Colma Creek Hydrology and Hydraulic Modeling Analysis

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PREPARED FOR

COUNTY OF SAN MATEO

DEPARTMENT OF PUBLIC WORKS

FLOOD AND SEA LEVEL RISE

RESILIENCY DISTRICT

PREPARED BY

PARADIGM ENVIRONMENTAL

NORTHWEST HYDRAULIC CONSULTANTS

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EXECUTIVE SUMMARY

This report summarizes the development of hydrology and hydraulic models of the Colma Creek watershed and flood control channel. The hydrology model for this study was adapted from a previously configured and calibrated watershed model used to support countywide stormwater management planning. The hydraulic model was customized for the remnant tidal channel Navigable Slough. Colma Creek and Navigable Slough are prone to flooding, especially during high tide levels in the San Francisco Bay. The Colma Creek flood channel was designed to pass a 50-year storm (2% Annual Exceedance Probability [AEP] Flood) with 2 feet of freeboard. The models were developed to support regional planning efforts to address flooding and climate change resiliency.

The objectives of model development were to address the following:

1. Represent current hydrologic conditions for a range of design storms ranging from the 2-year (50% AEP Flood), 6-hour storm event to the 200-year (0.5% AEP Flood), 6-hour storm event, in terms of runoff volume and peak flow.
2. Evaluate the performance of planned green infrastructure (GI) in the Colma Creek watershed for mitigating runoff volume and peak flow for current hydrologic conditions.
3. Evaluate the impact of climate change using an ensemble of future climate change projections.
4. Assess how much planned GI implementation provides flood resilience to projected future climate change.
5. Determine the peak water surface elevations and minimum freeboard in Colma Creek under the range of design storms during a mean higher high tide (6.8 feet NAVD 88), as well as a 100-year storm given year 2100 sea-level rise.
6. Analyze the reduction of the extent of inundation during a 100-year storm (1% AEP Flood) provided by the Utah Avenue-Navigable Slough Floodwall.
7. Map the extent of inundation for all the modeled scenarios.
8. Provide a modeling system that can support future flood resiliency planning for Colma Creek.

Under current climate conditions, Colma Creek can pass a 50-year storm with 2 feet of freeboard for much of the channel above Utah Avenue, with some deficiency above Spruce Avenue. Below Utah Avenue, however, flooding occurred for events as frequent as the 10-year event. The areas surrounding Navigable Slough are subject to even more frequent inundation. The proposed Utah Avenue-Navigable Slough floodwall provides a measurable reduction in inundated areas during the 100-year event.

Modeling results using the ensemble of climate projections to drive the model, relative to baseline historical climate conditions, suggest that climate change causes higher-intensity storms and increases flood risk. GI can mitigate the effects of smaller, more frequent storms even as these storm magnitudes increase as a result of climate change. However, for less-frequent, larger storms, future climate conditions will drastically impact the degree of flood protection offered by the existing flood control channel. Hydraulic model results demonstrate that the current 100-year storm passes through much of the channel with 2 feet of freeboard. Under a future climate state, the 100-year storm causes flooding from Spruce to Produce Avenue and extensive flooding along Navigable Slough. Sea-level rise projected for the year 2100 (+3.01 feet) also presents a major increase in flood risk for the areas near Utah Avenue. Higher stages will result in a much larger volume of water spilling from Navigable Slough and Colma Creek below Utah Avenue.

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1 INTRODUCTION

The Colma Creek watershed drainage area encompasses 15.4 square miles of the northern San Francisco Peninsula, including portions of unincorporated San Mateo County, Daly City, Colma, South San Francisco, and San Bruno. The watershed outlet is at the confluence of Colma Creek and San Fransisco Bay. Much of the watershed consists of developed impervious and semi-impervious areas. Undeveloped portions of the watershed include the southwest face of San Bruno Mountain.

Colma Creek is a 5.4 mile-long reach tributary to San Francisco Bay, between A Street downstream to its confluence with Navigable Slough. The County of San Mateo Department of Public Works (Public Works) maintains the Colma Creek flood control channel in order to safely convey runoff collected by the stormwater system into the San Francisco Bay. Prior to the construction of flood control improvements, lower reaches of the Colma Creek watershed were prone to flooding, especially during high Bay water levels.

Public Works has delineated three primary reaches in Colma Creek for planning and conducting maintenance:

- **Reach 1: A Street/El Camino Real to Spruce Avenue** – This segment consists entirely of a concrete- lined channel and concrete box culverts. Downstream of A Street, the channel is culverted and then daylights from the entrance to the Holy Cross Cemetery along Mission Road. The channel is also culverted beneath the South San Francisco BART station. Immediately downstream of the BART station, the creek transitions to an open trapezoidal concrete channel. This reach is not tidally influenced.
- **Reach 2: Spruce Avenue to Produce Avenue** – Colma Creek flows through a concrete U-shaped channel. Approximately one foot of sediment has deposited across the channel bed, though in some locations, deposition is greater (Horizon, 2016). This section of Colma Creek is tidally influenced but is only inundated during high tides.
- **Reach 3: U.S Highway 101 to the confluence of Navigable Slough at the Produce Avenue crossing** – Colma Creek transitions to an earthen channel. The channel is approximately 70 to 80 feet wide, and the bed is comprised of soft sediments. The banks have a narrow band of emergent marsh dominated by pickleweeds, which transitions to an upland community dominated by ruderal species. The channel widens as Colma Creek flows toward the Bay. At the mouth of the creek, there is a wetland complex characterized by broad expanses of mudflat habitat with narrow bands of intertidal marsh, rocky intertidal areas, and upland habitats along the shoreline-Bay ecotone. This reach is tidally influenced.

Because of the connection of Colma Creek to San Francisco Bay, water levels in Reach 2 and 3 during flood events can be influenced by tide levels. Before entering the Bay, Colma Creek also receives water from Navigable Slough, a remnant tidal channel. The slough channel passes through culverts under South Airport Boulevard and Highway 101 before joining Colma Creek 3,200 feet downstream of its start near San Mateo Avenue.

This report outlines the development of a hydrology model of the Colma Creek watershed, including Navigable Slough, and the routing of those hydrographs in a coupled 1D/2D hydraulic model of Colma Creek and Navigable Slough. The hydrology model used was developed by Paradigm Environmental for the City/County Association of Governments of San Mateo County (C/CAG) (SMCWPPP 2018). Scenarios examined for this study included rainfall events ranging from the 2- to the 200-year events under: 1) current hydrology, 2) the addition of GI projects, and 3) possible future climate conditions.

2 HYDROLOGIC MODEL DEVELOPMENT

The model used for this study is a high-resolution hydrology and water quality model that was configured and calibrated to support countywide stormwater management planning. As described in Section 2.2, high-resolution spatial characterization of land cover and meteorological conditions makes that model a robust predictor for local hydrology and a useful tool for this study. Model subwatersheds were subdivided to align with inflow points to the hydraulic model. Model inputs were then resampled according to the revised delineation. This section describes (1) subwatershed delineation for discretizing hydrological inputs to the hydraulic model for flood modeling, (2) model parameterization for representing current hydrology, and (3) development of local design storms hyetographs to serve as meteorological boundary conditions for modeling flooding events.

2.1 Subwatershed Delineation

The area surrounding Colma Creek was delineated into subwatersheds using 25 points of interest as drainage points. Of the 25 points of interest, 15 represent inlets to the hydraulic model and 10 represent locations of high flow suggested by Public Works. The points of interest and their respective subwatersheds can be seen in Figure 2-1 below.

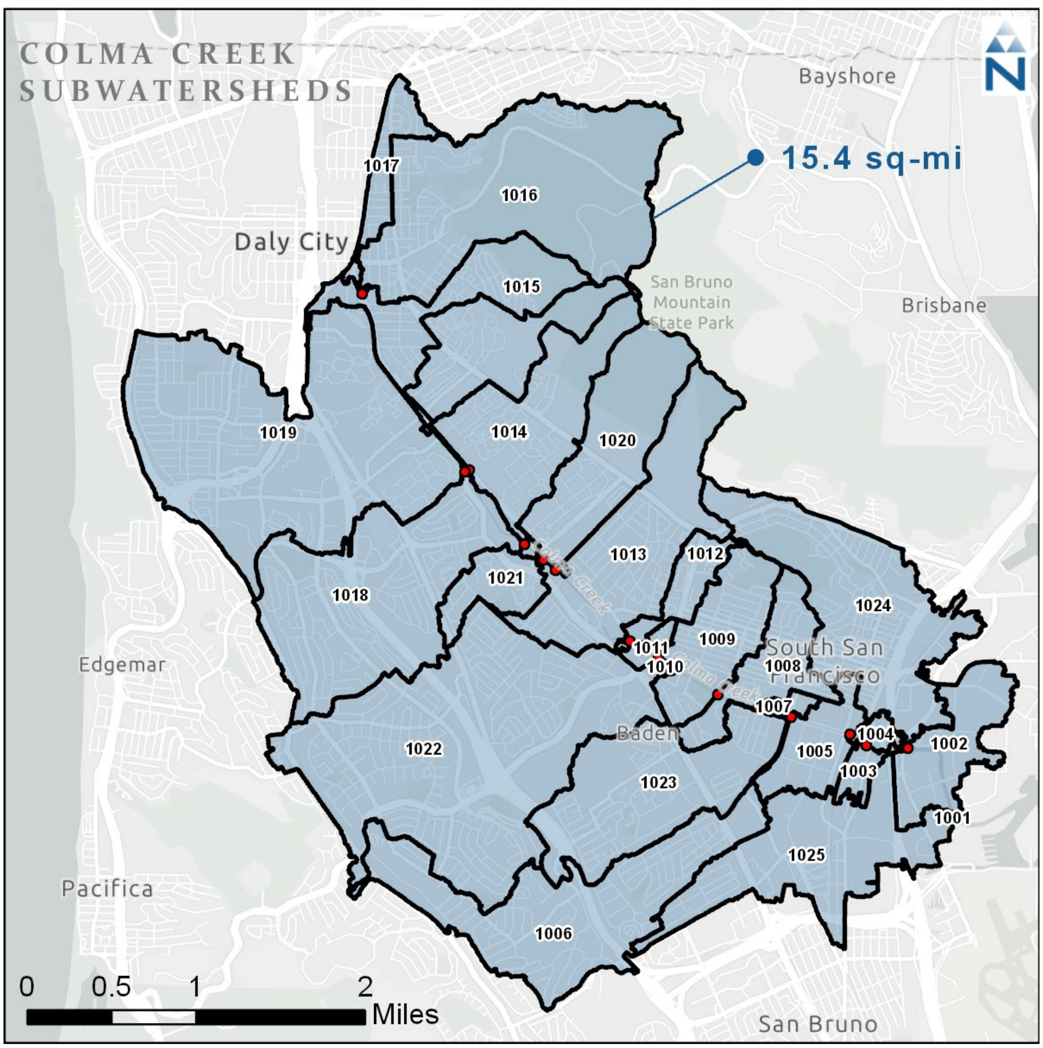


Figure 2-1. Modeled Colma Creek subwatersheds.

2.2 Current Hydrology

The current hydrology was modeled using the Loading Simulation Program in C++ (LSPC). The model provides dynamic (hourly) simulation of rainfall/runoff processes within each subwatershed for prediction of flow inputs to the separate hydraulic model. The model was built using datasets that describe land, meteorological, and hydrological characteristics of the subwatersheds. A Hydrologic Response Unit (HRU) represents the smallest modeling unit in LSPC. An HRU represents the unique combination of physical characteristics including land use/land cover, soil type, and slope. Table 2-1 lists and describes the data sources used to represent HRUs in the model. Figure 2-3 conceptually illustrates the intersection of the various layers described in Table 2-1 and summarizes the final HRU area distribution for the Colma Creek watershed. The parameters associated with HRUs are collectively used to simulate aggregated hydrologic and water quality responses which are then routed to each of the 25 subwatershed points of interest.

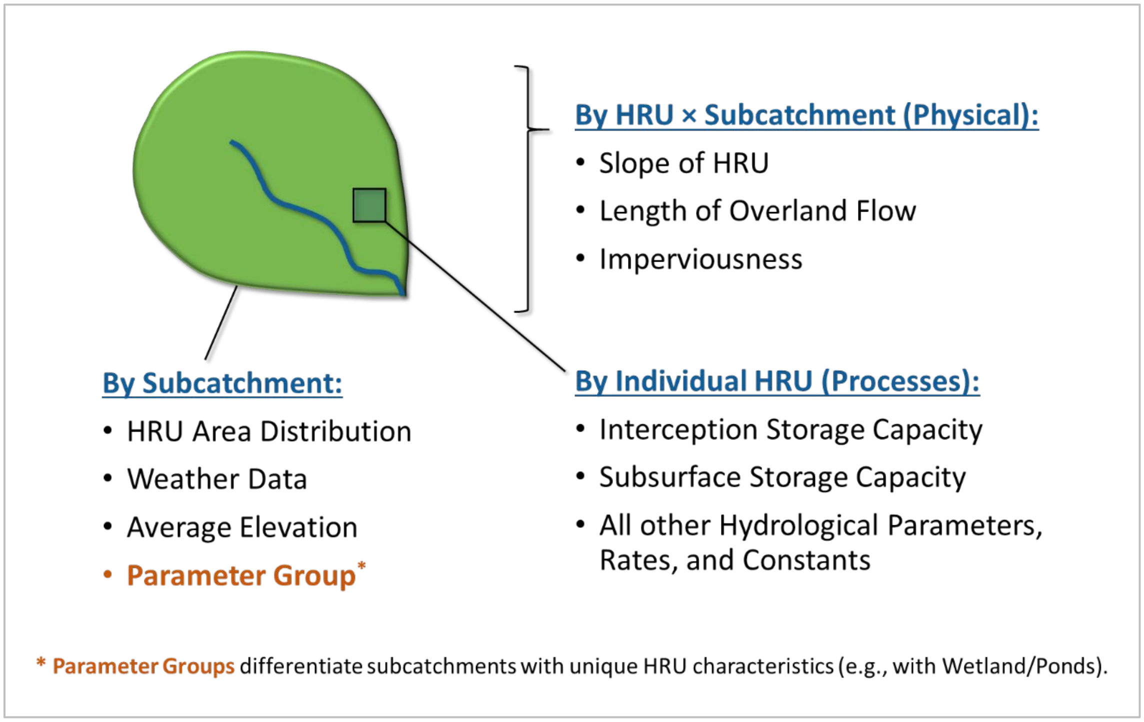
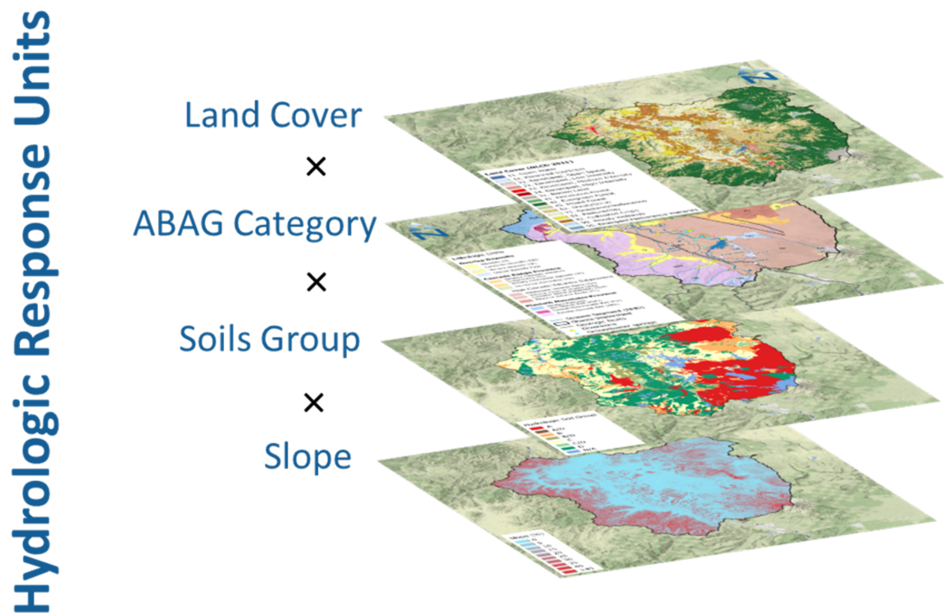


Figure 2-2. Conceptual organization of model parameters within LSPC.

Table 2-1. Data used for HRU analysis

GIS Layer	Description	Source
Land Cover	Polygon layer – contains vegetation type (if any).	National Land Cover Database
Soil Type	Polygon layer – contains soil type.	United States Department of Agriculture
ABAG Category	Land use classification – contains land use as classified by ABAG.	Association of Bay Area Governments
Slope	Raster layer - contains slope information.	Generated from DEM



Group	Description	Area (Acres)	Percent
Land Cover	Developed	8,609	87%
	Forest	552	6%
	Shrub/Grass	683	7%
ABAG Category	Open	2,879	29%
	New Urban	16	0%
	New Industrial	58	1%
	Old Industrial	529	5%
	Old Residential	3,051	31%
	Old Urban	3,192	32%
	Source Areas	120	1%
Soil Type	B	21	0%
	C	6,017	61%
	D	158	2%
	Impervious	3,648	37%
Slope	Low	9,079	92%
	Med	765	8%

Figure 2-3. Conceptual intersection of HRU layers and the summary table of Colma Creek watershed HRU distribution.

2.3 Design Storms

Point precipitation volume estimates and distributions were downloaded from The National Oceanic and Atmospheric Administration's (NOAA) Atlas 14 frequency estimates at San Francisco WSO AP gage (047769), which is 1 mile from the Colma Creek outlet (NOAA 2014). Figure 2-4 presents distributions for the cumulative percentage of precipitation to fall over a 6-hour event by probability of occurrence. 6-hr duration storms were selected for the recent Colma Creek analysis to be consistent with the Drainage Master Plan (1991) and Hydrologic Analyses of Colma Creek Storm Drainage System (2008). The 90% distribution, prominently featured in the graph below, was selected because it represents the most conservative wetting sequence for flooding.

Time (hours)	Distributions of Cumulative Percent of Precipitation by Probability of Occurence								
	90%	80%	70%	60%	50%	40%	30%	20%	10%
0.0	0	0	0	0	0	0	0	0	0
0.5	2.35	3.41	4.31	5.03	6.01	6.9	7.98	9.22	12.19
1.0	5.6	7.49	9.18	10.99	12.75	14.45	16.52	19.13	24.36
1.5	9.86	13.18	15.79	18.49	20.87	23.26	26.04	30.16	36.76
2.0	15.35	20.39	23.89	27.14	30.06	32.97	36.33	41.58	48.94
2.5	22.3	28.76	32.95	36.45	39.86	43.08	46.96	52.65	60.37
3.0	30.8	38.04	42.6	46.18	49.91	53.24	57.55	63.01	70.7
3.5	40.74	48.07	52.67	56.26	59.97	63.27	67.73	72.58	79.73
4.0	51.81	58.7	63.03	66.51	69.83	72.91	77.07	81.26	87.3
4.5	63.58	69.61	73.36	76.48	79.09	81.76	85.11	88.66	93.18
5.0	75.6	80.311	83.12	85.44	87.25	89.25	91.4	94.14	97.12
5.5	87.64	90.34	91.83	92.94	93.99	95.06	95.98	97.41	99.08
6.0	100	100	100	100	100	100	100	100	100

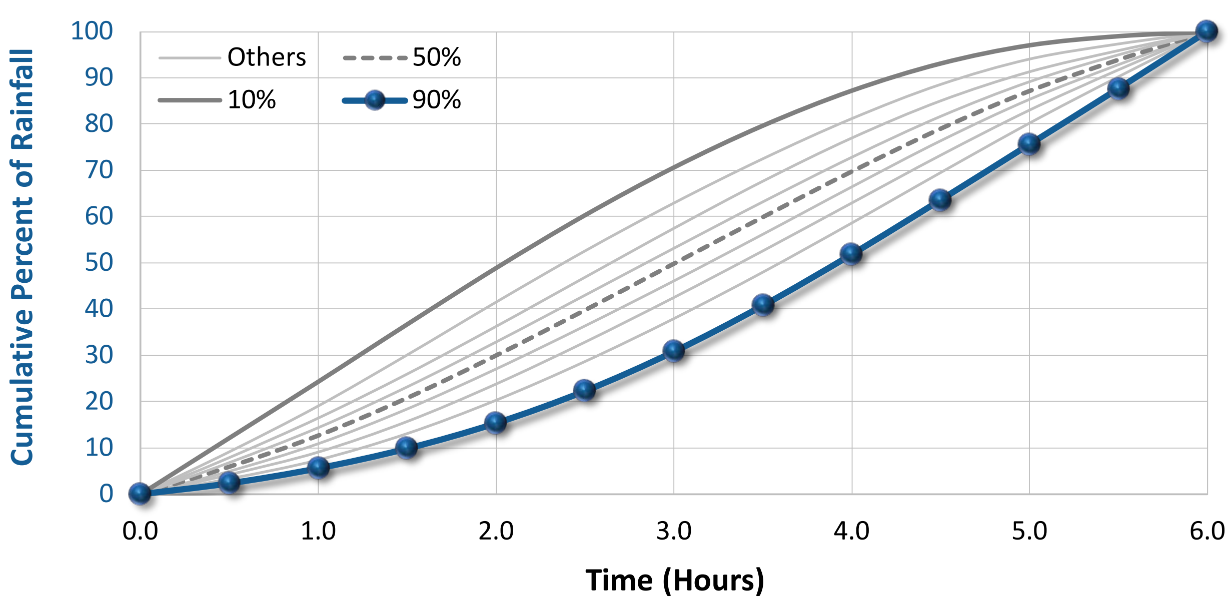


Figure 2-4. Storm distribution for 6-hour hyetographs (90% occurrence).

Because peak flood discharges can be sensitive to the simulation timestep, the 90% occurrence distribution was disaggregated from the native 30-minute timestep to a 5-minute timestep to generate boundary condition runoff for the hydraulic model. A best-fit polynomial function was used to derive the 5-minute incremental storm hyetograph, as shown in Figure 2-5. Recurrence intervals were also calculated using the historical rainfall record at the San Francisco WSO AP gage (Table 2-2). Totals were disaggregated to a 5-minute timestep using the incremental rainfall distribution in Figure 2-5.

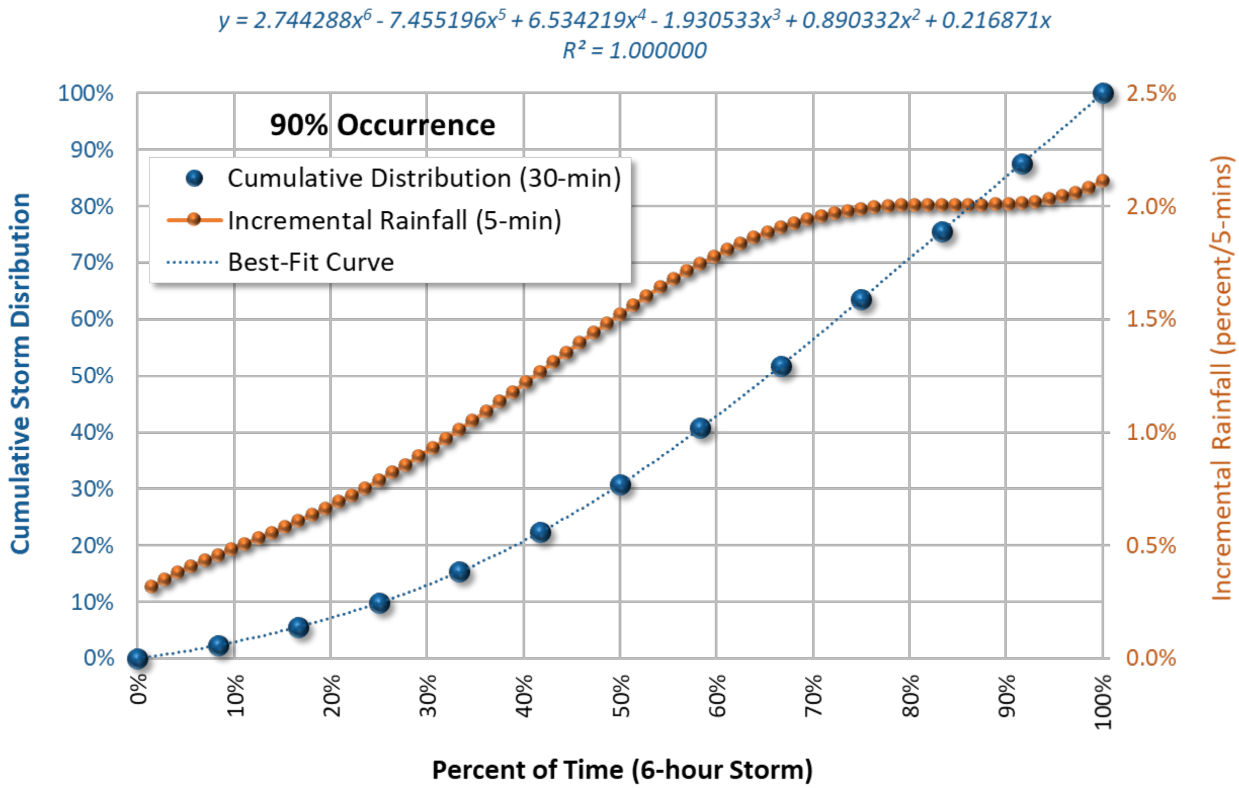


Figure 2-5. Storm distribution for 6-hour hyetographs (90% occurrence).

