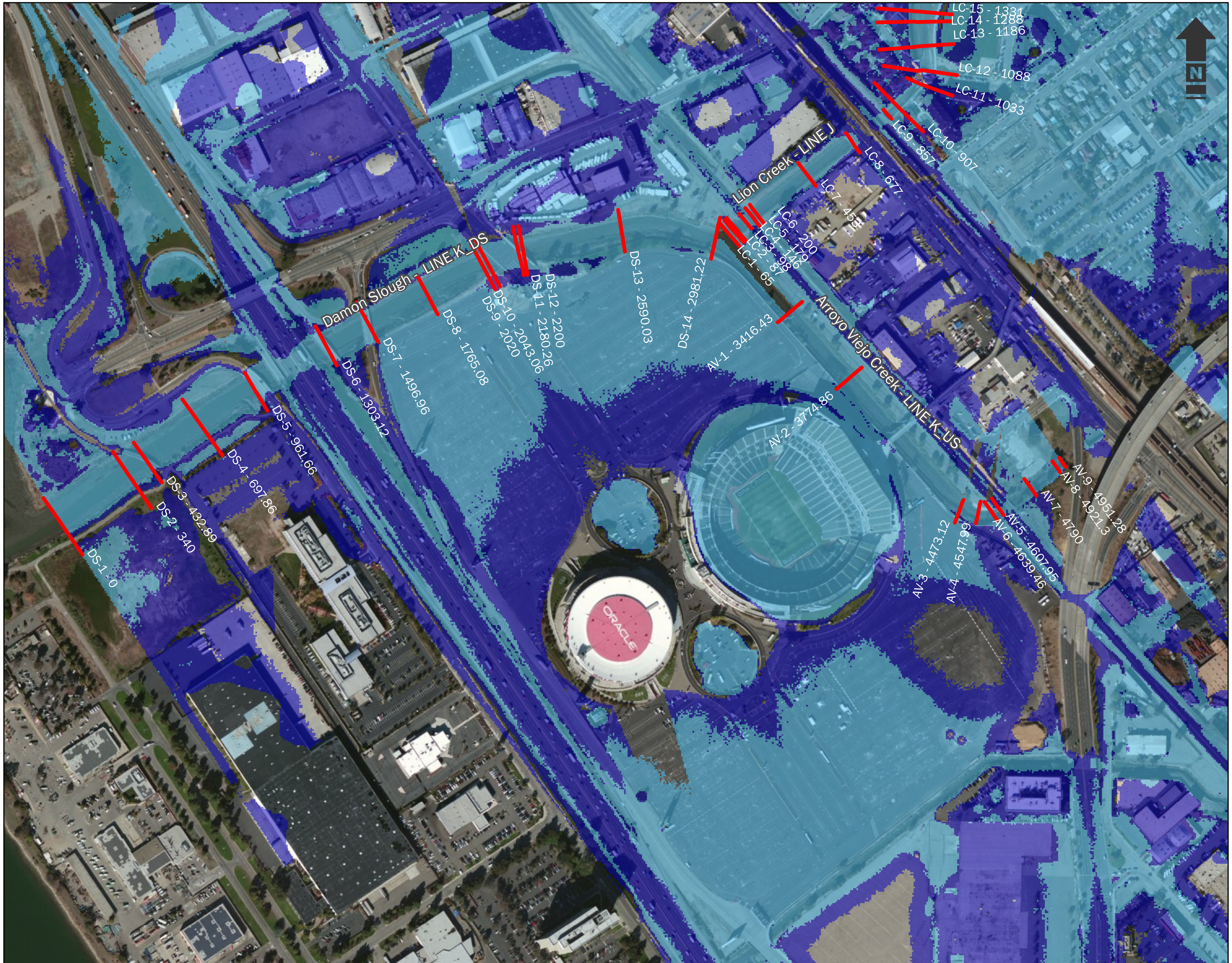
North American Vertical Datum 1988

NAD 1983 StatePlane California III FIPS 0403 Feet

AECOM

4/20/2014

FIGURE 3



MTC CLIMATE ADAPTATION
Damon Slough Focus Area
Alameda County

FLOODING EXTENTS

100-YR Extreme Tide + 10-YR Peak Flow

100-YR Extreme Tide (24" SLR) + 10-YR Peak Flow

HEC-RAS XS

0 250 500 1,000 Feet

North American Vertical Datum 1988

NAD 1983 StatePlane California III FIPS 0403 Feet

AECOM

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FIGURE 4