Table 2-2. Historical rainfall depths by recurrence interval at the San Francisco WSO AP Atlas 14 gage

Scenario	6-hour Storm Size (in.) by Recurrence Interval						
	2-yr	5-yr	10-yr	25-yr	50-yr	100-yr	200-yr
Historical	1.41	1.73	1.99	2.35	2.64	2.93	3.25

Predictions of single storm events are extremely sensitive to assumptions about initial soil moisture conditions. To ensure saturated soil moisture conditions for each design storm, sensitivity tests were performed to determine how many days of antecedent storms were required to reach steady-state soil saturation. The runs showed that after inundation during consecutive days of 6-hour storms (separated by 18 dry hours), soil moisture reached a steady-state saturation with no excess runoff. The model was run in this manner for 11 consecutive days and model results were evaluated on Day 11 for each storm. Figure 2-6 shows runoff hydrograph comparisons for Days 1 and 2 (dry) versus Days 10 and 11 (wet) for 2-year and 100-year storms. The graphs show that the 'wet' curve reaches a steady-state saturated soil condition by day 10 for both the 2-year and 100-year storms, ensuring that the model was unbiased with regard to assumptions about initial moisture conditions.

Hydrograph inputs for the hydraulic model (Section 3) were taken from the 11th day of the simulated time period.

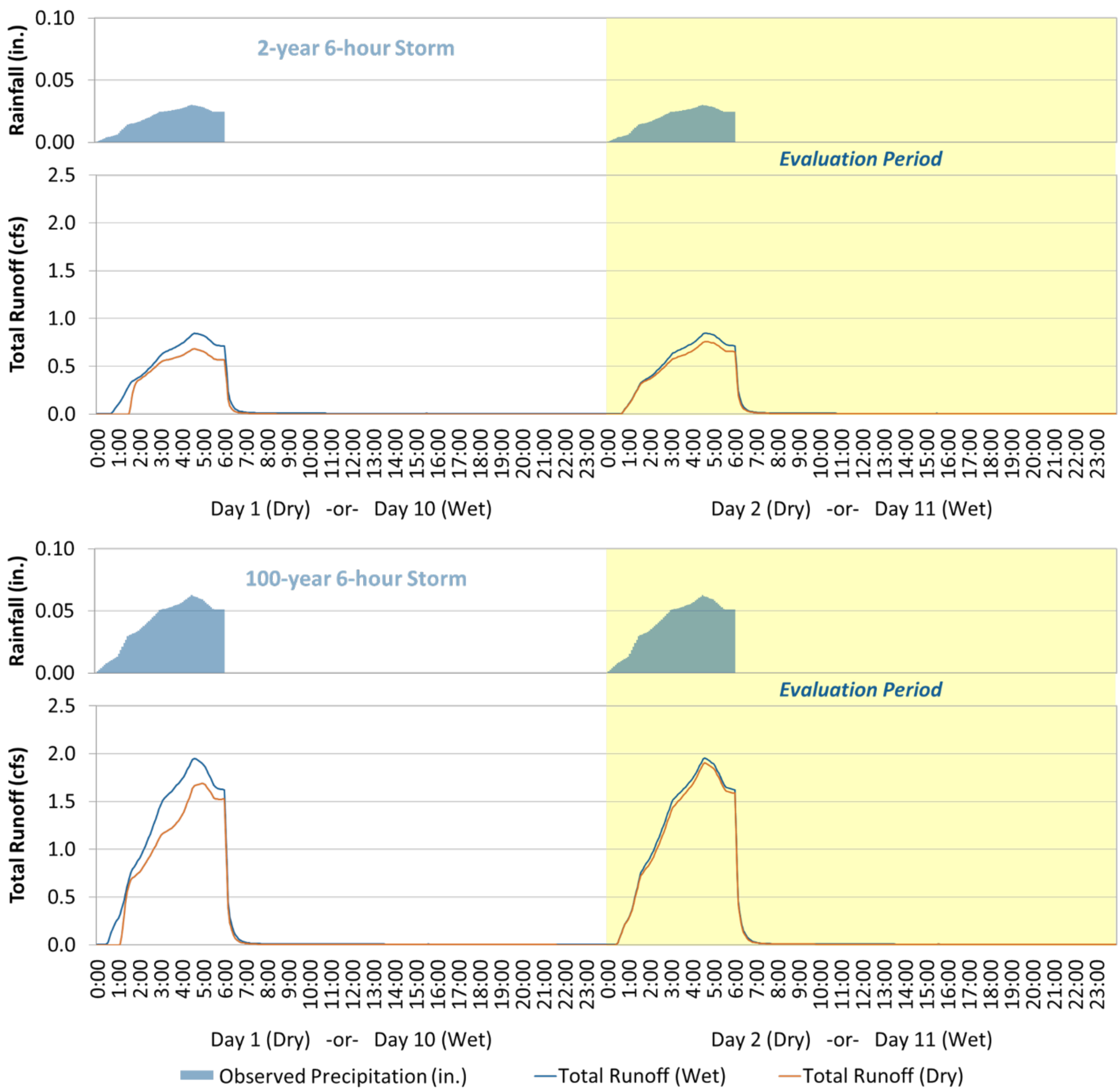


Figure 2-6. Validation of saturated conditions for 2-year and 100-year 6-hour storms.

2.4 GI Benefit Analysis

An assessment of GI performance was conducted using a countywide watershed and stormwater management modeling system that was previously applied for a study led by C/CAG for a Reasonable Assurance Analysis (RAA). The RAA supported the development of GI Plans for each municipality within San Mateo County to demonstrate compliance with the Municipal Regional Stormwater Permit (MRP) (SMCWPPP 2018 and 2019). The objective of the RAA was to identify how much additional GI (expressed as low-, medium-, and high-priority green street opportunity) was required to achieve water quality objectives by 2040 while minimizing overall lifecycle costs. The current-conditions hydrology model integrated insights from decades of local research, monitoring, and modeling conducted by several agencies. The effectiveness of potential GI solutions was modeled using a combination of LSPC and the System for Urban Stormwater Treatment and Analysis INtegration (SUSTAIN). LSPC was used to simulate hydrology for each model subwatershed, while SUSTAIN was used to simulate GI hydraulic processes and reductions of runoff volumes.

The modeled baseline scenario for the RAA was a continuous simulation of runoff volume for water year 2002 (10/1/2001 –9/30/2002), an average annual hydraulic condition identified in the *Bay Area Reasonable Assurance Analysis Guidance Document* (BASMAA 2017). The baseline scenario also included: (1) existing facilities, (2) MRP-required GI for projected new and redevelopment areas, and (3) five large regional projects that provide stormwater capture, infiltration, and treatment from multiple jurisdictions. One of those five regional projects was completely contained within the Colma Creek watershed. It is an inline treatment facility at Orange Memorial Park that treats about 67 percent of the watershed. Table 2-3 lists the dimensional and operational specifications for Orange Memorial Park. Figure **2-7** shows the drainage area of the Orange Memorial Park regional project within the Colma Creek watershed.

Table 2-3. Dimensional and operational specifications for the Orange Memorial Park regional facility.

Orange Memorial Park Facility			
Dimensions		Operations	
Footprint	1.2 acres	Diversion:	35 cfs
Storage	5.4 acre-ft	Infiltration/Drawdown:	0.5 in./hr.
Depth	2.5 ft	Filtration Outflow:	10 cfs

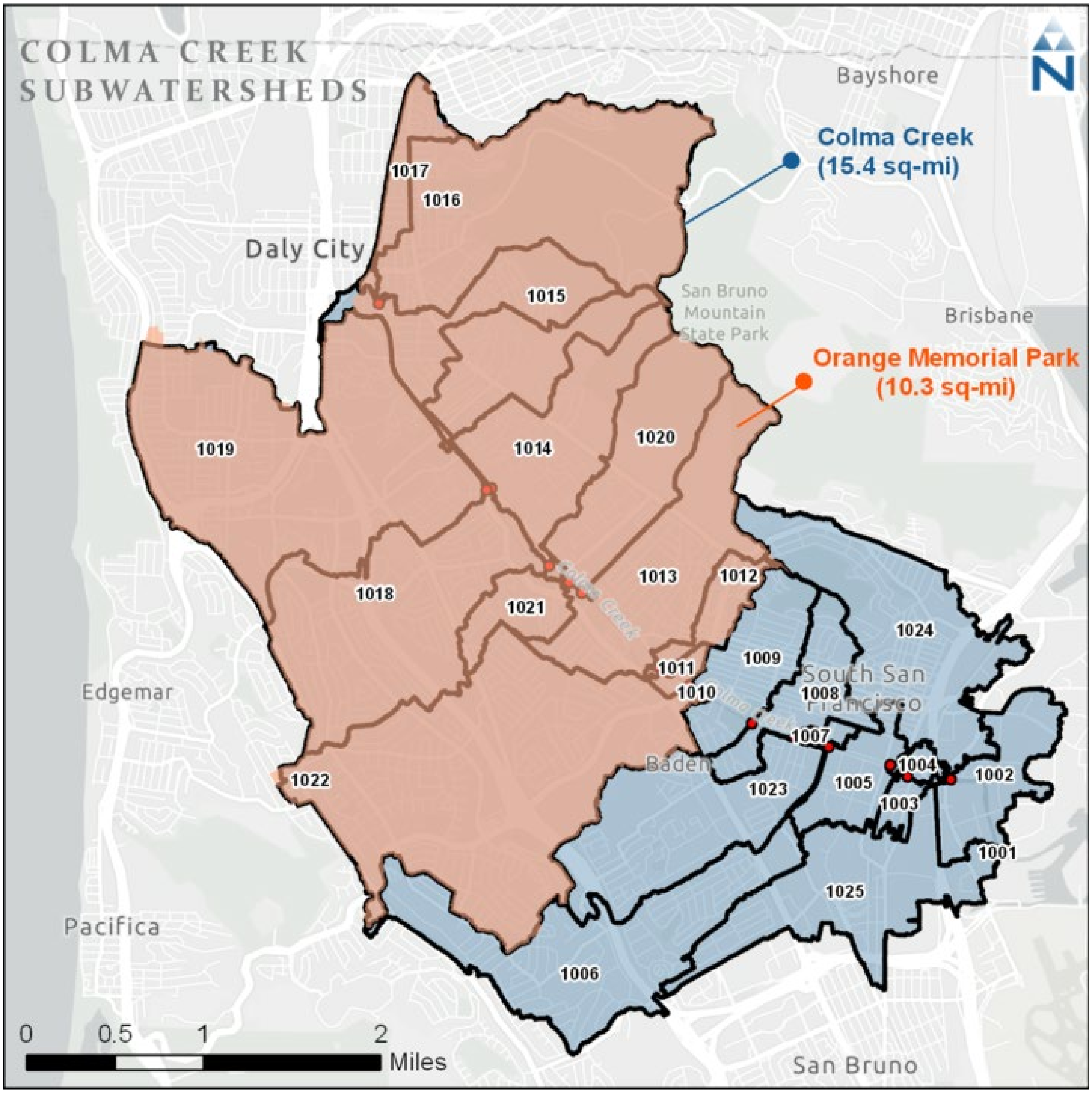


Figure 2-7. Drainage area for Orange Memorial Park regional project within the Colma Creek watershed.Table 2-4 summarizes the modeled capacity for all other GI within the Colma Creek watershed (not including the Orange Memorial Park regional project). The GI capacities summarized in Table 2-4 were also modeled within the Colma Creek watershed for a baseline representing current hydrology as well as the future climate change scenarios.

Table 2-4. Modeled Green Infrastructure capacities for Colma Creek subwatersheds.

Sub-watershed	Modeled Green Infrastructure Capacity (acre-feet) [1, 2]						
	Total Capacity	Existing/Planned		Green Streets			Other GI Projects (TBD)
		Existing Projects	Future New & Redevelopment	High	Medium	Low	
Total	**48.29**	**22.24**	**8.64**	**15.49**	**1.22**	**0.54**	**0.16**
1001	**0.00**	0.00	0.00	0.00	0.00	--	--
1002	**1.99**	0.85	0.37	0.75	0.02	--	--
1003	**0.46**	0.20	0.08	0.17	0.00	--	--
1004	**0.28**	0.11	0.05	0.11	0.00	--	--
1005	**1.71**	0.75	0.31	0.63	0.01	--	--
1006	**5.36**	1.97	1.03	2.28	0.08	--	--
1007	**0.07**	0.03	0.01	0.03	0.00	--	--
1008	**1.97**	0.75	0.38	0.82	0.02	--	--
1009	**1.10**	0.14	0.37	0.57	0.01	--	--
1010	**0.01**	0.00	0.00	0.00	0.00	--	--
1011	**0.11**	0.02	0.04	0.05	0.00	--	--
1012	**0.40**	0.03	0.14	0.22	0.00	--	--
1013	**1.58**	0.23	0.48	0.83	0.04	--	--
1014	**0.26**	0.06	0.06	0.14	0.00	--	--
1015	**0.54**	0.25	0.14	0.12	0.03	0.00	0.00
1016	**1.01**	0.42	0.28	0.25	0.07	--	--
1017	**0.10**	0.04	0.03	0.02	0.01	--	--
1018	**2.01**	0.72	0.30	0.63	0.35	0.00	0.00
1019	**10.15**	8.68	0.50	0.24	0.04	0.54	0.16
1020	**0.51**	0.07	0.13	0.30	--	--	--
1021	**0.36**	0.13	0.06	0.11	0.06	--	--
1022	**3.99**	1.16	1.15	1.38	0.30	--	--
1023	**4.50**	1.67	0.86	1.90	0.06	--	--
1024	**5.61**	2.19	1.06	2.29	0.07	--	--
1025	**4.21**	1.78	0.78	1.62	0.04	--	--

1: The RAA also includes Orange Memorial Park, which is modeled directly in the hydraulic model and not represented in the table.

2: Color gradients show Low (White) to High (Dark) GI capacity (by Subwatershed and Total).

2.5 Climate Change Scenarios

One objective of the Colma Creek study was to assess the potential future impacts of climate change on the hydrology of the watershed. This section describes the selected climate change scenarios, the methodology for the climate change analysis, and the results and outcomes.

2.5.1 Boundary Conditions

For this analysis, an ensemble of 20 climate change projections from the California Department of Water Resources was considered. The projections are from two future projection carbon emissions scenarios, or Representative Concentration Pathways (RCPs) 4.5 and 8.5, from 10 global climate models (GCMs) as recommended by the Climate Change Technical Advisory Group. The two selected RCPs are best- and worst-case projections of future carbon emissions. RCP 8.5 represents a scenario in which carbon emissions continue to climb at historical rates, whereas the RCP 4.5 predicts a stabilization of carbon emissions by 2100 (IIASA 2009). Although these are estimated future trajectories, comparisons to actual emissions levels at the time of the study suggest that observed emissions have been outpacing the RCP 8.5 scenario (Figure 2-8).

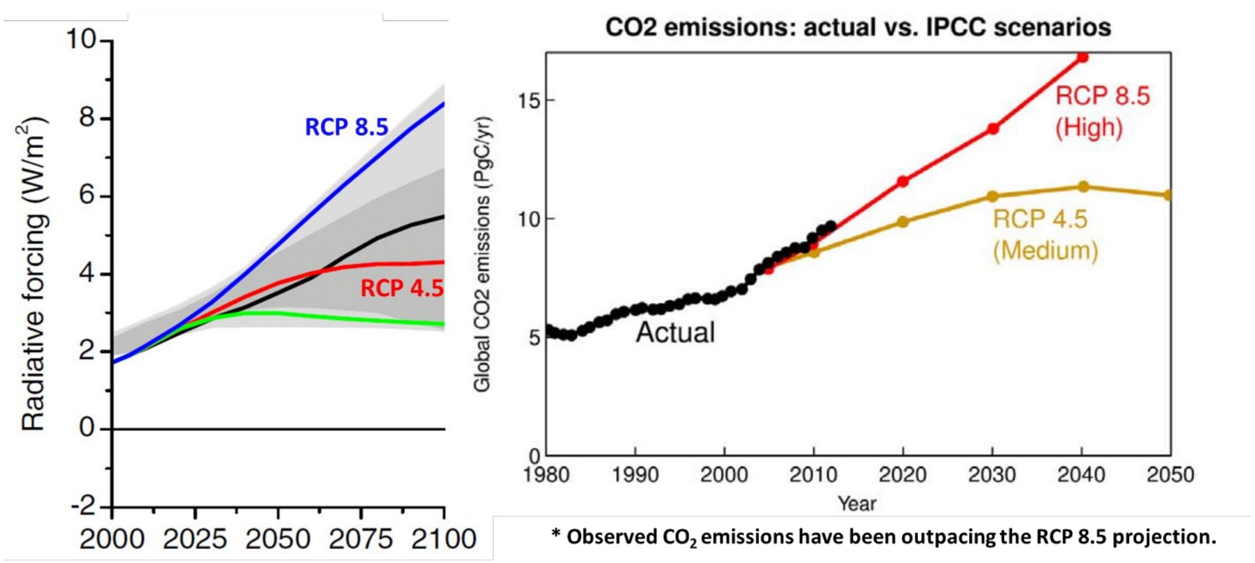


Figure 2-8. Selected Representative Concentration Pathways for climate change analysis (IIASA 2009).

After evaluating the central tendency and spread of the full ensemble of GCM projections, Pierce et al. (2016) identified four representative models that bracket the range of projected future climate change. As described in Table 2-5, the models include cool/wet (CNRM-CM5), average (CCSM4), and warm/dry (GFDL-CM3) climatic conditions, as well as one that is dissimilar to the other three (HadGEM2-CC) that generally projects cool/dry conditions associated with small storms and warm/wet conditions associated with large storms. The aggregated mean of those four models provides a robust sample set for climate change analysis.

Table 2-5. Description of Global Climate Model Scenarios

Global Climate Model		Description
Scenario	Historical Baseline	Describe key assumptions, representative period
	RCP 4.5 *Stabilization*	Radiative forcing level stabilizes at 4.5 W/m^2 before 2100 by employment of a range of technologies and strategies for reducing greenhouse gas emissions.
	RCP 8.5 *Business-as-Usual*	Radiative forcing level reaches 8.5 W/m^2 before 2100 as greenhouse gas emissions continue to rise on the current trajectory.
Model	GFDL-CM3[1]	Model representing Warm/Dry[5] scenario
	CCSM4[2]	Model representing Average[5] scenario
	CNRM-CM5[3]	Model representing Cool/Wet[5] scenario
	HadGEM2-CC[4]	Most dissimilar to other three models[5]

1: Cal-Adapt, NOAA Geophysical Fluid Dynamics Laboratory
2: Cal-Adapt, National Science Foundation, US Department of Energy, US National Center for Atmospheric Research
3: Cal-Adapt, Centre National de Recherches Meteorologiques
4: Cal-Adapt, United Kingdom Meteorological Office
5: California Energy Commission

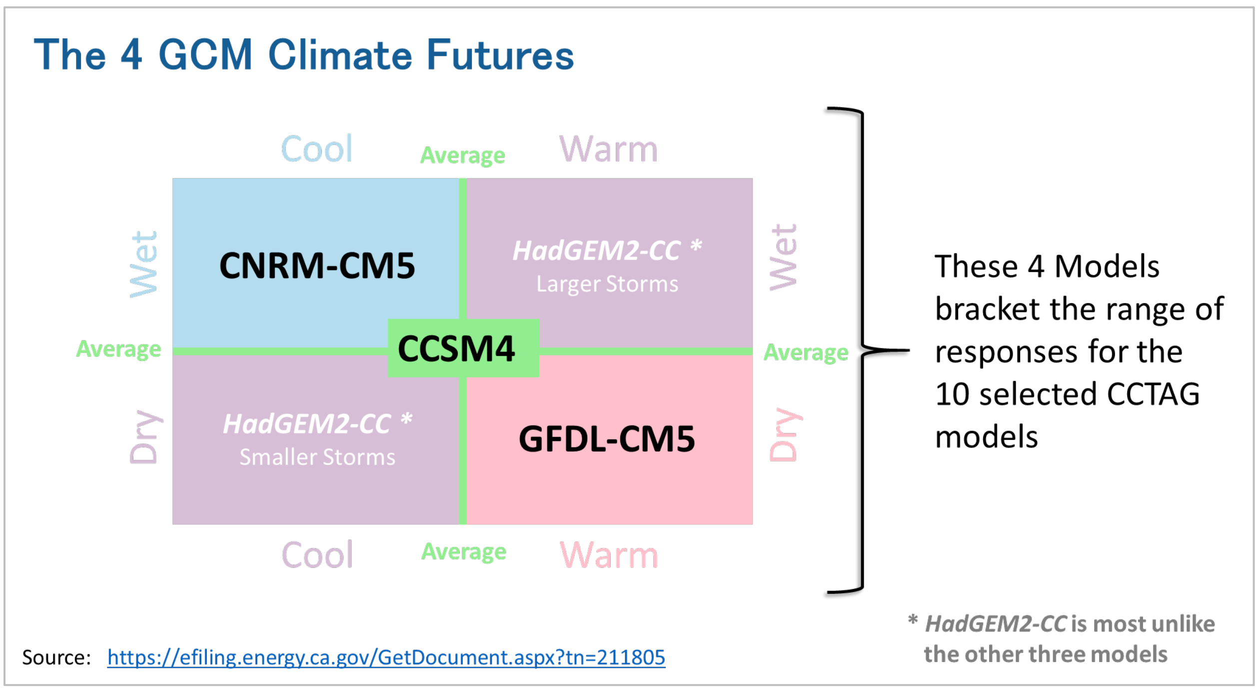


Figure 2-9. Climate futures represented by the selected Global Climate Models.

2.5.2 Projected Storm Sizes

6-hour storm rainfall hyetographs were generated for each climate future (combination of GSM and RCP scenario). Daily timeseries for a modeled historical (1950-2005) and climate future (2006-2100) were retrieved and analyzed from each GCM. Generalized Extreme Value probability distributions were fit to each timeseries from which storms of varying return frequencies were calculated (2-, 5-, 10-, 25-, 50-, and 100-year). For each combination of GCM, RCP scenario, and return period, the ratio of the projected rainfall depth to historical rainfall depth was calculated to reflect the projected impact of climate change on historical rainfall. Table 2-6 is a summary of the projected storm sizes for each GCM under the two RCP scenarios. Additionally, the mean and median of the four GCMs are reported.

Summary statistics for the four GCMs under RCP 4.5, the four GSMs under RCP 8.5, and all eight combinations of GCMs and RCP scenarios (All Futures) are shown in Table 2-7. Projected future storms that exceeded the magnitude of the historical 200-year storm are highlighted in Table 2-6 and Table 2-7.

These summaries show that the greatest impact from projected climate futures is seen in the lower frequency, more intense storm events, suggesting an increased likelihood of extreme flooding events.

Table 2-6. Summary of design storm sizes by climate change scenario

Climate Change		6-hour Storm Size (in.) by Return Period [1]					
Scenario	Model	2-yr	5-yr	10-yr	25-yr	50-yr	100-yr
Current (Historical)		1.41	1.73	1.99	2.35	2.64	2.93
RCP 4.5	Mean (4.5)	1.51	1.94	2.28	2.76	3.15	3.56
	Median (4.5)	1.46	1.79	2.09	2.48	2.79	3.11
	CNRM-CM5	1.78	2.44	3.00	3.85	4.59	5.39
	CCSM4	1.47	1.83	2.13	2.49	2.77	3.05
	GFDL-CM3	1.45	1.73	1.93	2.21	2.43	2.64
	HadGEM2-CC	1.35	1.75	2.05	2.47	2.80	3.16
RCP 8.5	Mean (8.5)	1.54	2.02	2.43	3.04	3.58	4.19
	Median (8.5)	1.51	1.88	2.22	2.74	3.21	3.75
	CNRM-CM5	1.75	2.49	3.16	4.21	5.17	6.26
	CCSM4	1.52	1.85	2.11	2.47	2.74	3.01
	GFDL-CM3	1.49	1.90	2.18	2.52	2.77	3.00
	HadGEM2-CC	1.38	1.82	2.25	2.96	3.65	4.48

1: Highlighted future storms are larger than the historical 200-year 6-hour rainfall depth (3.25 in.)

Table 2-7. Summary of central tendency by RCP scenario among the 4 GCMs.

Climate Change		6-hour Storm Size (in.) by Return Period [1]					
Scenario	Model	2-yr	5-yr	10-yr	25-yr	50-yr	100-yr
Current (Historical)		1.41	1.73	1.99	2.35	2.64	2.93
GCM Means	All Futures	1.52	1.98	2.35	2.9	3.37	3.87
	RCP 4.5	1.51	1.94	2.28	2.76	3.15	3.56
	RCP 8.5	1.54	2.02	2.43	3.04	3.58	4.19
GCM Medians	All Futures	1.47	1.83	2.13	2.49	2.77	3.05
	RCP 4.5	1.46	1.79	2.09	2.48	2.79	3.11
	RCP 8.5	1.51	1.88	2.22	2.74	3.21	3.75
Percent Change (Means)	All Futures	8%	14%	18%	23%	27%	32%
	RCP 4.5	7%	12%	14%	17%	19%	22%
	RCP 8.5	9%	16%	22%	29%	36%	43%
Percent Change (Medians)	All Futures	4%	6%	7%	6%	5%	4%
	RCP 4.5	4%	3%	5%	6%	6%	6%
	RCP 8.5	7%	9%	12%	17%	22%	28%

1: Highlighted future storms are larger than the historical 200-year 6-hour rainfall depth (3.25 in.)

2.5.3 Significance Tests

The hydrologic model was run for all historical and future climate change scenarios, with and without GI, and summarized for runoff volume and peak flow. Model outputs were evaluated to identify which scenarios were different than the current hydrology scenario using a standard test (Zou and Donner 2008) that has been used to assess the significance of differences in hydrological and water quality models (Riverson et al. 2011). Significance was measured by calculating 95 percent confidence limits (α=0.05) and testing for differences between the mean historical and climate futures across the 25 subwatersheds in Colma Creek. These significance tests helped determine which storm scenarios would be the most meaningful for evaluation by routing the associated modeled runoff timeseries to the hydraulic model. Table 2-8 shows runoff volume and peak flow test results for each future climate scenario relative to the corresponding baseline historical storm outputs using the current hydrology model without planned GI. Table 2-9 shows test results using the model with planned GI.

Under the modeled climate change scenarios, most storms produced significantly higher runoff volumes and peak flows compared to the current hydrology without the implementation of planned GI. However, some storm scenarios resulted in no significant change, while the GFDL-CM3 (the warm/dry model) showed a significant decrease in both runoff volume and peak flow for some of the larger storms. For the scenarios with GI, a change from either (1) *Significantly Higher* to *No Significant Change* or (2) *No Significant Change* to *Significantly Lower* signals that the GI provides some resilience to projected climate change. That signal was seen among the 2-year and 5-year storms for most models, but notably also for the 100-year peak flow in the GFDL-CM3 scenario. For the central tendency scenario (i.e., mean for *All Futures*), GI showed a significant benefit for only the 2-year storm. Results suggest that GI can mitigate the effects of smaller, more frequent storms even as these storm depths increase as a result of climate change.

Table 2-8. Test of significant changes relative to baseline historical for current hydrology (α=0.05).

Scenarios		Runoff Volume						Peak Flow					
Pathway	Climate Change Model	2-yr	5-yr	10-yr	25-yr	50-yr	100-yr	2-yr	5-yr	10-yr	25-yr	50-yr	100-yr
All Futures	*Mean*	▲	▲	▲	▲	▲	▲	▲	▲	▲	▲	▲	▲
	Median	-	▲	▲	▲	▲	▲	-	▲	▲	▲	▲	▲
RCP 4.5	*Mean (4.5)*	▲	▲	▲	▲	▲	▲	▲	▲	▲	▲	▲	▲
	Median (4.5)	-	-	▲	▲	▲	▲	-	-	▲	▲	▲	▲
	CNRM-CM5	▲	▲	▲	▲	▲	▲	▲	▲	▲	▲	▲	▼
	CCSM4	-	▲	▲	▲	▲	▲	-	▲	▲	▲	▲	▲
	GFDL-CM3	-	-	-	▼	▼	▼	-	-	-	▼	▼	▲
	HadGEM2-CC	-	-	-	▲	▲	▲	-	-	-	▲	▲	▲
RCP 8.5	*Mean (8.5)*	▲	▲	▲	▲	▲	▲	▲	▲	▲	▲	▲	▲
	Median (8.5)	▲	▲	▲	▲	▲	▲	▲	▲	▲	▲	▲	-
	CNRM-CM5	▲	▲	▲	▲	▲	▲	▲	▲	▲	▲	▲	▲
	CCSM4	▲	▲	▲	▲	▲	-	▲	▲	▲	▲	▲	▲
	GFDL-CM3	▲	▲	▲	▲	▲	-	▲	▲	▲	▲	▲	▲
	HadGEM2-CC	-	▲	▲	▲	▲	▲	-	▲	▲	▲	▲	▲

Significantly Higher ▲ Significantly Lower ▼ No Significant Change -

Table 2-9. Test of significant changes relative to baseline historical, with green infrastructure (α=0.05).

Scenarios		Runoff Volume						Peak Flow					
Pathway	Climate Change Model	2-yr	5-yr	10-yr	25-yr	50-yr	100-yr	2-yr	5-yr	10-yr	25-yr	50-yr	100-yr
All Futures	*Mean*	-	▲	▲	▲	▲	▲	▲	▲	▲	▲	▲	▲
	Median	-	-	▲	▲	▲	-	-	▲	▲	▲	▲	▲
RCP 4.5	*Mean (4.5)*	-	▲	▲	▲	▲	▲	▲	▲	▲	▲	▲	▲
	Median (4.5)	-	-	-	-	▲	▲	-	-	▲	▲	▲	▲
	CNRM-CM5	▲	▲	▲	▲	▲	▲	▲	▲	▲	▲	▲	▼
	CCSM4	-	-	▲	▲	▲	-	-	▲	▲	▲	▲	▲
	GFDL-CM3	-	-	▼	▼	▼	▼	-	-	-	▼	▼	▼
	HadGEM2-CC	▼	-	-	-	▲	▲	-	-	-	▲	▲	▲
RCP 8.5	*Mean (8.5)*	-	▲	▲	▲	▲	▲	▲	▲	▲	▲	▲	▲
	Median (8.5)	-	▲	▲	▲	▲	▲	▲	▲	▲	▲	▲	-
	CNRM-CM5	▲	▲	▲	▲	▲	▲	▲	▲	▲	▲	▲	▲
	CCSM4	-	-	-	-	-	-	▲	▲	▲	▲	▲	▲
	GFDL-CM3	-	▲	▲	▲	▲	-	▲	▲	▲	▲	▲	▲
	HadGEM2-CC	▼	-	▲	▲	▲	▲	-	▲	▲	▲	▲	▲

Significantly Higher ▲ Significantly Lower ▼ No Significant Change -

Table 2-10 summarizes storm sizes for the historical and mean future climate scenarios, i.e. the mean storm size across the modeled climate futures (RCP 4.5 and 8.5) and GCMs. The impact of GI on mitigating floods is also evaluated over the 2-year and 5-year intervals.

Table 2-10. Summary of Historical and Mean Future climate scenario storm sizes.

Return Period	Climate Scenarios [1, 2] (6-hour Storm Size, in.)		Green Infrastructure (GI) Scenarios (● Run, - Do Not Run)	
	Historical (1950-2005)	Mean Future (2006-2100)	Without GI	With GI
2-yr	1.41	1.52	●	●
5-yr	1.73	1.98	●	●
10-yr	1.99	2.35	●	-
25-yr	2.35	2.90	●	-
50-yr	2.64	3.37	●	-
100-yr	2.93	3.87	●	-

1: Yellow Highlights show storms larger than the historical 200-year 6-hour storm (3.25 in.)
2: Gray Highlights show 5-yr and 10-yr Future storms ≈ Historical 10-yr and 25-yr storms, respectively.

2.6 Selected Hydrologic Scenarios for Hydraulic Modeling

The following scenarios were selected for simulation in the hydraulic model:

1. Current hydrology conditions (without GI): 2-, 5-, 10-, 25-, 50-, 100-, and 200-year events
2. Mean future climate conditions (without GI): 2-, 25-, 50-, and 100-year events
3. Scenarios with GI:
    a. *Current hydrology climate conditions*: 2-year and 5-year
    b. *Mean future climate conditions*: 2-year and 5-year

Additionally, the current-conditions 100-year storm event hydrology will be used to examine water surface elevation with sea-level rise (year 2100 conditions) and with the addition of the Utah Avenue-Navigable Slough floodwall.

The mean future climate scenarios allow for a robust comparison of climate change impacts on runoff volume and peak flow for storms ranging from the 2-year to the 100-year storm. For conditions without GI, the 5-year and 10-year mean future events are equivalent to the current hydrology 10-year and 25-year storms, and therefore were selected for hydraulic analysis. The 2-year and 5-year current hydrology storms, with and without GI, can be used to assess the impact of GI on flood resiliency. Evaluating the Mean Future 2-year and 5-year storms with GI vs. current hydrology without GI can be used to assess the ability of GI to mitigate the impacts of climate change.

3 HYDRAULIC MODEL DEVELOPMENT

A hydraulic model of Colma Creek was constructed to examine the capacity of the flood control channel across a wide range of storm magnitudes and for those cases in which capacity was exceeded, to assess the extent of the resulting inundated area. Modeled maximum water depths are intended to guide planners in their assessment of flood risk and capital improvement projects.

Model construction took place in HEC-RAS (version 5.0.7). The completed model unites three separate modeling efforts into one HEC-RAS project:

- **Colma Creek (A Street to South Airport Boulevard)** – The constructed flood control channel from the upstream junction box in Colma, CA to the beginning of the natural channel below South Airport Boulevard was developed specifically for this effort based as-built specifications and informed by site reconnaissance.
- **Colma Creek (South Airport Boulevard to San Francisco Bay)** – The natural channel below South Airport Boulevard had been previously developed by WRECO (2018) from bathymetry collected in 2017 by Meridian Surveying Engineering. Floodwalls not included in the original geometry were added to the cross-sections based on as-built and proposed design plans.
- **Navigable Slough** – The remnant tidal channel and surrounding area was modeled by ESA (2019) for an investigation of flood risk. The 2D model that was produced, along with underlying terrain data, was imported into the current project. The model mesh (i.e. computation area) was trimmed back to include only Navigable Slough, with the interaction between it and Colma Creek modeled by means of lateral structures connecting the 1D and 2D portions of the models.

A full description of the sources used for the model can be found in Section 3.2.2.

The HEC-RAS model, along with all hydrological inputs, are provided as a digital attachment. Geometry input and output from the 1D routing model may be viewed through the HEC-RAS interface. RAS Mapper, included with the HEC-RAS software (under "GIS Tools") may be used to view 2D output, such as inundation depths. HEC-DSSVue is recommended for viewing timeseries data in the model.

3.1 Site Reconnaissance

A site inspection of Colma Creek and Navigable Slough was conducted prior to the construction of the model in HEC-RAS. Three purposes guided the site visit: 1) to identify junctions of Colma Creek with other significant tributaries, including storm drains; 2) to assess channel condition with respect to maintenance and sediment load; and 3) to make a preliminary comparison of as-built plans with existing channel geometries. Based on the site visit, it was determined that the as-built plans provided by Public Works sufficed for model construction and no further surveying was necessary.

The following sub-sections detail observations about open channel portions of Colma Creek, moving from its emergence at Holy Cross Cemetery to the Bay, that informed model development. The *Colma Creek Flood Control Channel Box Culvert Condition Assessment Report* led by Public Works provides a detailed study of the condition of the enclosed portions of Colma Creek from A Street to the end of the box culvert at Mission Street (CDM Smith 2018).

3.1.1 Old Colma Creek

A remnant of the creek channel that existed prior to the construction of the box culverts along El Camino Real and Mission Street diverts flow into Colma Creek flood channel at two points: 1) near the intersection of El Camino Real and Mission Street (Figure 3-1); and 2) approximately 450 feet upstream before Colma Creek enters a triple-chambered box culvert at McClellan Drive (Figure 3-2). During large events, flow in excess of the Colma Creek channel capacity at the first point of entry will continue down Old Colma Creek and re-enter the main channel at the second point.

Figure 3-1. Old Colma Creek, looking upstream from the culvert entrance into the Colma Creek main channel.

Figure 3-2. The junction of Old Colma Creek (right channel) with the Colma Creek main channel (left).

The upper flow split is not represented in the final hydraulic model, as this would require further development of a hydraulic model of Old Colma Creek. Instead, all flow collected between A Street and McClellan Drive was assumed in the model to enter Colma Creek at the lower confluence.

3.1.2 12 Mile Creek Confluence

The next major open channel tributary is 12 Mile Creek, which joins Colma Creek approximately 600 feet downstream of the Chestnut Avenue Bridge (Figure 3-3). The hydraulic capacity of 12 Mile Creek requires future study. Sandbags piled along Centennial Way Trail (not shown) suggest previous attempts at flood mitigation, but the extent and source of historical flooding is unknown. For this study, all flow draining to the junction was assumed in the model to enter Colma Creek.

Figure 3-3. The confluence of 12 Mile Creek (left channel) with Colma Creek (right), looking upstream.

3.1.3 Orange Memorial Park

Approximately 200 feet downstream of 12 Mile Creek, Colma Creek enters Orange Memorial Park. The constructed channel through the park is a complex mixture of pedestrian bridges, sudden shifts in channel alignment (Figure 3-4), and compound channel geometries (Figure 3-5). The abrupt changes in the shape of the open channel lead to increased energy losses, which are mimicked in the model with increased expansion and contraction coefficients. Pedestrian bridges through Orange Memorial Park were not included in the model because the decks, perched higher than the adjacent banks and above the highest water levels, would not constrict flow.

Photographs (Figure 3-5) of the compound trapezoidal channel sections downstream of the first pedestrian bridges show a vertical section at the top not represented in the as-built plans. The 20” section height was added to the cross-sectional geometry in the model.

Figure 3-4. A shift in the Colma Creek alignment, looking upstream to the confluence with 12 Mile Creek.

Figure 3-5. Compound trapezoidal-rectangular channel geometry in Colma Creek, looking downstream.

Immediately downstream of the park at Orange Avenue Bridge, a 36-inch diameter pipe discharges into Colma Creek, as indicated in a GIS map layer of the stormwater system and confirmed during the site visit (Figure 3-6). Major stormwater pipes empty into the channel above the Spruce Avenue

Bridge and below the bridges along Linden Avenue and South Airport Boulevard. Discharge from all these pipes are included as hydrograph inputs in the model.

Figure 3-6. Orange Avenue Bridge, looking upstream, with the 36" storm drain shown (right).

3.1.4 Dissipator Structure

A critical component of the flood control channel is an energy dissipation structure, located approximately 300 feet upstream of Spruce Avenue (Figure 3 7).

Figure 3-7. Energy dissipation structure located 300 feet above Spruce Avenue looking upstream.

The site visit confirmed the observation by Horizon (2018) that small sediment deposits are located near the teeth but, otherwise, the structure appeared to match as-built conditions. Also of note is the top of the bank existing at ground-level, with the narrow bank running along North Canal Street to the north and abutting several residential parcels to the south. Below the dissipator teeth, the channel widens while the channel slope becomes less steep (Figure 3-8).

It is the role of this structure to enforce, through turbulence, a rapid loss of energy in the flow coming from the relatively steep channel above it. The sudden loss of energy results in a decrease in velocity and consequently greater depths. In the model, the dissipator teeth are represented as a row of eight flow obstructions, each measuring 1 foot tall by 2 feet wide.

Figure 3-8. Colma Creek below the Linden Avenue Bridge, looking downstream during high tide.

During the reconnaissance, tidal influence was clearly demonstrated by water levels extending to the dissipator teeth. NOAA tidal records for the gauges at Redwood City, CA and Alameda, CA indicate a high tide comparable to their respective mean high-water levels at approximately the time of the site visit (December 12, 2018 at 2:45 pm PST). Thus, Figures 3-7 through 3-12 demonstrate the approximate tide level of the starting condition used for the model simulations.

3.1.5 Natural Channel

Below Produce Avenue Bridge, Colma Creek becomes a natural channel under full-tidal influence. Observation of the condition of the channel was consistent with those of Horizon (2018), as indicated by sediment bars and shrubby plants such as pickleweed along the banks (Figure 3-10). The site visit confirmed the selection by WRECO (2017) of a roughness coefficient (n = 0.025) consistent with a natural channel with a regular section and little brush (Cf. Chow 1959).

Figure 3-9. Colma Creek below South Airport Boulevard, looking upstream.

Figure 3-10. The natural banks along Colma Creek below South Airport Boulevard, looking downstream.

3.1.6 **Navigable Slough**

Navigable Slough upstream of South Airport Boulevard (Figure 3-12) was not accessible in the absence of pedestrian walkways. The culvert beneath South Airport Boulevard (Figure 3-11) was consistent with the 8-foot diameter in the model. The degree of sedimentation could not be determined.

Figure 3-11. The culvert along Navigable Slough beneath South Airport Boulevard.

Figure 3-12. The confluence of Navigable Slough (left channel) with Colma Creek (right), looking upstream.

3.2 Unsteady 1D Model Geometry

3.2.1 Horizontal and Vertical Datums

The HEC-RAS model is georeferenced and projected according to the following datums:

- **Horizontal:** NAD 1983 State Plane California Zone III, FIPS 0403 feet
- **Vertical:** North American Vertical Datum of 1988 (NAVD 88)

A standard adjustment of +2.7 feet was used to convert all elevations from NGVD 29, consistent with standard practice by Public Works.

3.2.2 Cross-section geometry

The main channel of Colma Creek is represented as a stream centerline and 270 cross-sections. Cross-sections were added to characterize changes in channel geometry (cross-sectional area and slope) or interpolated between stations to increase model stability. Station numbering decreases from upstream to downstream, and correlate with stationing along the centerline of the channel. The following sources were used to develop schematics for the 168 original cross-sections:

Table 3-1. Source information for developing the cross-sectional geometry of the HEC-RAS 1D model.

Stations	As-Built Plan or Model Source	Agency	Year
29961 - 23482	El Camino Box Culvert Installation	Caltrans	2004
23461 - 22372	Mission Road Box Culvert	Public Works	2000
21901 - 16129	SFO Extension: Module 1 – Work Pkg A	BART	2003
15923 - 15083	Channel Improvements Sta. 79+00 to Sta. 87+85	South San Francisco	1976
14978 - 14180	Chestnut Avenue Box Culvert and 12 Mile Cr. Confluence	South San Francisco	1975
14061 - 12778	Channel Improvements Sta. 97+62 to Sta. 110+45	South San Francisco	1985
12693 - 12448	Channel Improvements & Orange Avenue Box Culvert	South San Francisco	1982
11673 - 10323	Channel Improvements Sta. 113+25 to Sta. 137+00	South San Francisco	1978
10224 - 8123	Channel Improvements San Mateo Avenue to Spruce Avenue	Public Works	2003
7487 - 6974	Flood Control Project: San Mateo Avenue to Produce Avenue	Public Works	1996
6900	Produce Avenue Bridge	South San Francisco	1977
6866 - 6360	S. Airport Boulevard Bridge Replacement (floodwall height)	Public Works	1999
6236 - 156	HEC-RAS geometry incorporating 2017 bathymetry[1]	WRECO	2018
4304 – 2831[2]	Flood Control Wall Project from Utah Avenue to N. Slough	Public Works	2018

1: Floodwalls and channel widths adapted from as-built plans for Channel Improvements Sta. 174+30 to Sta. 207+70 (1976)
2: Floodwall added to geometry "Colma-Cr-NS-Floodwall" only

Each original cross-section includes information under "Description" citing the source used to develop it, along with the as-built station number (if applicable) and page number. Interpolated cross-sections, used to improve model stability, are indicated by an asterisk.

Figure 3-13 demarcates the extents of the model geometry imported from two previous efforts. The natural channel below South Airport Boulevard had been previously developed by WRECO (2018) from bathymetry collected in 2017 by Meridian Surveying Engineering. Floodwalls not included in the original geometry were added to the cross-sections based on as-built plans as needed. Navigable Slough was modeled by ESA (2019) as a fully 2D model for an investigation of flood risk.

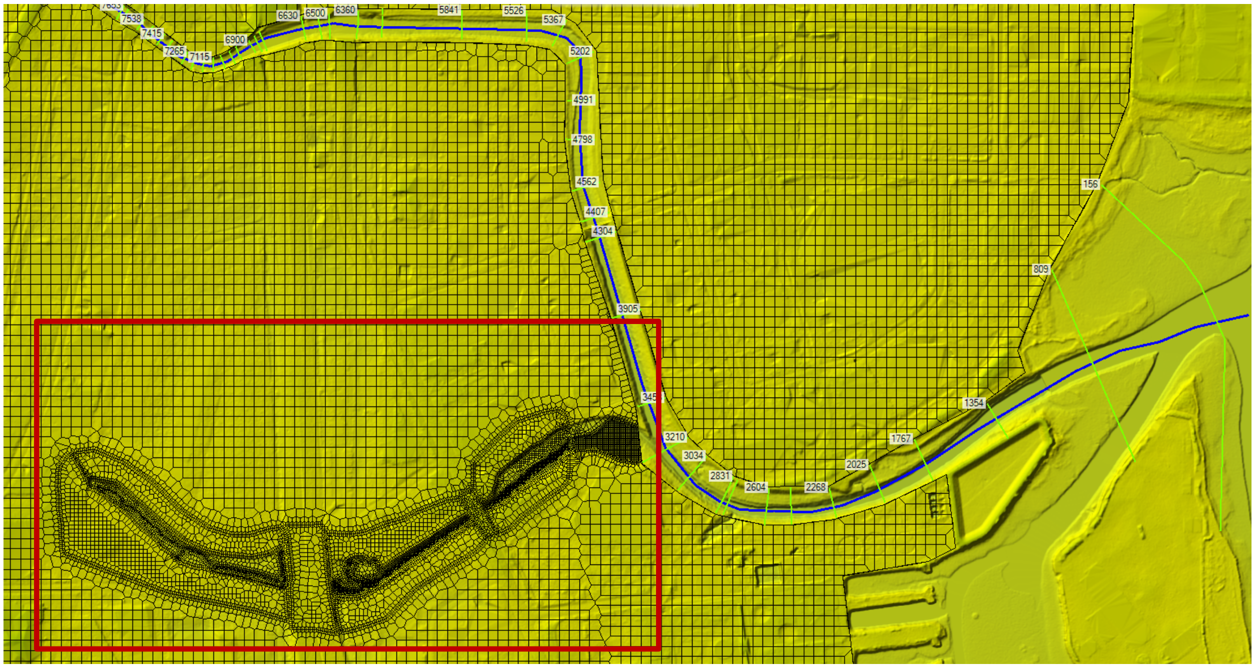


Figure 3-13. The imported models, comprising Navigable Slough (boxed) and the channel below Utah Avenue.

3.2.3 Hydraulic Structures

Four types of hydraulic structures are used in the model: bridges, lids, culverts, and lateral structures.

Bridges – Geometry information for each bridge consists of dimensions for a deck and piers (except for Linden Avenue Bridge, which has no piers). The following inventory lists the bridges in the model and the primary source from which dimensions were derived:

Table 3-2. Source information for developing bridge and lid schematics in the HEC-RAS 1D model

Stations	Bridge or Lid	As-Built Plan or Model Source	Year
29961 - 23482	El Camino Culvert	El Camino Box Culvert Installation	2004
23461 - 22372	Mission Road Culvert	Mission Road Box Culvert	2000
20021 - 18699	BART Culvert	SFO Extension: Module 1 – Work Pkg A	2003
15988	Oak Avenue	Channel Improvements Sta. 79+00 to Sta. 87+85	1976
14880	Chestnut Avenue	Chestnut Avenue Box Culvert and 12 Mile Cr. Confluence	1975
12693	Orange Avenue	Orange Avenue Box Culvert	1982
10308	Spruce Avenue	Channel Improvements Sta. 113+25 to Sta. 137+00	1978
8545	Linden Avenue	Flood Control Project: San Mateo Avenue to Produce Avenue	1996
8084	Caltrain bridge	Colma Creek Bridge Replacement	2001
7623	San Mateo	Channel Improvements & Orange Avenue Box Culvert	1982
6968	Produce Avenue	Flood Control Project: San Mateo Avenue to Produce Avenue	1996
6833	Highway 101	Spruce to Bay model	-
6483	S. Airport Boulevard	Spruce to Bay model[1]	-
4357	Utah Avenue	WRECO model for Resiliency by Design	2018
2815	Pedestrian bridge	WRECO model for Resiliency by Design	2018

1: Dimensions checked with the South Airport Boulevard Bridge Replacement Project (2002) as-built plans

Pedestrian bridges were not included in the model because the decks, perched higher than the adjacent banks and above the highest water levels, would not constrict flow.

Pier debris was included for the Utah Avenue Bridge, close to the bay, consistent with the WRECO model. Pier debris was not included for piers upstream of Utah Avenue. During the site reconnaissance, debris, such as branches, was not observed at any of the bridge piers.

Lids – Sensitivity runs of the model for bridges downstream of the energy dissipators (station 10623) demonstrated that the bridge computational method used by HEC-RAS was unable to mimic the supercritical flow upstream of bridges, regardless of whether flows approaching and leaving the bridge were supercritical. For this reason, the three bridges (at Oak, Chestnut, and Orange Avenue) located upstream of the energy dissipators were modeled as lids placed above a standard HEC-RAS channel cross-section to preserve the expected supercritical behavior.

The El Camino and Mission Road box culverts, because of their length and complexity were modeled as standard cross-sections with lids, as suggested by the user manual supplied with HEC-RAS (2018).

Culverts – The double-barrel culvert under US Highway 101 was included in the model of Navigable Slough and uses the HEC-RAS routine for solving flow through a culvert.

Lateral Structures – Flow can pass back and forth from the 1D to the 2D model by means of lateral structures in HEC-RAS. Lateral Structures were placed on the top of the banks of Colma Creek either at high ground or on the floodwall, where the 1D and 2D models meet. Structures on either side of Colma Creek run from Orange Avenue to approximately the outlet of the channel at San Francisco Bay, with discontinuities only at bridge crossings. HEC-RAS calculates flow over lateral structures with a weir-based equation or with normal 2D routing. Investigation of the surrounding terrain determined which of the two methods would be used. If the height of the lateral structure was great enough that it could act as a hydraulic control, the weir method was adopted. For all other instances, normal 2D equations were used.

Table 3-3. Lateral structures, identified by the upstream station, in the model

Stations	Equation Method
12656	Normal 2D
10233	Weir
8479	Weir
7992	Weir
7537	Weir
6899 (north)	Normal 2D
6899 (south)	Weir
6629	Weir
6359	Weir
4303	Normal 2D
2797	Normal 2D
Floodwall 2[1]	Weir

1: Added to the model of Navigable Slough

Furthermore, the confluence of Navigable Slough with Colma Creek was modeled as part of the lateral structure running from the Utah Avenue Bridge to the Bay.

3.2.4 Manning's Roughness Values

Resistance to flow (i.e. friction) in the channel is approximated using Manning's n, except for the energy dissipators, for which a K-value matching the height of the blocks (1 foot) was used. A standard Manning's n of 0.015 was adopted for the concrete channel above the energy dissipators, while a higher resistance value of 0.025 was adopted for the bottom of the rectangular channel below to mimic the influence of sediment in the channel. The imported WRECO model of the natural channel uses a Manning's n of 0.025 throughout and was unchanged for this project.

3.2.5 Orange Memorial Park Pump

The proposed regional stormwater capture project at Orange Memorial Park consists of an in-channel variable speed pump that discharges into a 5.4 acre-feet infiltration basin. The pump is operational at any channel stage, up to a maximum rate of 35 cfs at a stage of 3 feet. The Orange Memorial Park pump is part of the planned GI and is included for those simulations for the 2-year and 5-year Events.

Table 3-4. Operational specifications for the Orange Memorial Park regional facility

Orange Memorial Park Facility			
Storage Volume	Pumping rate	Rate (cfs)	Stage (ft)
5.4 acre-ft	Minimum	0	0
	Maximum	35	3 to 5

Simulation of the pump is included by the addition of an outflow timeseries that mimics the rate of pumping during the specified storm event based on the computed stage at the cross-section (14061) nearest the site of the proposed pump. A separate geometry file ("Colma-Cr-Green") includes the addition of the lateral structure used to simulate the pump discharge.

3.2.6 Utah Avenue to Navigable Slough Floodwall

The Utah Avenue Navigable Slough Floodwall is a defined future project that Public Works has requested to be analyzed with the updated model. Sheet pile walls stretching from Utah Avenue to the pedestrian bridge (left bank) and above the confluence of Navigable Slough (right bank) have been selected as a flood-management measure to pass the 100-year water surface elevation with 3 feet of freeboard. The flood walls were added as lateral structures within a separate geometry file ("Colma-Cr-NS-Floodwall"). Specifications within the 95% design plans show a uniform top-of-wall elevation of 16.4 feet NAVD 88 for the right wall, and 16.4 feet NAVD 88 for the first 800 linear feet along the left bank wall, followed by a top elevation of 15.7 feet NAVD 88 to the pedestrian bridge. Additionally, a plexiglass extension of the parapet along Utah Avenue, to an elevation of 16.8 feet NAVD 88, is intended to prevent overtopping of the roadway. This has been added to the deck dimensions within the same geometry file.

3.3 Unsteady 2D Model Geometry

The overland routing model in HEC-RAS consists of a computational mesh that calculates flow depths and velocities over a digital terrain.

Terrain Data – A composite terrain was created from a DEM based on 2017 LiDAR supplied by Public Works and the terrain file included with the model of Navigable Slough. The higher resolution Navigable Slough terrain incorporates 2017 LiDAR, bathymetry, and field surveys.

2D Mesh – The computational domain of the 2D model was separated into one mesh each for the north and south of Colma Creek. Both begin at Orange Avenue and extend approximately to the San Francisco Bay. The core part of the southern mesh ("Navigable Slough") was imported from the model of Navigable Slough developed by ESA (2019). The domain was altered by trimming the model boundary to the right bank of Colma Creek and hence, excluding Colma Creek from the 2D computations. The mesh was then extended to Orange Avenue. The northern portion of the 2D model ("Utah-Bay-N") was developed for this project. Both the extended portions of the Navigable Slough model and the new mesh adopted the default 50-foot by 50-foot grid cell dimensions of the ESA model. The 2D routing process preserves the resolution of the underlying DEM but produces a single water surface elevation for each cell.

The exchange of flow between the 2D and 1D models occurs across the lateral structures, as described previously. Water surfaces in Navigable Slough are determined through 2D routing, while flows in Colma Creek are determined at each cross-section through the unsteady 1D computations.

The imported model of Navigable Slough applied a Manning's n value of 0.06, which was adopted for the expanded 2D domain.

3.4 HEC-RAS Simulations

The following sections describe the individual HEC-RAS simulations used for the project and provide information on model parameters including time-step, calculation schemes, and downstream boundary conditions. Each HEC-RAS Model simulation routes the developed hydrology (Section 2) over the 1D (Section 3.2) and 2D (Section 3.3) geometries that represent Colma Creek, Navigable Slough, and the Overbank Floodplains.

3.4.1 HEC-RAS Modeled Scenarios

The following flows were routed in the HEC-RAS model using hydrology developed in Section 2:

- Current climate: 2-, 5-, 10-, 25-, 50-, 100-, and 200-year events
- Green Infrastructure: 2- and 5-year events, both current and future climate conditions
- Future state climate: 2-, 25-, 50-, and 100-year
- Current 100-year event with Utah Avenue-Navigable Slough Floodwall
- Current 100-year event with the year 2100 sea-level rise

Each scenario has a plan in HEC-RAS that links together two files: a model geometry and a flow dataset. The plan file itself details calculation methods and error tolerances. There are 17 plans within the final project, one for each modeled scenario. The naming convention for both the flow and plan files is described in Table 3-5:

Table 3-5. The HEC-RAS plan naming convention adopted for the final model.

Name	Description	Code
Existing-xxx	Existing (current hydrology) climate xxx-year event and existing watershed conditions	EC
Existing-xxx-GI	Existing (current hydrology) climate xxx-year event and the addition of green infrastructure	EG
Future-xxx	Future climate xxx-year event and existing watershed conditions	FC
Future-xxx-GI	Future climate conditions and the additions of green infrastructure	FG
Existing-100-NS-Floodwall	Existing (current hydrology) climate 100-year event and Utah Avenue floodwall in place	EC100NS
Existing-100-SLR	Existing (current hydrology) climate 100-year event with mean higher high water (MHHW) tide and sea-level rise	EC100SLR

The return period event is indicated by a three-number code (e.g., "050" is the 50-year).

Three geometry files are included within the final HEC-RAS project: 1) "Colma-Cr-Existing" representing existing infrastructure; 2) "Colma-Creek-NS-Floodwall" which adds the floodwalls from Utah Avenue to Navigable Slough; and 3) "Colma-Creek-Green" for use with hydrologic scenarios considering GI implementation.

Hydrograph input locations (Table 3-6) represent the major points at which the stormwater system discharges into the Colma Creek channel. In some instances, hydrographs developed in separate subwatershed were summed to create a single inflow at a given confluence, resulting in 12 unique hydrographs for each simulation.

Table 3-6. Relation of hydrograph inputs locations to subwatershed boundaries and major junctions.

HEC-RAS Cross-Section	Junction description	Subwatersheds
29961	Start of Colma Creek flood channel at A St in Colma, CA	1016, 1017
20402	Downstream confluence of Old Colma Creek	1014, 1015, 1019, 1018
19191	Stormwater pipe entering beneath BART Station	1020, 1021
16043	Stormwater pipe	1011, 1012, 1013
14180	Confluence of 12 Mile Creek	1010, 1022
12631	Stormwater pipe below Orange Avenue Bridge	1009
11223	Stormwater pipe	1008
10368	Stormwater pipe entering above Spruce Avenue Bridge	1007, 1023
10186	Stormwater pipe entering below Spruce Avenue Bridge	1006
8445	Stormwater pipe entering below Linden Avenue Bridge	1005
6236	Double pipes entering below South Airport Boulevard Bridge	1003, 1004, 1024
NS Upstream	Navigable Slough culvert below Spruce Avenue	1001, 1002, 1025
156	Confluence of Colma Creek and San Francisco Bay	Tidal condition

In the case of inflows into Navigable Slough, the entire summed hydrograph was placed at the most upstream culvert, rather than attempting to reapportion the volume along the channel. Figure 3-14 shows the location of the hydrograph input locations described above.

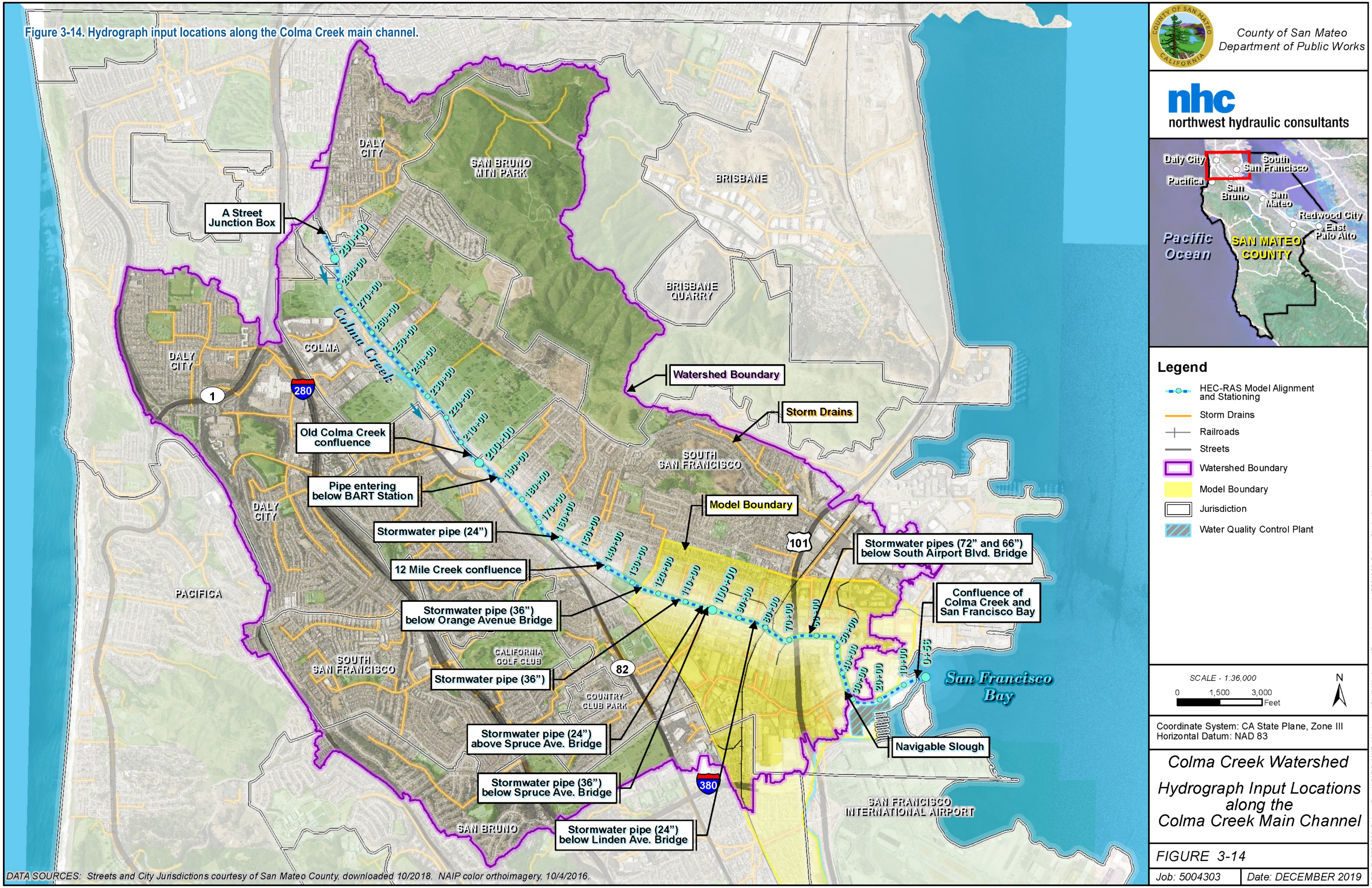


Figure 3-14. Hydrograph input locations along the Colma Creek main channel.

3.4.2 Tidal Boundary Conditions

A constant mean higher high water (MHHW) tide elevation of 6.8 feet (NAVD 88) is used for all simulations. This datum was established specifically for the San Francisco Bay at SFO by AECOM (2016) in a comprehensive revision of tidal datums based on hydrodynamic modeling and statistical analysis. ESA (2019) subsequently adopted this value in their model of Navigable Slough. The modeled datum is an improvement over the MHHW value of 6.5 feet (NAVD 88) used by WRECO (2018), based as it was on gauged data recorded at Alameda, CA across the Bay. For the simulation of a 100-year storm with the impact of sea-level rise, the value of +3.01 feet, estimated by the National Academy of Sciences (2012), was added to the MHHW datum, for a value of 9.81 feet NAVD 88.

3.4.3 Time-Step and Scheme

Calculations in the Colma Creek channel are based on the unsteady routing of hydrographs using the conservation of mass and energy. Calculations in the 2D portions of the model use the full momentum equation. Flows may be either super- or subcritical, depending on the results of the solving routine. The timestep used for model calculations can vary with the velocity of flows in the channel. Timesteps were chosen based on the Courant Number, which is a ratio of model spacing to velocity and time. HEC-RAS default values for solution tolerances were adopted except where noted.

3.5 HEC-RAS Simulation Results

3.5.1 Main Channel Results

Results in Colma Creek were evaluated primarily for the ability of the channel to convey flood hydrographs downstream without flow spilling out of bank. The Colma Creek flood channel was designed to pass a 50-year storm with 2 feet of freeboard (i.e. the distance between the water surface and the top of the bank). Figure 3-15 shows the estimated freeboard for scenarios as large or larger than the 50-year event. For cases in which the height of the left and right bank differed, the lower of the two was used to determine freeboard deficiency.

The following observations were made based on inspection of Figure 3-15:

Dissipator Teeth – The sudden increase in flow depth at that location, combined with the ground-level top-of-bank, makes this a flood-risk area. The 50-year event passes with less than 1 foot of freeboard, and spill at this location occurs with the current hydrology 100-year event. As was noticed during the site inspection, this area is also tidally influenced. However, a comparison of the current hydrology 100-year event with the same event with sea-level rise shows only a minor increase in overflow. This suggests that upstream reduction in peak discharges could decrease the risk of overflow at that point, regardless of sea-level rise.

Spruce Avenue to Utah Avenue – Freeboard uniformly decreases within channel reaches with increasing event magnitude. Under current conditions, the 50-year event passes without spilling out of bank and with a minimum of 2 feet of freeboard throughout the channel, except for the area immediately after the dissipator teeth where flows transition to subcritical. Up to the 200-year current hydrology event, this remains the only spill location above Utah Avenue. However, under future climate conditions, the 100-year event forces flooding along the length of the channel below Spruce Avenue.

Downstream of Utah Avenue – Flooding occurs along the right (i.e. west) bank for events as frequent as the 10-year event, with surcharge spreading to the north of Utah Avenue with events larger than the 50-year storm. The Utah Avenue-Navigable Slough floodwall significantly improves the freeboard available downstream of Utah Avenue during the 100-year event.

Future Climate Events and Sea-Level Rise – Future climate conditions will drastically impact the degree of flood protection offered by the existing Colma Creek flood control channel. The 100-year storm under current hydrology climate passes through much of the channel with 2 feet of freeboard. Under a future climate state, the 100-year storm spills along much of the reach from Spruce to Produce Avenue.

Sea-level rise (+3.01 feet) also presents a major increase in flood risk for the areas near Utah Avenue. As seen in Figure 3-15, the freeboard that was available immediately below Navigable Slough (approximately Station 2500) will no longer be available given the future MHHW stage. The higher stage there results in a much larger volume of water spilling from Navigable Slough and Colma Creek below Utah Avenue.

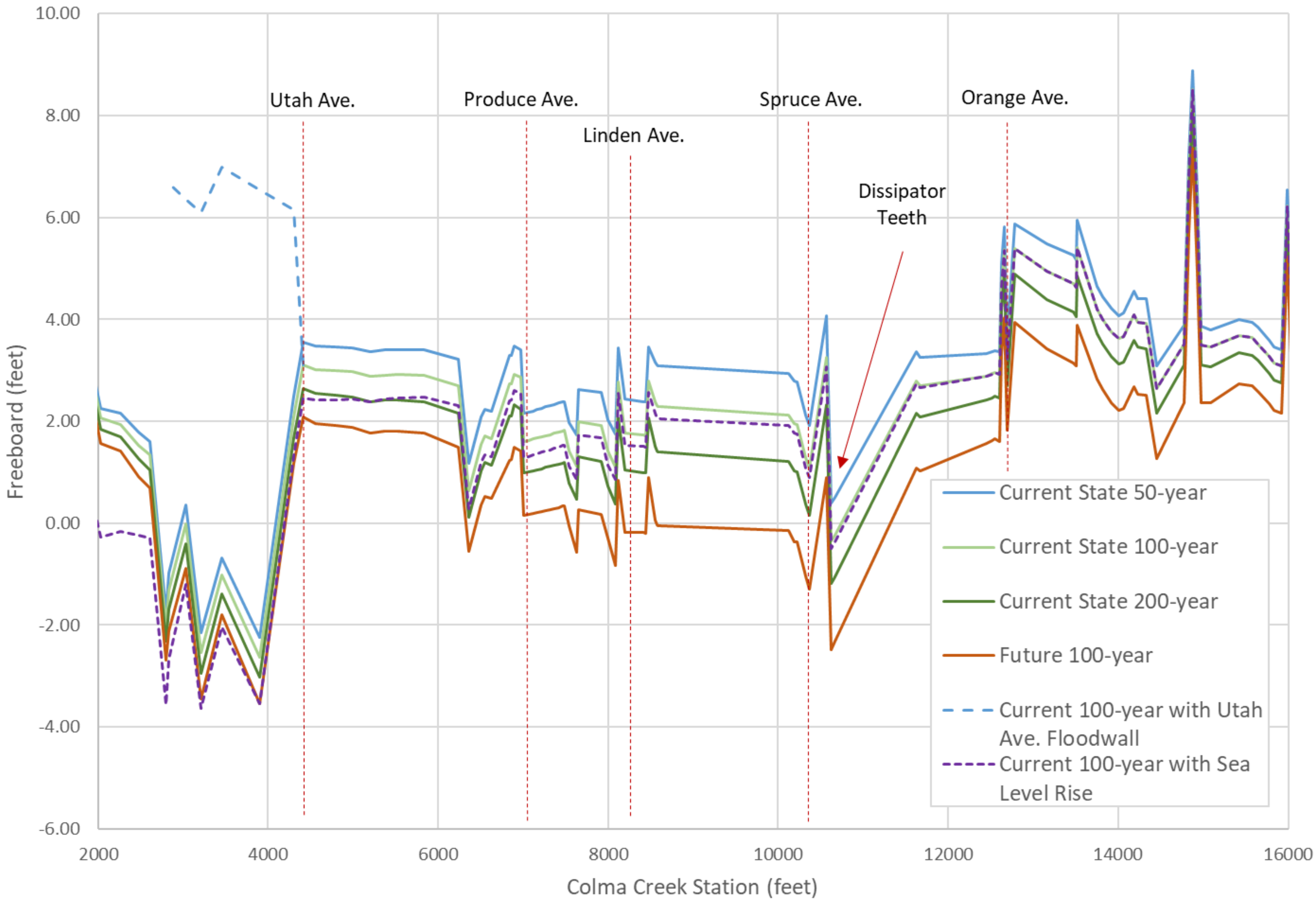


Figure 3-15. Estimated channel freeboard (i.e. top of bank less maximum water surface elevation) along the open portions of Colma Creek.

3.5.2 Orange Memorial Park Project Results

The Orange Memorial Park project was simulated for the 2-year and 5-year design storms (with GI since the project is considered a component of future GI implementation). Assuming operation of the pump at the start of the events, the 5.4 acre-feet of the infiltration basin is filled approximately 2.25 hours into the simulation for both the 2- and the 5-year storm events under current and future climate conditions. Figure 3-16 demonstrates the pump's subtraction of volume from the flood hydrograph during the current 2-year storm event, an example of the difference between the hydrographs calculated above and below the location of the pump. Given the capacity of the basin, the pump does not operate long enough to impact the peak stage in the channel for the given storm.

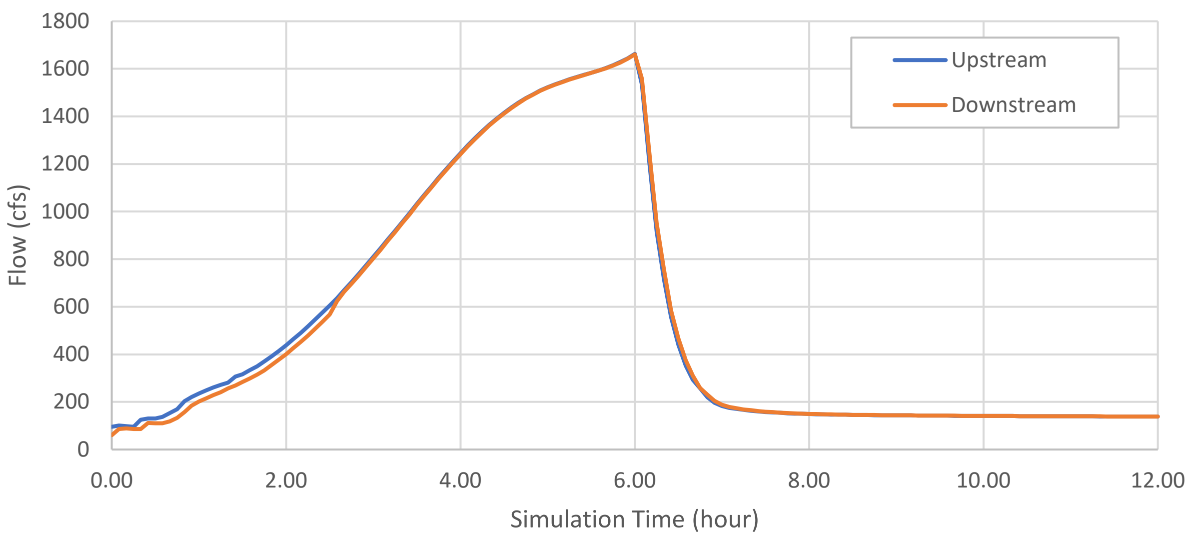


Figure 3-16. Simulated hydrographs above and below the Orange Memorial Park pump for the 2-year event.

3.5.3 Utah Avenue to Navigable Slough Floodwall

The addition of the floodwall from Utah Avenue to the Navigable Slough showed the desired reduction in overbank flooding along Colma Creek. The increases in stage along Colma Creek due to the floodwall were shown to have a negligible adverse impact on Navigable Slough flooding. This appears to be due in part to the offset in the timing of peak stages between the two systems and the available capacity of the slough near the mouth. The sources of flooding for the Navigable Slough are primarily from water leaving the channel upstream of the South Airport Culvert constriction.

3.5.4 Inundation Extents

Inundation maps were developed for the 17 modeled scenarios listed below:

- Current state climate: 2-, 5-, 10-, 25-, 50-, 100-, and 200-year events
- Green Infrastructure: 2- and 5-year events, both current and future climate conditions
- Future state climate: 2-, 25-, 50-, and 100-year
- Current 100-year event with Utah Avenue-Navigable Slough Floodwall
- Current 100-year event with the year 2100 sea-level rise

The maps for individual events are provided in Appendix A.

The modeled results suggest that under current hydrological conditions up to the 100-year event, Navigable Slough is the sole source of flooding originating from the channel network. A very limited surcharge is predicted at the dissipator structure above Spruce Avenue for the 100-year event and larger (i.e. the future condition 50- and 100-year storms). Only for the future condition 100-year storm event is overbank flooding from the Colma Creek channel observed between Spruce Avenue and Highway 101. Results do not define FEMA flood hazards. The model would need to go through the Letter of Map Change process with FEMA prior to any changes in mapping.

3.6 Comparison of Results with Previous Studies

A direct comparison of the current results with previous estimates of stage and inundation areas is made difficult primarily by the differences in the hydrology between studies. CDM Smith (2013) created a steady-state model for a flow of 5,800 cfs, the official FEMA 100-year event at San Francisco Bay. The resulting profile predicts stages above the soffit of all bridges below Spruce Avenue, with overtopping of San Mateo Avenue bridge suggested:

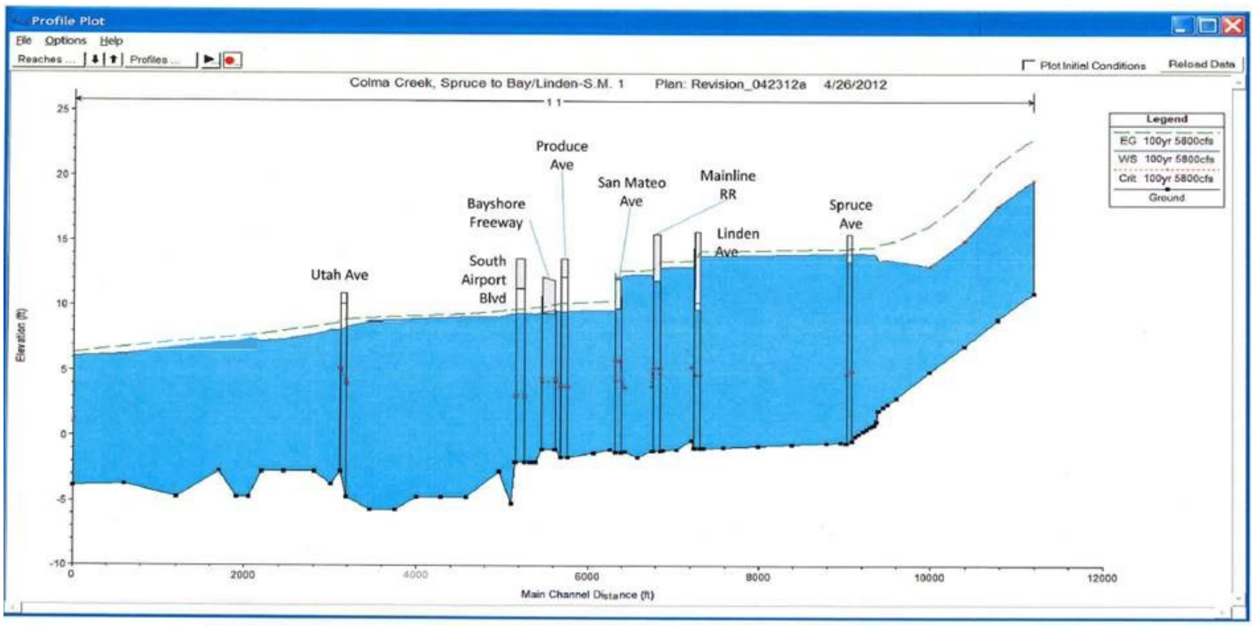


Figure 3-17. HEC-RAS profile plot of the steady-state 100-year flow of 5,800 cfs by CDM Smith (2012).

Table 3-7 shows the approximate differences between the current results and those shown in the profile taken from their report, along with the difference in the current modeled flow at each location from 5,800 cfs. Except for the flows between Spruce and San Mateo Avenue, the results agree. The higher WSEL at Spruce Avenue would seem to be due in part to there being 890 cfs more in the CDM Smith model. Other explanations could include pier debris, geometry or changes in bridge routines. A thorough review and comparison to the CDM Smith model and hydrology will be required if the developed model is to be used for any future FEMA applications.

Table 3-7. Comparison of current results with the 100-year profile estimated by CDM Smith (2013).

	CDM Smith	Paradigm/NHC		
Reach	Depth (ft)	Depth (ft)	Δ Depth (ft)	Δ Flow (cfs)
Spruce Avenue to Linden	15	12.8	-2.2	-887.3
Linden to Mainline RR	14	12.0	-2.0	-456.6
Mainline RR to San Mateo	13.5	11.6	-1.9	-346.7
San Mateo to Produce	11	11.3	0.3	-346.7
Produce to South Airport	11	11.3	0.3	-346.7
South Airport to Utah	13	13.6	0.6	105.9

WRECO (2017) modeled a 50-year profile based on the official FEMA flow of 5,100 cfs for this event. The comparison of the stages reported from their model and those for the current hydrology 50-year event simulated in this project is shown in Table 3-8. The stages are understandably much closer to those predicted by the current study, varying on average by 0.2 feet, despite tidal boundary condition larger by 0.3 feet. The minor difference is presumably due to the shared geometry and modeling assumptions between the models and the much smaller differences in peak flow values.

Table 3-8. Comparison of 50-year stages with those predicted by WRECO (2017).

Station	WRECO (2017)	Current Study	∆Stage (ft)	∆Flow (cfs)
6236	11.2	11.5	0.3	-265
5841	11.0	11.2	0.2	145
5526	10.8	11.0	0.2	144
5367	10.8	10.9	0.1	143
5202	10.7	10.9	0.2	143
4991	10.4	10.5	0.1	143
4798	10.3	10.4	0.1	142
4562	10.1	10.2	0.1	142
4407	10.0	10.1	0.1	141
4304	9.6	9.8	0.2	139
3905	9.2	9.5	0.3	143
3453	8.8	9.1	0.3	135
3210	8.9	9.2	0.3	387
3034	8.7	9.0	0.3	387
2831	8.4	8.7	0.3	387
2798	8.2	8.4	0.2	387
2604	8.1	8.3	0.2	387
2480	8.0	8.1	0.1	387
2268	7.7	7.8	0.1	387
2025	7.4	7.6	0.2	387
1767	7.2	7.3	0.1	387
1354	6.7	6.8	0.1	387
809	6.2	6.8	0.6	387
156	6.6	6.8	0.2	387

ESA (2019) focused their study of inundation to discharges along Navigable Slough, without a coincident flow along Colma Creek. A side-by-side comparison of the flood areas for the 100-year event shows a similar spread for the area south of Navigable Slough. The models used by ESA and this current study shared the same 2D HEC-RAS representation of Navigable Slough, with the primary differences being inflow locations and hydrology. The ESA (2019) study used two inflow locations (the culverts below Spruce Avenue and Highway 101) compared to one at the culvert below Spruce Avenue. Finally, the 100-year discharge used by ESA was 280 cfs larger than the peak discharge adopted here (507 cfs).

3.7 Summary and Potential Next Steps

The project developed a 1D/2D HEC-RAS Model for Colma Creek and Navigable Slough that incorporated the best available as-built plans and existing hydrologic and hydraulic models for the watershed. Updated hydrologic conditions were developed using the countywide LSPC model to simulate watershed hydrology and predict flows under scenarios considering current hydrologic conditions, green infrastructure projects, and climate change impacts based on different design storms ranging from 2- to 200-year. The impacts of the Orange Memorial Park Project, the Floodwall from Utah Avenue to Navigable Slough, and the change in sea level were analyzed with the model.

The channel was designed to pass the 50-year event with 2 feet of freeboard. For the reach downstream to Utah Avenue, these conditions are met with the exception being at the Dissipator Teeth where the flows turn subcritical, resulting in a sudden increase in water level. The reach downstream from Utah Avenue has less than 2 feet of freeboard and includes portions with low levels of flooding. The proposed floodwall would resolve these deficiencies.

Through modeling of the various current and future conditions, a greater understanding of the existing and potential future flood hazards was gathered. Additionally, the model can be used in the future to assess potential changes in hydrology and the impact of capital improvement projects.

The project modeled the 100-year inundation extents under existing conditions, which is the same condition used for FEMA flood hazard mapping. A natural extension for the use of this model could be to re-map the FEMA flood hazards for Colma Creek and Navigable Slough to reflect the current best available data. There are differences in the inundation mapping flood extents compared to the FEMA mapped flood hazards, with the most significant being between Spruce Avenue and San Mateo Avenue. This study shows (in general) lower discharges and extents of flooding along Colma Creek. The reasons for the difference in inundation extents will need to be determined through a review of the previous FEMA studies, as well as testing of the model for the assumptions used by FEMA. Once this has been performed, then discussions with FEMA regarding the Letter of Map Change (LOMC) process to update flood mapping can be initiated. The first step would be to coordinate with FEMA to obtain the previous studies and supporting documents.

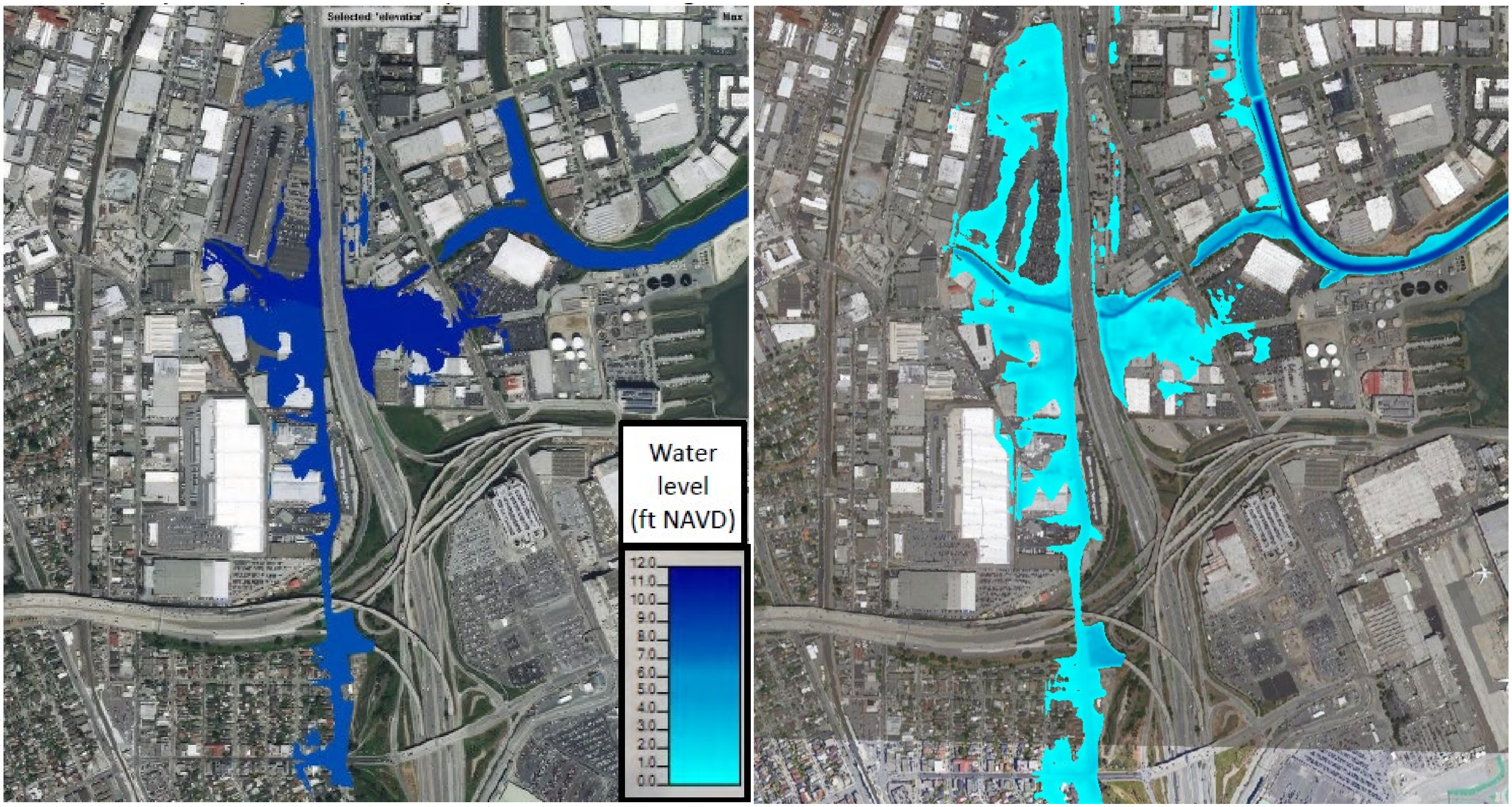


Figure 3-18. Comparison of flood extents modeled by ESA for the 100-year discharge along Navigable Slough (left) with current study results (right).

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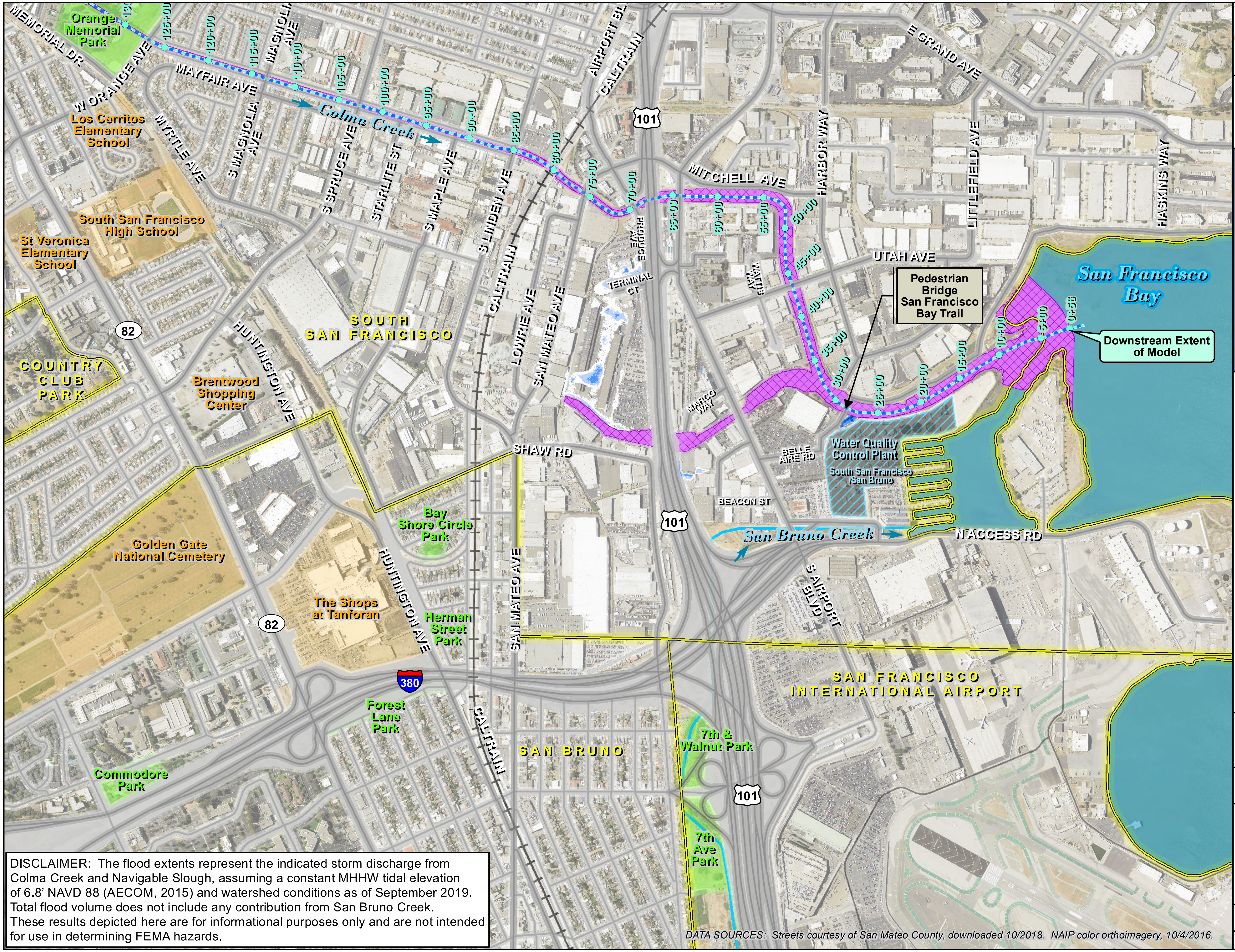
APPENDIX A: INUNDATION MAPS



DISCLAIMER: The flood extents represent the indicated storm discharge from Colma Creek and Navigable Slough, assuming a constant MHHW tidal elevation of 6.8' NAVD 88 (AECOM, 2015) and watershed conditions as of September 2019. Total flood volume does not include any contribution from San Bruno Creek. These results depicted here are for informational purposes only and are not intended for use in determining FEMA hazards.

DATA SOURCES: Streets courtesy of San Mateo County, downloaded 10/2018. NAIP color orthoimagery, 10/4/2016.

County of San Mateo
Department of Public Works

nhc
northwest hydraulic consultants

Legend

HEC-RAS Model Alignment and Stationing

Depth (in ft)

0.0 - 0.5
0.5 - 1.0
1.0 - 3.0
3.0 - 5.0
5.0 - 10.0
10.0 +

Flow in Channel

Railroads
Streets

Jurisdiction

Water Quality Control Plant

SCALE - 1:12,000
0 500 1,000 Feet
N

Coordinate System: CA State Plane, Zone III
Horizontal Datum: NAD 83

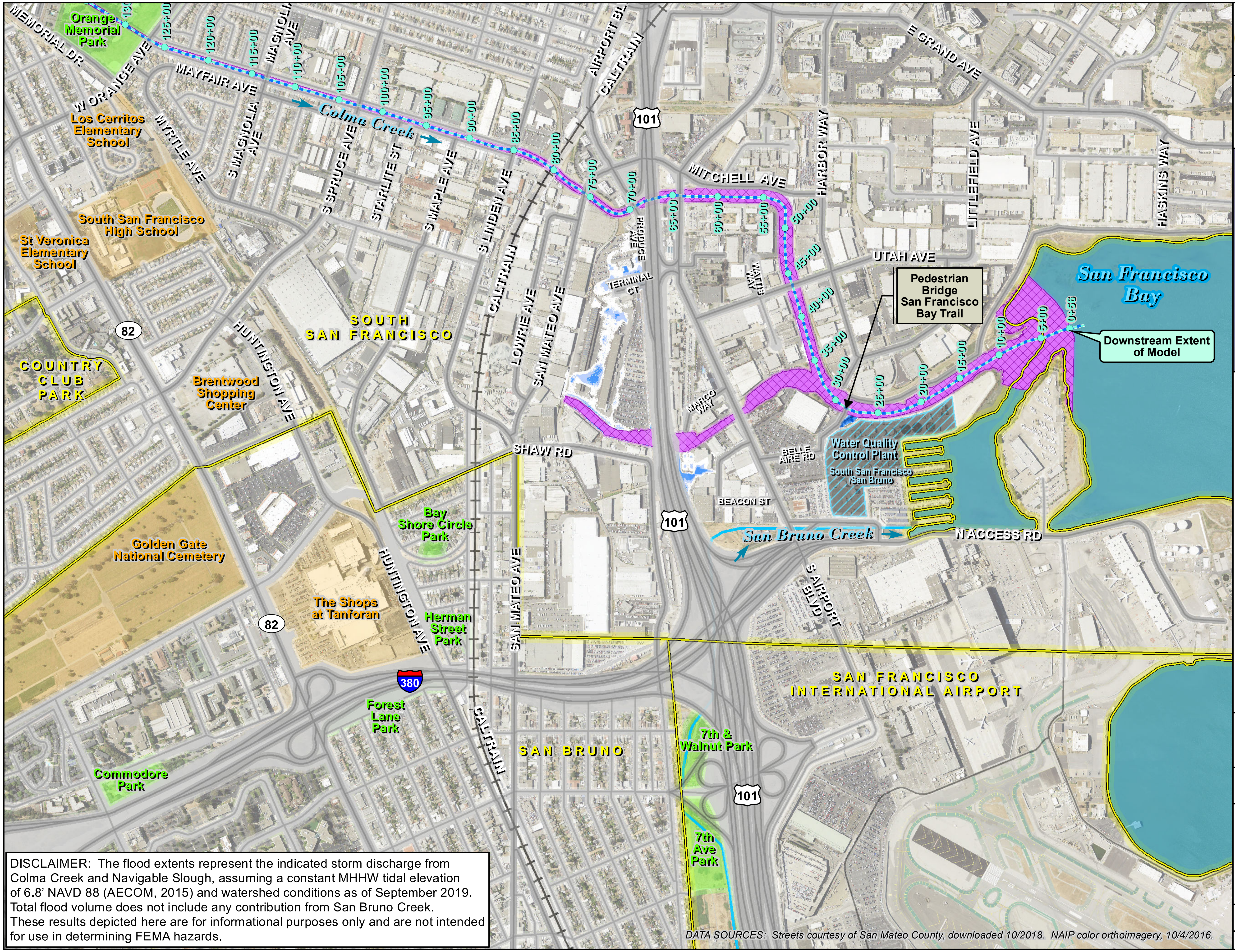
Colma Creek Watershed

Inundation Extent 2-year 12-hr Event Current State

FIGURE A-1

Job: 5004303 | Date: DECEMBER 2019

ABC_P:\5004303-Colma_Creek\GIS\2_MXD_Workmaps\Staff_Workmaps\Dawn_Lasprugato\5004303-Colma-Inundation-Maps_DL_Rev4.mxd



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Legend

HEC-RAS Model Alignment and Stationing

Depth (in ft)

- 0.0 - 0.5
- 0.5 - 1.0
- 1.0 - 3.0
- 3.0 - 5.0
- 5.0 - 10.0
- 10.0 +

Flow in Channel

Railroads

Streets

Jurisdiction

Water Quality Control Plant

SCALE - 1:12,000

0 500 1,000 Feet

N

Coordinate System: CA State Plane, Zone III
Horizontal Datum: NAD 83

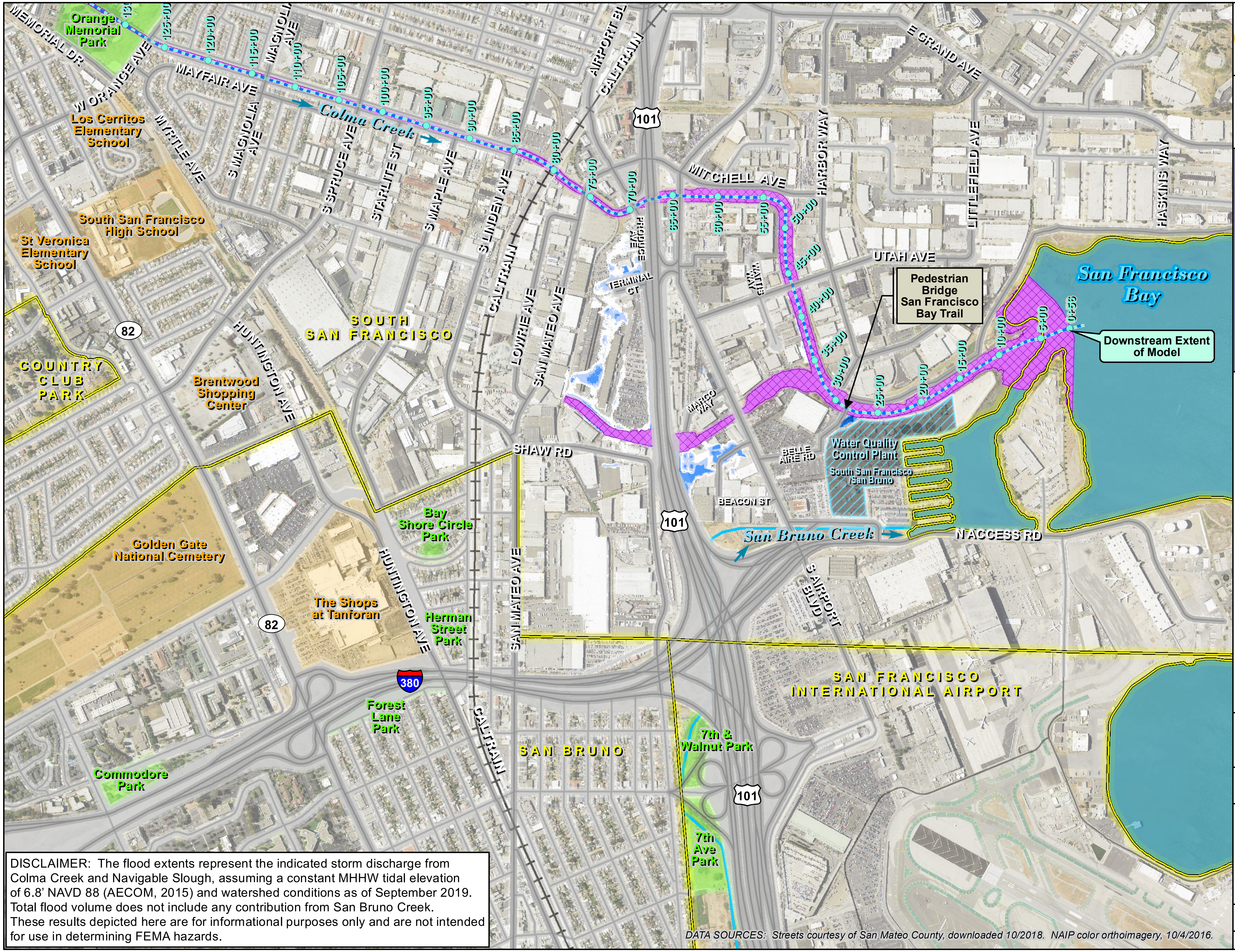
Colma Creek Watershed

Inundation Extent 5-year 12-hr Event Current State

FIGURE A-2

Job: 5004303 | Date: DECEMBER 2019

ABC_P:\5004303-Colma_Creek\GIS\2_MXD_Workmaps\Staff_Workmaps\Dawn_Lasprugato\5004303-Colma-Inundation-Maps_DL_Rev4.mxd



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Legend

- HEC-RAS Model Alignment and Stationing

Depth (in ft)

- 0.0 - 0.5
- 0.5 - 1.0
- 1.0 - 3.0
- 3.0 - 5.0
- 5.0 - 10.0
- 10.0 +
- Flow in Channel
- Railroads
- Streets
- Jurisdiction
- Water Quality Control Plant

SCALE - 1:12,000

0 500 1,000 Feet

N

Coordinate System: CA State Plane, Zone III
Horizontal Datum: NAD 83

Colma Creek Watershed

Inundation Extent
10-year 12-hr Event
Current State

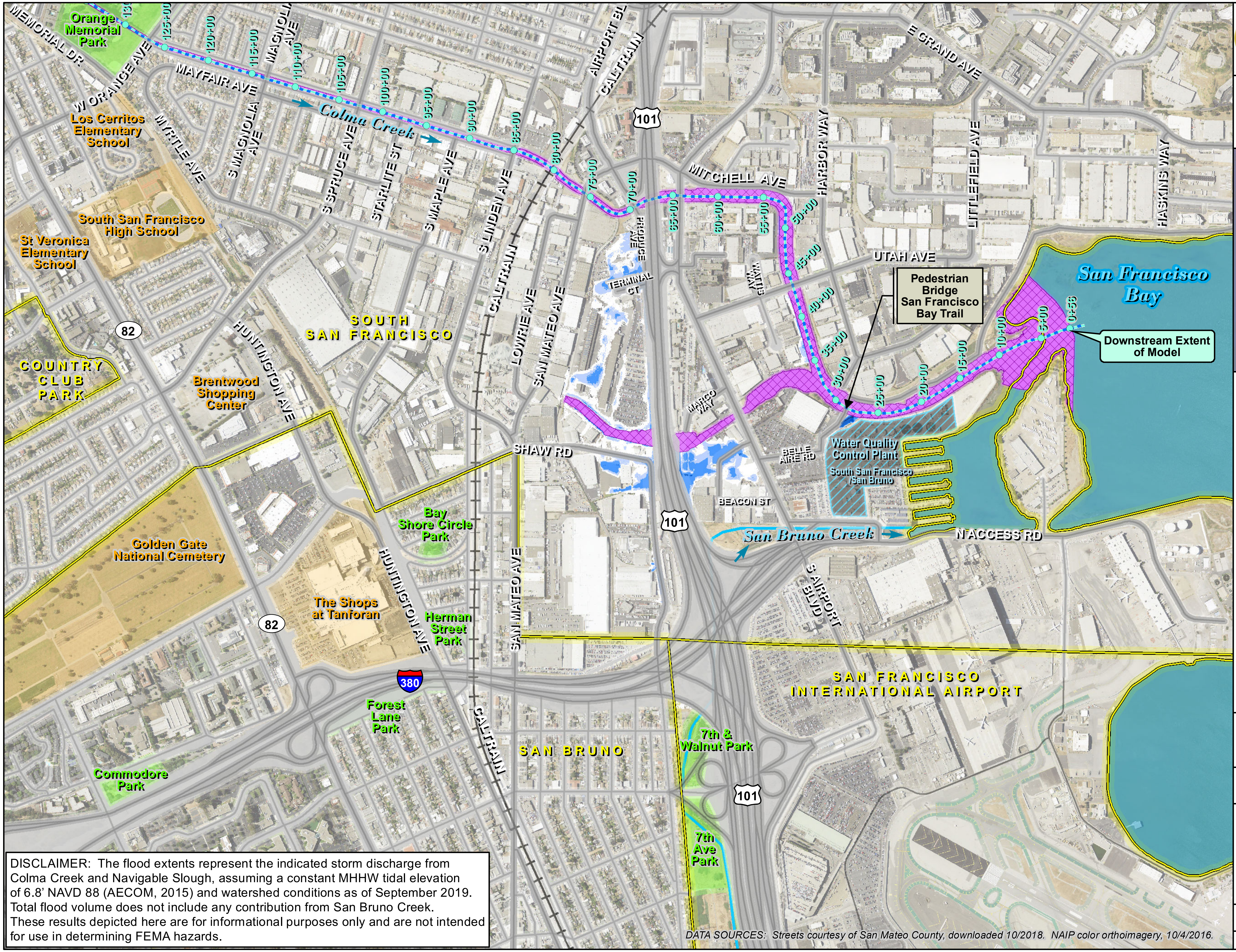
FIGURE A-3

Job: 5004303 | Date: DECEMBER 2019

DISCLAIMER: The flood extents represent the indicated storm discharge from Colma Creek and Navigable Slough, assuming a constant MHHW tidal elevation of 6.8' NAVD 88 (AECOM, 2015) and watershed conditions as of September 2019. Total flood volume does not include any contribution from San Bruno Creek. These results depicted here are for informational purposes only and are not intended for use in determining FEMA hazards.

DATA SOURCES: Streets courtesy of San Mateo County, downloaded 10/2018. NAIP color orthoimagery, 10/4/2016.

ABC_P:\5004303-Colma_Creek\GIS\2_MXD_Workmaps\Staff_Workmaps\Dawn_Lasprugato\5004303-Colma-Inundation-Maps_DL_Rev4.mxd



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Daly City
South San Francisco
Pacifica
San Bruno
San Mateo
Redwood City
East Palo Alto
Pacific Ocean
SAN MATEO COUNTY

Legend

HEC-RAS Model Alignment and Stationing

Depth (in ft)

- 0.0 - 0.5
- 0.5 - 1.0
- 1.0 - 3.0
- 3.0 - 5.0
- 5.0 - 10.0
- 10.0 +

Flow in Channel

Railroads

Streets

Jurisdiction

Water Quality Control Plant

SCALE - 1:12,000

0 500 1,000 Feet

N

Coordinate System: CA State Plane, Zone III
Horizontal Datum: NAD 83

Colma Creek Watershed

Inundation Extent 25-year 12-hr Event Current State

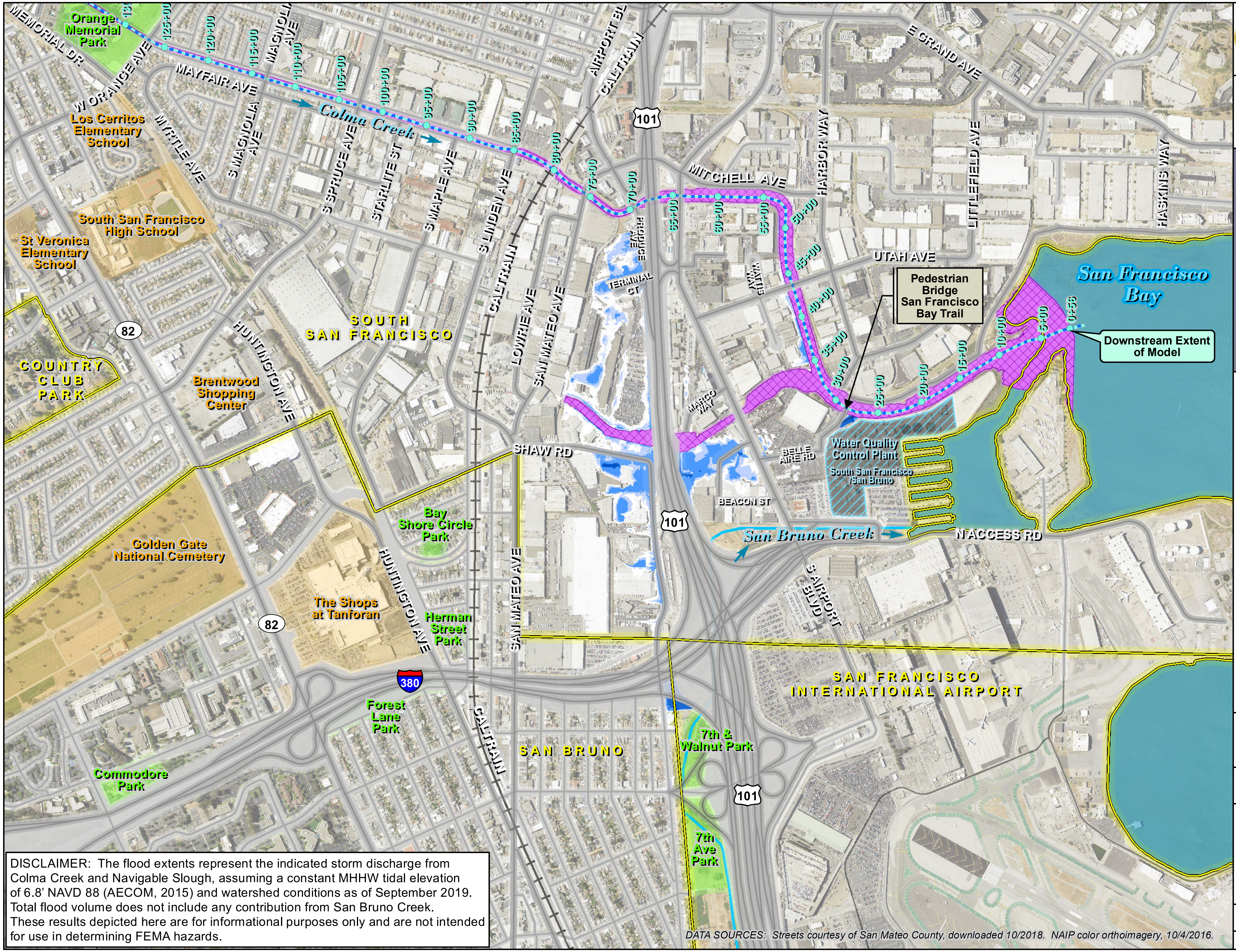
FIGURE A-4

Job: 5004303 | Date: DECEMBER 2019

DISCLAIMER: The flood extents represent the indicated storm discharge from Colma Creek and Navigable Slough, assuming a constant MHHW tidal elevation of 6.8' NAVD 88 (AECOM, 2015) and watershed conditions as of September 2019. Total flood volume does not include any contribution from San Bruno Creek. These results depicted here are for informational purposes only and are not intended for use in determining FEMA hazards.

DATA SOURCES: Streets courtesy of San Mateo County, downloaded 10/2018. NAIP color orthoimagery, 10/4/2016.

ABC_P:\5004303-Colma_Creek\GIS\2_MXD_Workmaps\Staff_Workmaps\Dawn_Lasprugato\5004303-Colma-Inundation-Maps_DL_Rev4.mxd



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Legend

- HEC-RAS Model Alignment and Stationing

Depth (in ft)

- 0.0 - 0.5
- 0.5 - 1.0
- 1.0 - 3.0
- 3.0 - 5.0
- 5.0 - 10.0
- 10.0 +
- Flow in Channel
- Railroads
- Streets
- Jurisdiction
- Water Quality Control Plant

SCALE - 1:12,000

0 500 1,000 Feet

N

Coordinate System: CA State Plane, Zone III
Horizontal Datum: NAD 83

Colma Creek Watershed

Inundation Extent
50-year 12-hr Event
Current State

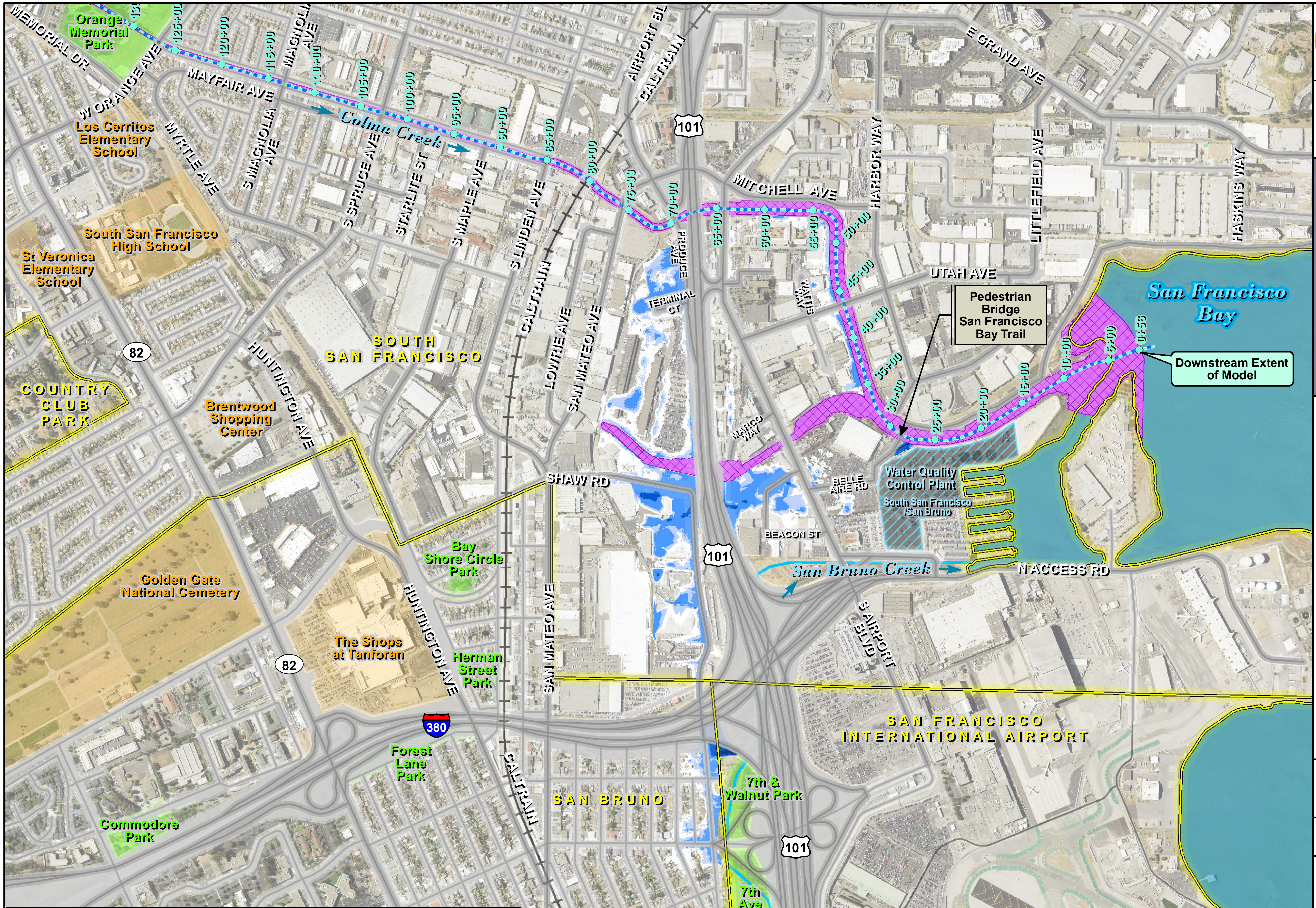
FIGURE A-5

Job: 5004303 | Date: DECEMBER 2019

DISCLAIMER: The flood extents represent the indicated storm discharge from Colma Creek and Navigable Slough, assuming a constant MHHW tidal elevation of 6.8' NAVD 88 (AECOM, 2015) and watershed conditions as of September 2019. Total flood volume does not include any contribution from San Bruno Creek. These results depicted here are for informational purposes only and are not intended for use in determining FEMA hazards.

DATA SOURCES: Streets courtesy of San Mateo County, downloaded 10/2018. NAIP color orthoimagery, 10/4/2016.

ABC_P:\5004303-Colma_Creek\GIS\2_MXD_Workmaps\Staff_Workmaps\Dawn_Lasprugato\5004303-Colma-Inundation-Maps_DL_Rev4.mxd



DISCLAIMER: The flood extents represent the indicated storm discharge from Colma Creek and Navigable Slough, assuming a constant MHHW tidal elevation of 6.8' NAVD 88 (AECOM, 2015) and watershed conditions as of September 2019. Total flood volume does not include any contribution from San Bruno Creek. These results depicted here are for informational purposes only and are not intended for use in determining FEMA hazards.

DATA SOURCES: Streets courtesy of San Mateo County, downloaded 10/2018. NAIP color orthoimagery, 10/4/2016.

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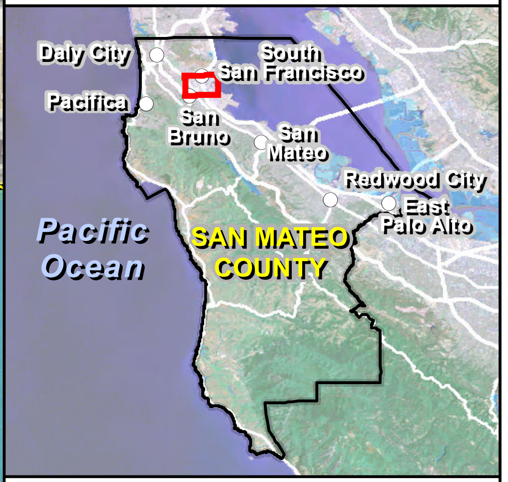


Legend

HEC-RAS Model Alignment and Stationing

Depth (in ft)

- 0.0 - 0.5
- 0.5 - 1.0
- 1.0 - 3.0
- 3.0 - 5.0
- 5.0 - 10.0
- 10.0 +

Flow in Channel

Railroads

Streets

Jurisdiction

Water Quality Control Plant

SCALE - 1:12,000

0 500 1,000 Feet

N

Coordinate System: CA State Plane, Zone III
Horizontal Datum: NAD 83

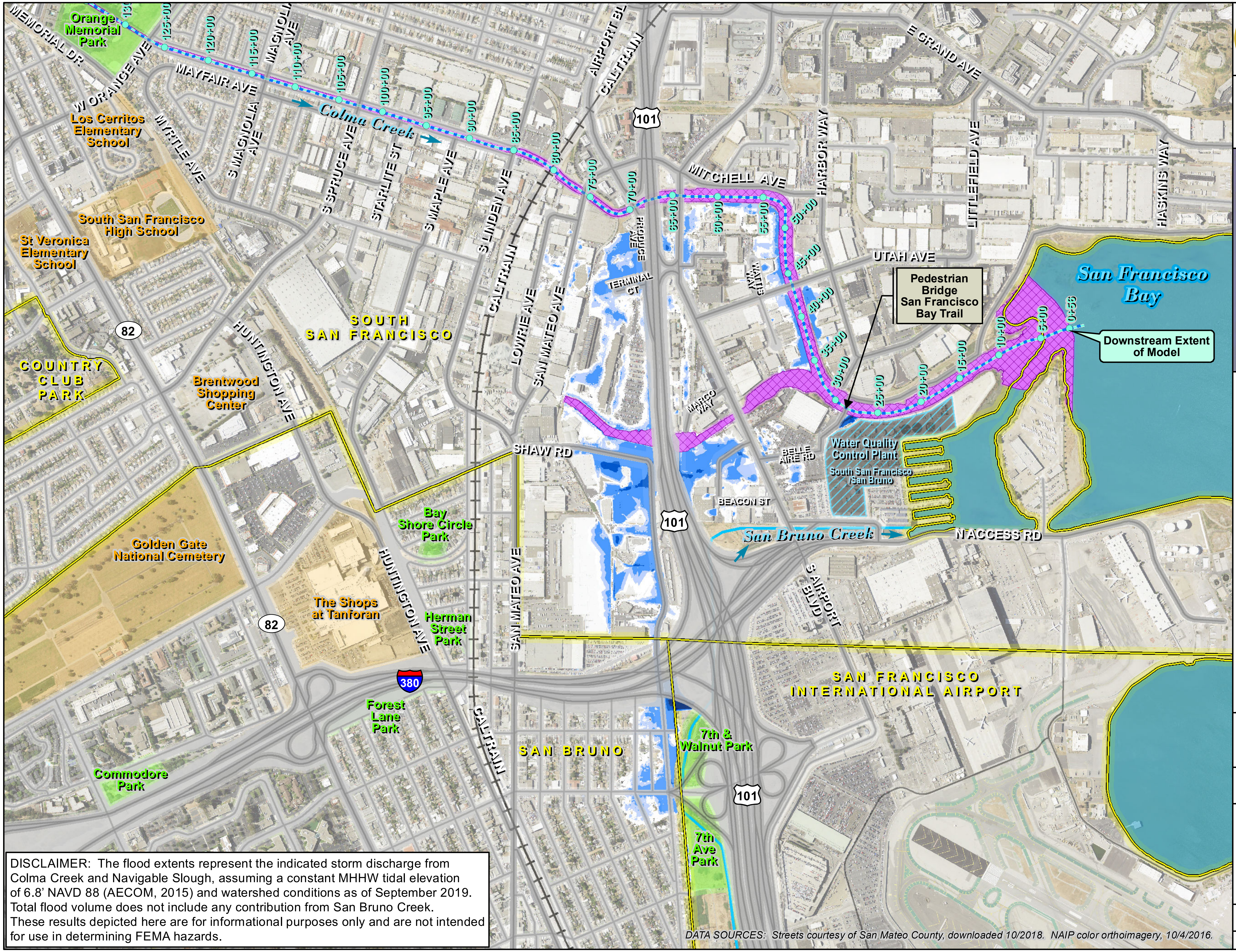
Colma Creek Watershed

Inundation Extent
100-year 12-hr Event
Current State

FIGURE A-6

Job: 5004303 | *Date: DECEMBER 2019*

ABC_P:\5004303-Colma_Creek\GIS\2_MXD_Workmaps\Staff_Workmaps\Dawn_Lasprugato\5004303-Colma-Inundation-Maps_DL_Rev4.mxd



DISCLAIMER: The flood extents represent the indicated storm discharge from Colma Creek and Navigable Slough, assuming a constant MHHW tidal elevation of 6.8' NAVD 88 (AECOM, 2015) and watershed conditions as of September 2019. Total flood volume does not include any contribution from San Bruno Creek. These results depicted here are for informational purposes only and are not intended for use in determining FEMA hazards.

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Legend

- HEC-RAS Model Alignment and Stationing

Depth (in ft)

0.0 - 0.5	3.0 - 5.0
0.5 - 1.0	5.0 - 10.0
1.0 - 3.0	10.0 +

- Flow in Channel
- Railroads
- Streets
- Jurisdiction
- Water Quality Control Plant

SCALE - 1:12,000

0 500 1,000 Feet

N

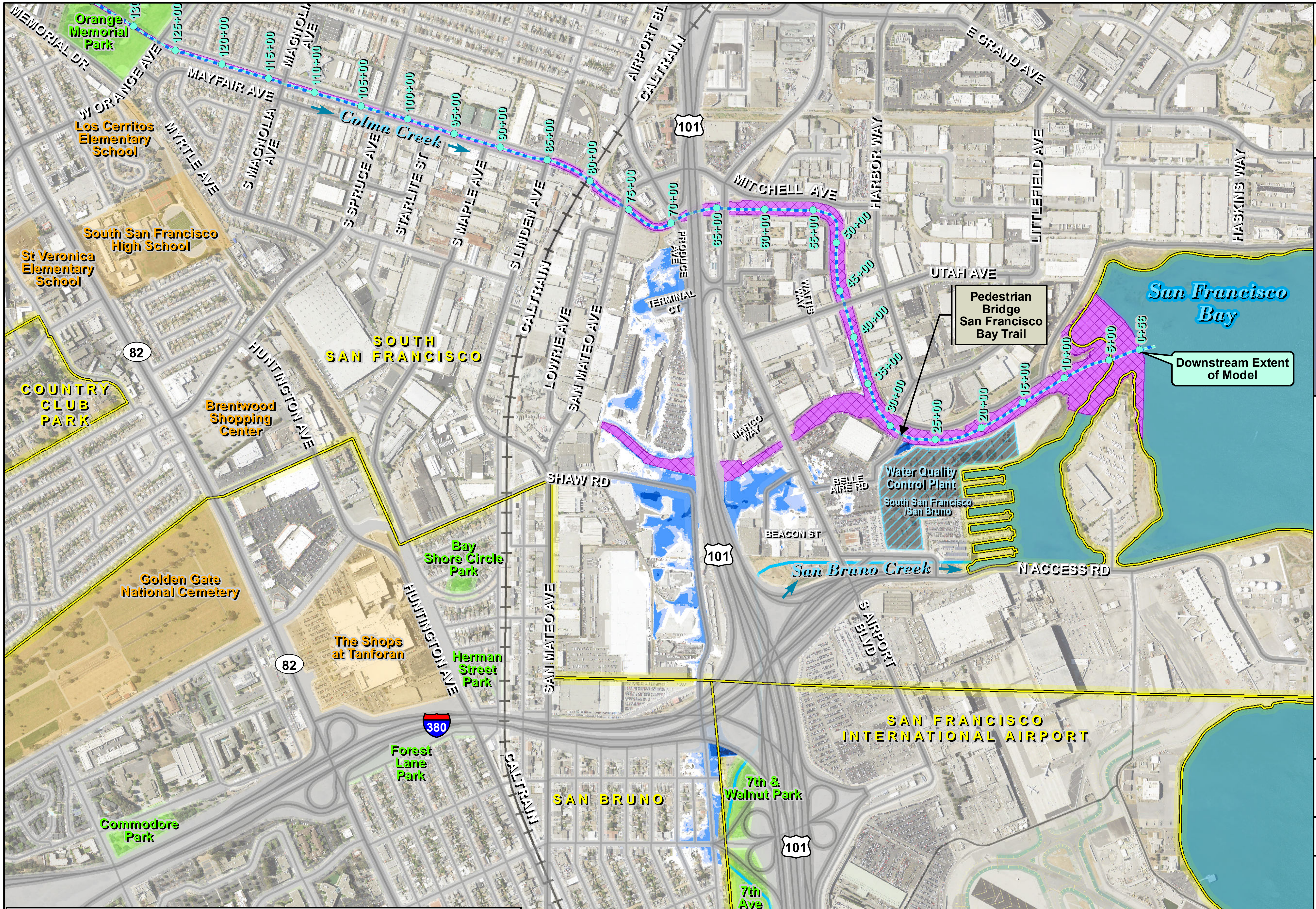
Coordinate System: CA State Plane, Zone III
Horizontal Datum: NAD 83

Colma Creek Watershed

Inundation Extent 200-year 12-hr Event Current State

FIGURE A-7

Job: 5004303 | Date: DECEMBER 2019



DISCLAIMER: The flood extents represent the indicated storm discharge from Colma Creek and Navigable Slough, assuming a constant MHHW tidal elevation of 6.8' NAVD 88 (AECOM, 2015) and watershed conditions as of September 2019. Total flood volume does not include any contribution from San Bruno Creek. These results depicted here are for informational purposes only and are not intended for use in determining FEMA hazards.

DATA SOURCES: Streets courtesy of San Mateo County, downloaded 10/2018. NAIP color orthoimagery, 10/4/2016.

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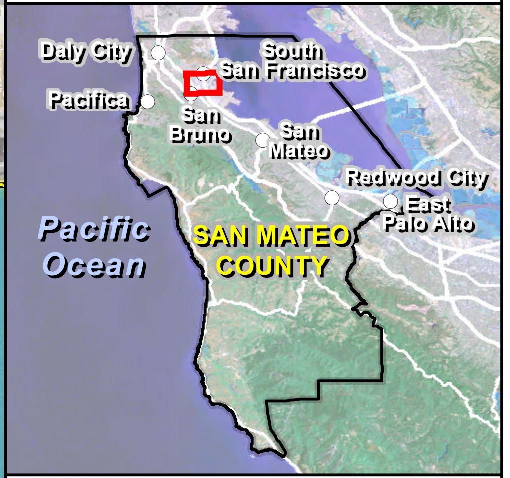


Legend

- HEC-RAS Model Alignment and Stationing

Depth (in ft)

- 0.0 - 0.5
- 0.5 - 1.0
- 1.0 - 3.0
- 3.0 - 5.0
- 5.0 - 10.0
- 10.0 +
- Flow in Channel
- Railroads
- Streets
- Jurisdiction
- Water Quality Control Plant

SCALE - 1:12,000
0 500 1,000 Feet
N

Coordinate System: CA State Plane, Zone III
Horizontal Datum: NAD 83

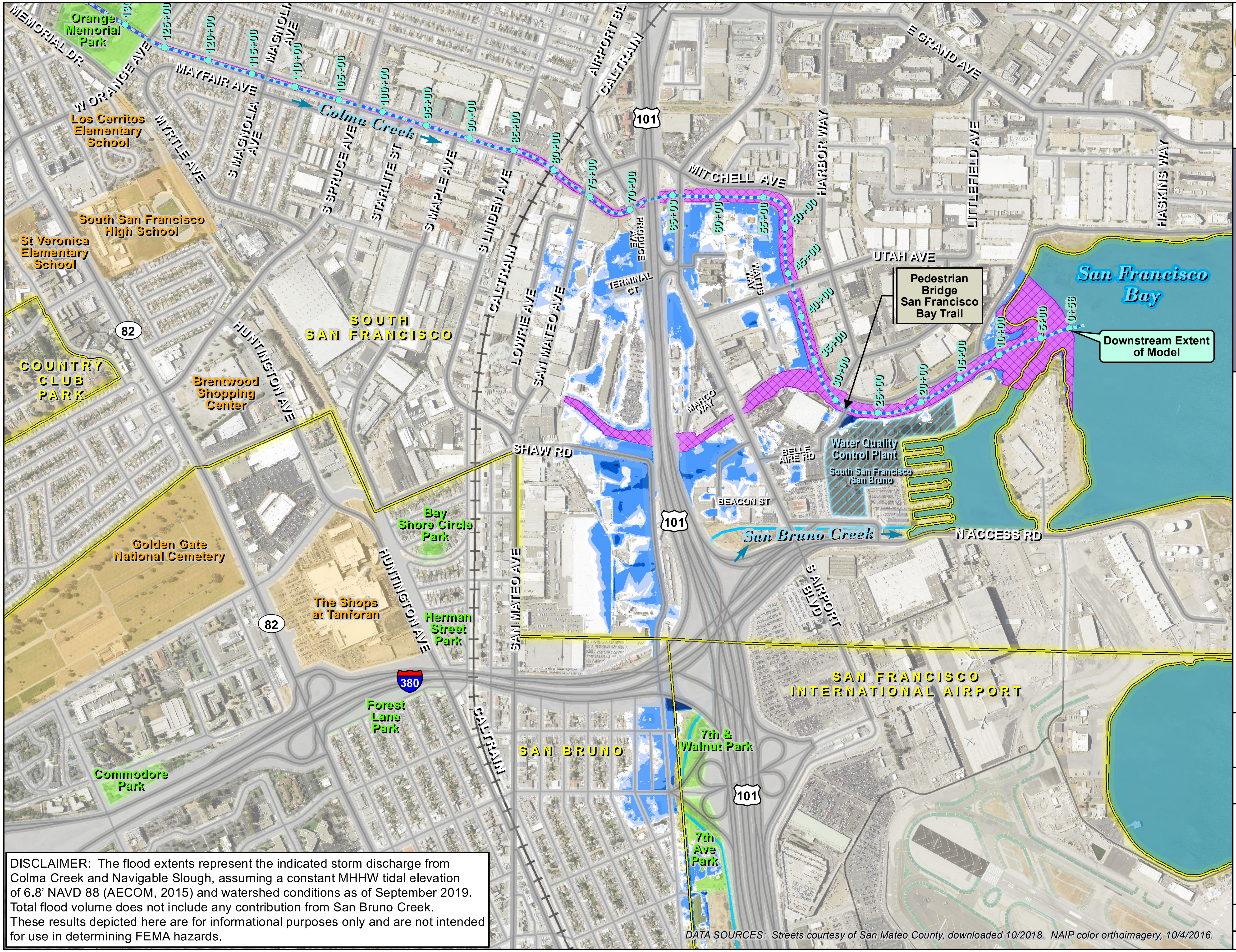
Colma Creek Watershed

Inundation Extent
100-year 12-hr Event
Current State, Utah Avenue-Navigable Slough Floodwall in Place

FIGURE A-8

Job: 5004303 | Date: DECEMBER 2019

ABC: P:\5004303-Colma_Creek\GIS\2_MXD_Workmaps\Staff_Workmaps\Dawn_Lasprugato\5004303-Colma-Inundation-Maps_DL_Rev4.mxd



DISCLAIMER: The flood extents represent the indicated storm discharge from Colma Creek and Navigable Slough, assuming a constant MHHW tidal elevation of 6.8' NAVD 88 (AECOM, 2015) and watershed conditions as of September 2019. Total flood volume does not include any contribution from San Bruno Creek. These results depicted here are for informational purposes only and are not intended for use in determining FEMA hazards.

DATA SOURCES: Streets courtesy of San Mateo County, downloaded 10/2018. NAIP color orthoimagery, 10/4/2016.

County of San Mateo
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Legend

- HEC-RAS Model Alignment and Stationing

Depth (in ft)

- 0.0 - 0.5
- 0.5 - 1.0
- 1.0 - 3.0
- 3.0 - 5.0
- 5.0 - 10.0
- 10.0 +
- Flow in Channel
- Railroads
- Streets
- Jurisdiction
- Water Quality Control Plant

SCALE - 1:12,000
0 500 1,000 Feet
N

Coordinate System: CA State Plane, Zone III
Horizontal Datum: NAD 83

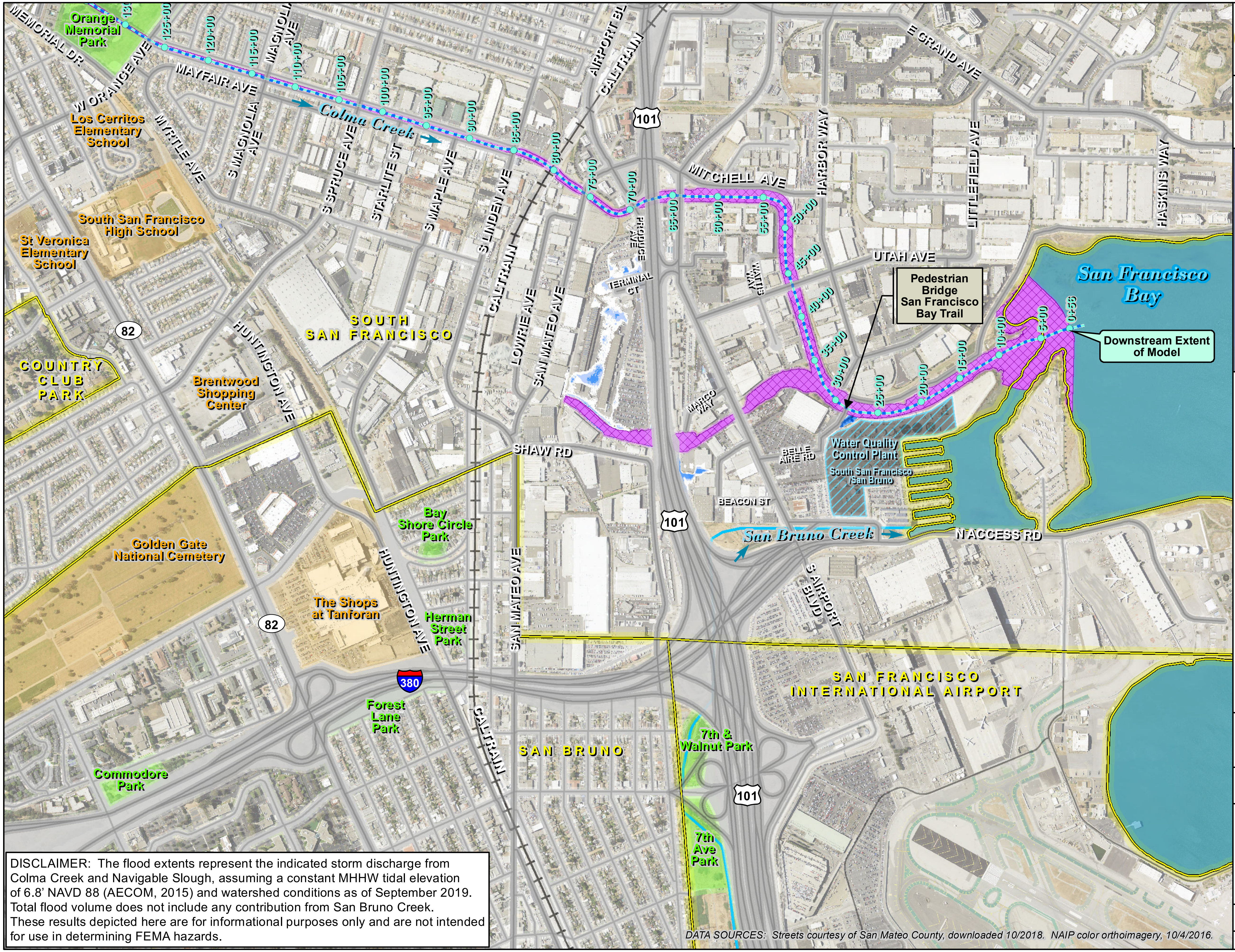
Colma Creek Watershed

Inundation Extent
100-year 12-hr Event
Current State, with Sea Level Rise

FIGURE A-9

Job: 5004303 | Date: DECEMBER 2019

ABC_P:\5004303-Colma_Creek\GIS2_MXD_Workmaps\Staff_Workmaps\Dawn_Laspragato\5004303-Colma-Inundation-Maps_DL_Rev4.mxd



DISCLAIMER: The flood extents represent the indicated storm discharge from Colma Creek and Navigable Slough, assuming a constant MHHW tidal elevation of 6.8' NAVD 88 (AECOM, 2015) and watershed conditions as of September 2019. Total flood volume does not include any contribution from San Bruno Creek. These results depicted here are for informational purposes only and are not intended for use in determining FEMA hazards.

DATA SOURCES: Streets courtesy of San Mateo County, downloaded 10/2018. NAIP color orthoimagery, 10/4/2016.

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Legend

HEC-RAS Model Alignment and Stationing

Depth (in ft)

- 0.0 - 0.5
- 0.5 - 1.0
- 1.0 - 3.0
- 3.0 - 5.0
- 5.0 - 10.0
- 10.0 +

Flow in Channel

Railroads

Streets

Jurisdiction

Water Quality Control Plant

SCALE - 1:12,000

0 500 1,000 Feet

N

Coordinate System: CA State Plane, Zone III
Horizontal Datum: NAD 83

Colma Creek Watershed

Inundation Extent 2-year 12-hr Event Future Climate

FIGURE A-10

Job: 5004303 | Date: DECEMBER 2019

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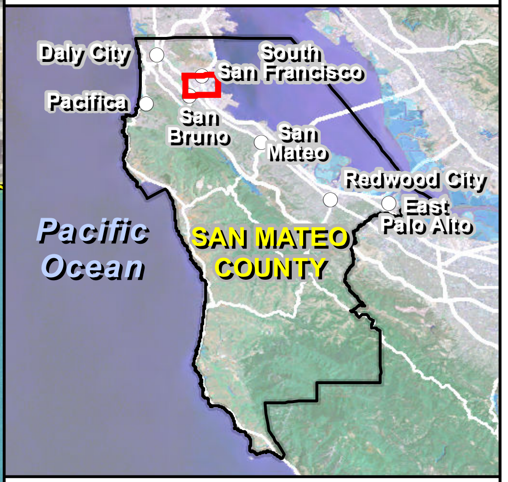
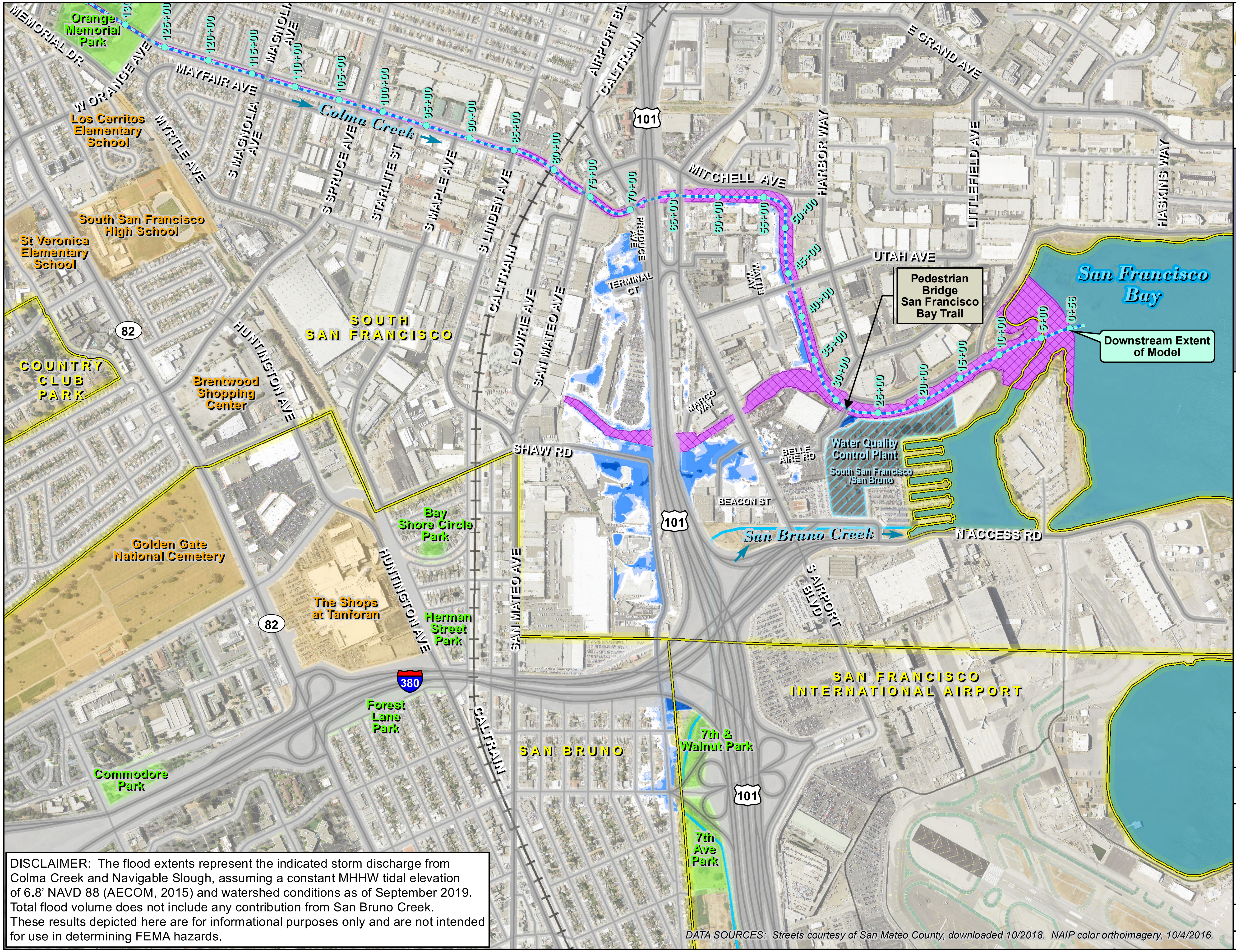




DISCLAIMER: The flood extents represent the indicated storm discharge from Colma Creek and Navigable Slough, assuming a constant MHHW tidal elevation of 6.8' NAVD 88 (AECOM, 2015) and watershed conditions as of September 2019. Total flood volume does not include any contribution from San Bruno Creek. These results depicted here are for informational purposes only and are not intended for use in determining FEMA hazards.

DATA SOURCES: Streets courtesy of San Mateo County, downloaded 10/2018. NAIP color orthoimagery, 10/4/2016.

Legend

HEC-RAS Model Alignment and Stationing

Depth (in ft)

- 0.0 - 0.5
- 0.5 - 1.0
- 1.0 - 3.0
- 3.0 - 5.0
- 5.0 - 10.0
- 10.0 +

Flow in Channel

Railroads

Streets

Jurisdiction

Water Quality Control Plant

SCALE - 1:12,000
0 500 1,000 Feet
N

Coordinate System: CA State Plane, Zone III
Horizontal Datum: NAD 83

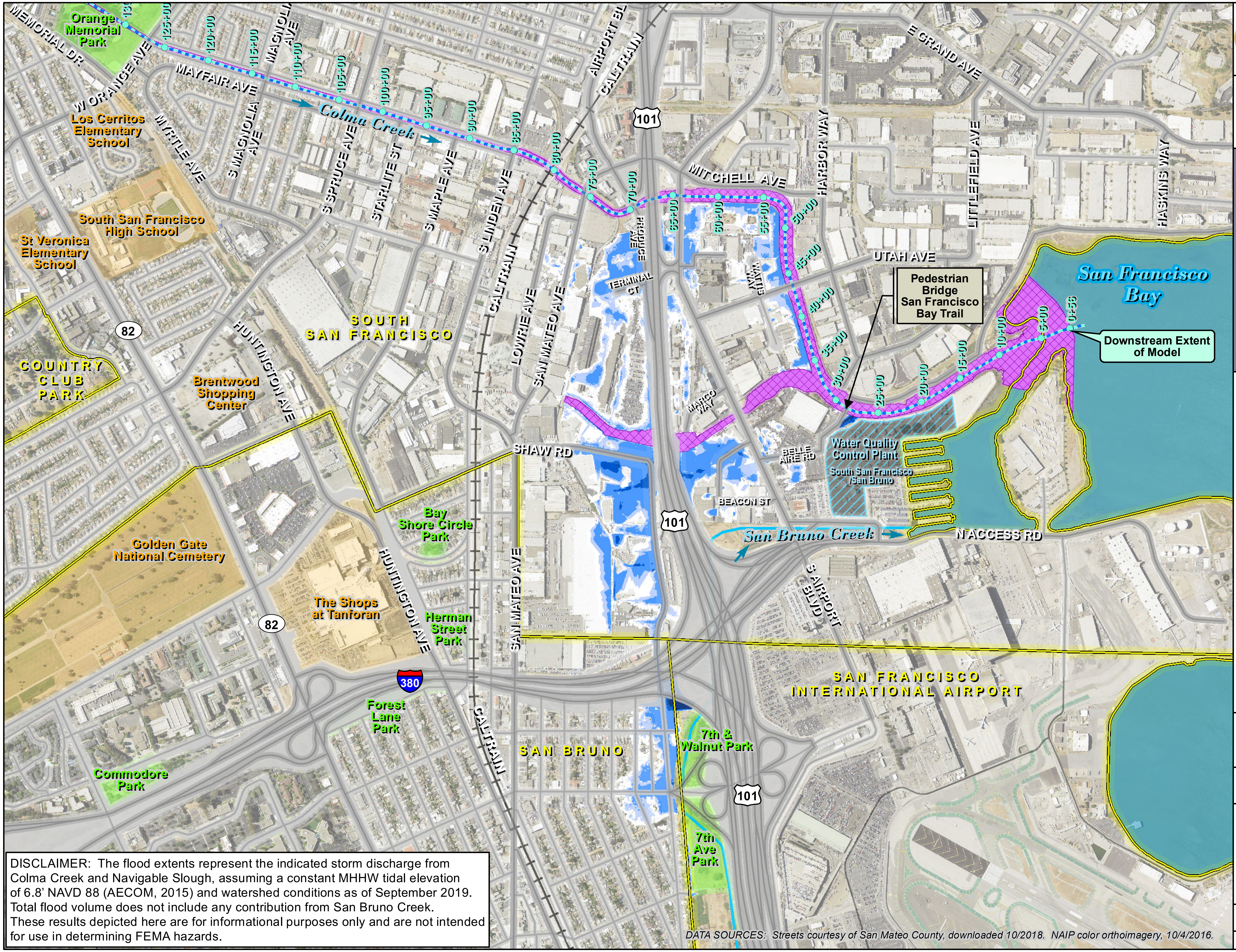
Colma Creek Watershed

Inundation Extent
25-year 12-hr Event
Future Climate

FIGURE A-11

Job: 5004303 | *Date: DECEMBER 2019*

ABC_P:\5004303-Colma_Creek\GIS\2_MXD_Workmaps\Staff_Workmaps\Dawn_Lasprugato\5004303-Colma-Inundation-Maps_DL_Rev4.mxd



DISCLAIMER: The flood extents represent the indicated storm discharge from Colma Creek and Navigable Slough, assuming a constant MHHW tidal elevation of 6.8' NAVD 88 (AECOM, 2015) and watershed conditions as of September 2019. Total flood volume does not include any contribution from San Bruno Creek. These results depicted here are for informational purposes only and are not intended for use in determining FEMA hazards.

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Legend

HEC-RAS Model Alignment and Stationing

Depth (in ft)

0.0 - 0.5
0.5 - 1.0
1.0 - 3.0
3.0 - 5.0
5.0 - 10.0
10.0 +

Flow in Channel
Railroads
Streets
Jurisdiction
Water Quality Control Plant

SCALE - 1:12,000
0 500 1,000 Feet
N

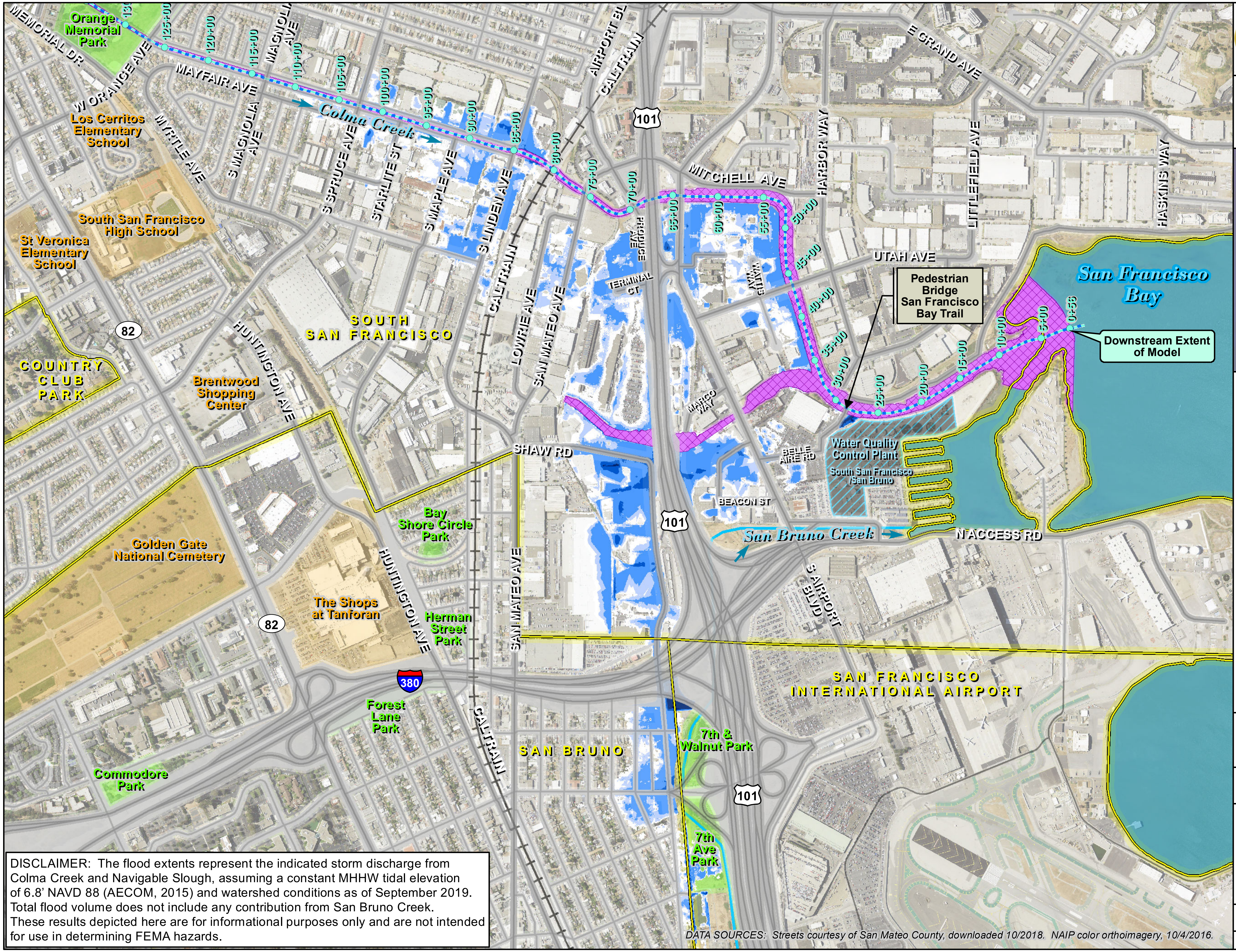
Coordinate System: CA State Plane, Zone III
Horizontal Datum: NAD 83

Colma Creek Watershed

Inundation Extent
50-year 12-hr Event
Future Climate

FIGURE A-12

Job: 5004303 | Date: DECEMBER 2019



DISCLAIMER: The flood extents represent the indicated storm discharge from Colma Creek and Navigable Slough, assuming a constant MHHW tidal elevation of 6.8' NAVD 88 (AECOM, 2015) and watershed conditions as of September 2019. Total flood volume does not include any contribution from San Bruno Creek. These results depicted here are for informational purposes only and are not intended for use in determining FEMA hazards.

DATA SOURCES: Streets courtesy of San Mateo County, downloaded 10/2018. NAIP color orthoimagery, 10/4/2016.

County of San Mateo
Department of Public Works

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Daly City, South San Francisco, Pacifica, San Bruno, San Mateo, Redwood City, East Palo Alto, Pacific Ocean, SAN MATEO COUNTY

Legend

- HEC-RAS Model Alignment and Stationing

Depth (in ft)

- 0.0 - 0.5
- 0.5 - 1.0
- 1.0 - 3.0
- 3.0 - 5.0
- 5.0 - 10.0
- 10.0 +
- Flow in Channel
- Railroads
- Streets
- Jurisdiction
- Water Quality Control Plant

SCALE - 1:12,000

0 500 1,000 Feet

N

Coordinate System: CA State Plane, Zone III
Horizontal Datum: NAD 83

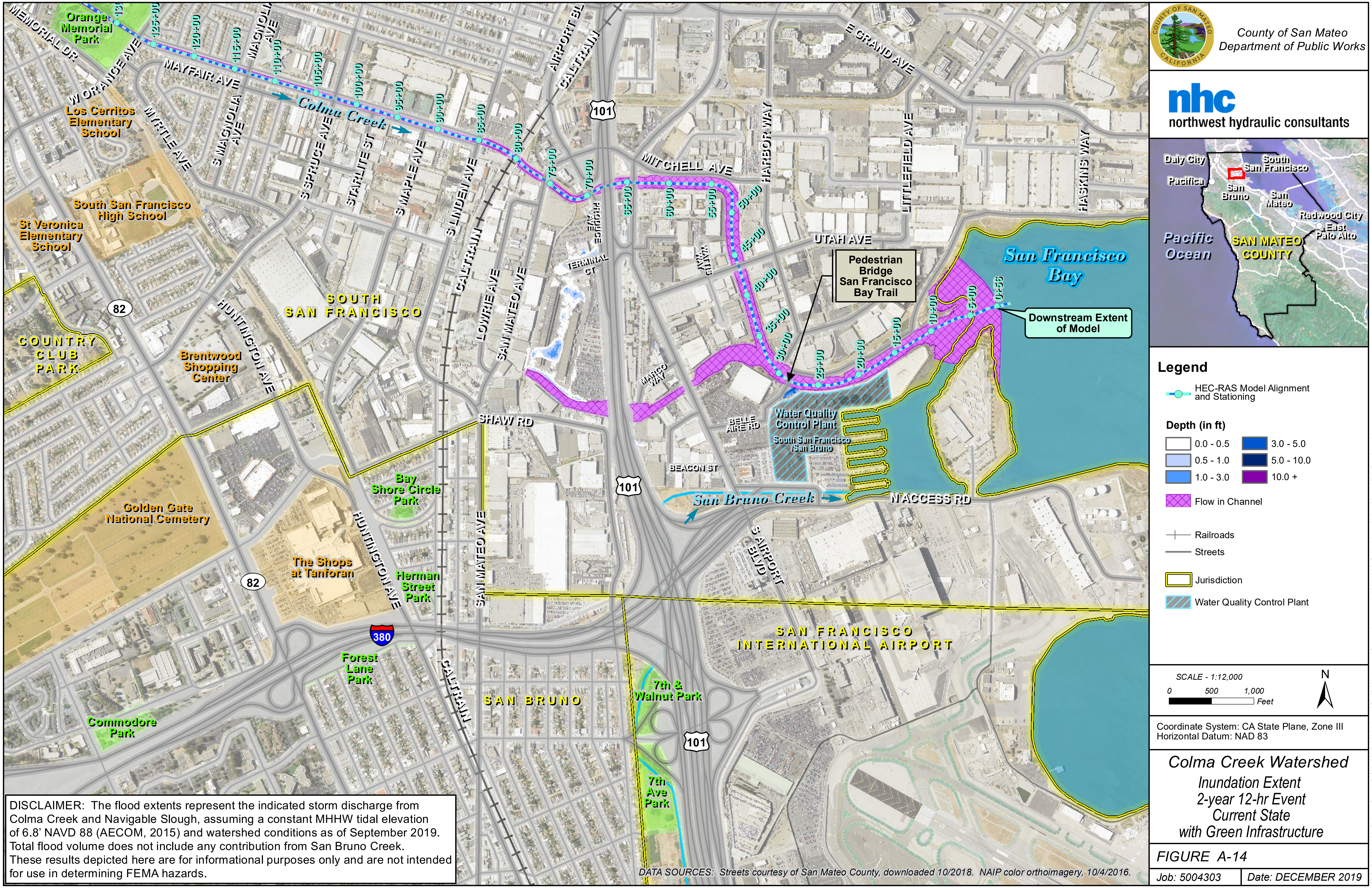
Colma Creek Watershed

Inundation Extent
100-year 12-hr Event
Future Climate

FIGURE A-13

Job: 5004303 | *Date: DECEMBER 2019*

ABC_P:\5004303-Colma_Creek\GIS\2_MXD_Workmaps\Staff_Workmaps\Dawn_Lasprugato\5004303-Colma-Inundation-Maps_DL_Rev4.mxd



DISCLAIMER: The flood extents represent the indicated storm discharge from Colma Creek and Navigable Slough, assuming a constant MHHW tidal elevation of 6.8' NAVD 88 (AECOM, 2015) and watershed conditions as of September 2019. Total flood volume does not include any contribution from San Bruno Creek. These results depicted here are for informational purposes only and are not intended for use in determining FEMA hazards.

DATA SOURCES: Streets courtesy of San Mateo County, downloaded 10/2018. NAIP color orthoimagery, 10/4/2016.

Coordinate System: CA State Plane, Zone III
Horizontal Datum: NAD 83

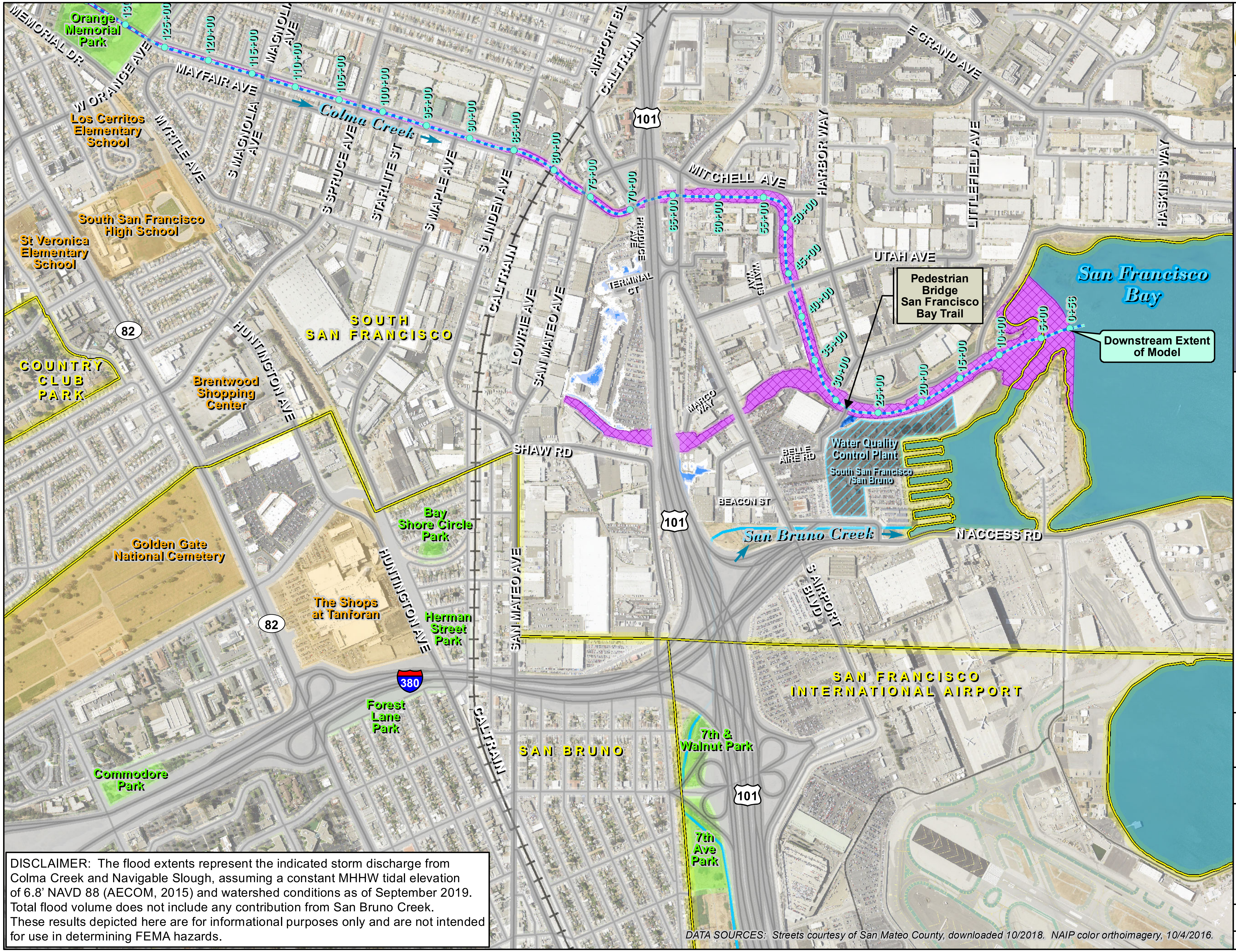
Colma Creek Watershed

Inundation Extent
2-year 12-hr Event
Current State
with Green Infrastructure

FIGURE A-14

Job: 5004303 | *Date: DECEMBER 2019*

ABC_P:\5004303-Colma_Creek\GIS\2_MXD_Workmaps\Staff_Workmaps\Dawn_Lasprugato\5004303-Colma-Inundation-Maps_DL_Rev4.mxd



DISCLAIMER: The flood extents represent the indicated storm discharge from Colma Creek and Navigable Slough, assuming a constant MHHW tidal elevation of 6.8' NAVD 88 (AECOM, 2015) and watershed conditions as of September 2019. Total flood volume does not include any contribution from San Bruno Creek. These results depicted here are for informational purposes only and are not intended for use in determining FEMA hazards.

DATA SOURCES: Streets courtesy of San Mateo County, downloaded 10/2018. NAIP color orthoimagery, 10/4/2016.

County of San Mateo
Department of Public Works

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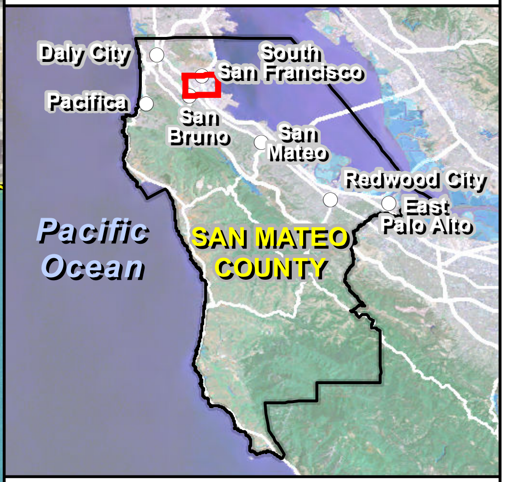


Legend

- HEC-RAS Model Alignment and Stationing

Depth (in ft)

- 0.0 - 0.5
- 0.5 - 1.0
- 1.0 - 3.0
- 3.0 - 5.0
- 5.0 - 10.0
- 10.0 +

- Flow in Channel
- Railroads
- Streets
- Jurisdiction
- Water Quality Control Plant

SCALE - 1:12,000

0 500 1,000 Feet

N

Coordinate System: CA State Plane, Zone III
Horizontal Datum: NAD 83

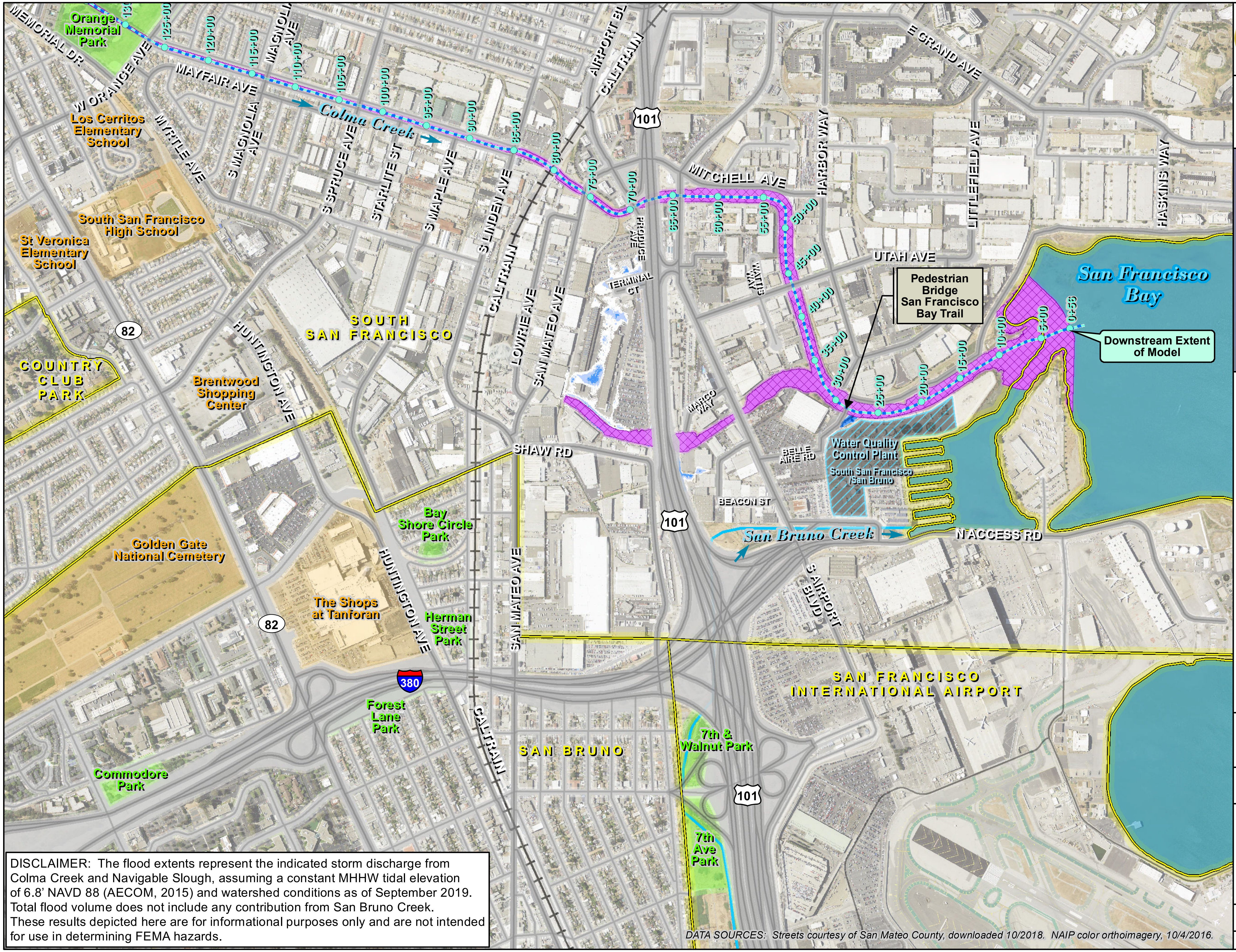
Colma Creek Watershed

Inundation Extent
5-year 12-hr Event
Current State
with Green Infrastructure

FIGURE A-15

Job: 5004303 | Date: DECEMBER 2019

ABC_P:\5004303-Colma_Creek\GIS\2_MXD_Workmaps\Staff_Workmaps\Dawn_Lasprugato\5004303-Colma-Inundation-Maps_DL_Rev4.mxd



DISCLAIMER: The flood extents represent the indicated storm discharge from Colma Creek and Navigable Slough, assuming a constant MHHW tidal elevation of 6.8' NAVD 88 (AECOM, 2015) and watershed conditions as of September 2019. Total flood volume does not include any contribution from San Bruno Creek. These results depicted here are for informational purposes only and are not intended for use in determining FEMA hazards.

County of San Mateo
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Legend

- HEC-RAS Model Alignment and Stationing

Depth (in ft)

- 0.0 - 0.5
- 0.5 - 1.0
- 1.0 - 3.0
- 3.0 - 5.0
- 5.0 - 10.0
- 10.0 +
- Flow in Channel
- Railroads
- Streets
- Jurisdiction
- Water Quality Control Plant

SCALE - 1:12,000
0 500 1,000 Feet
N

Coordinate System: CA State Plane, Zone III
Horizontal Datum: NAD 83

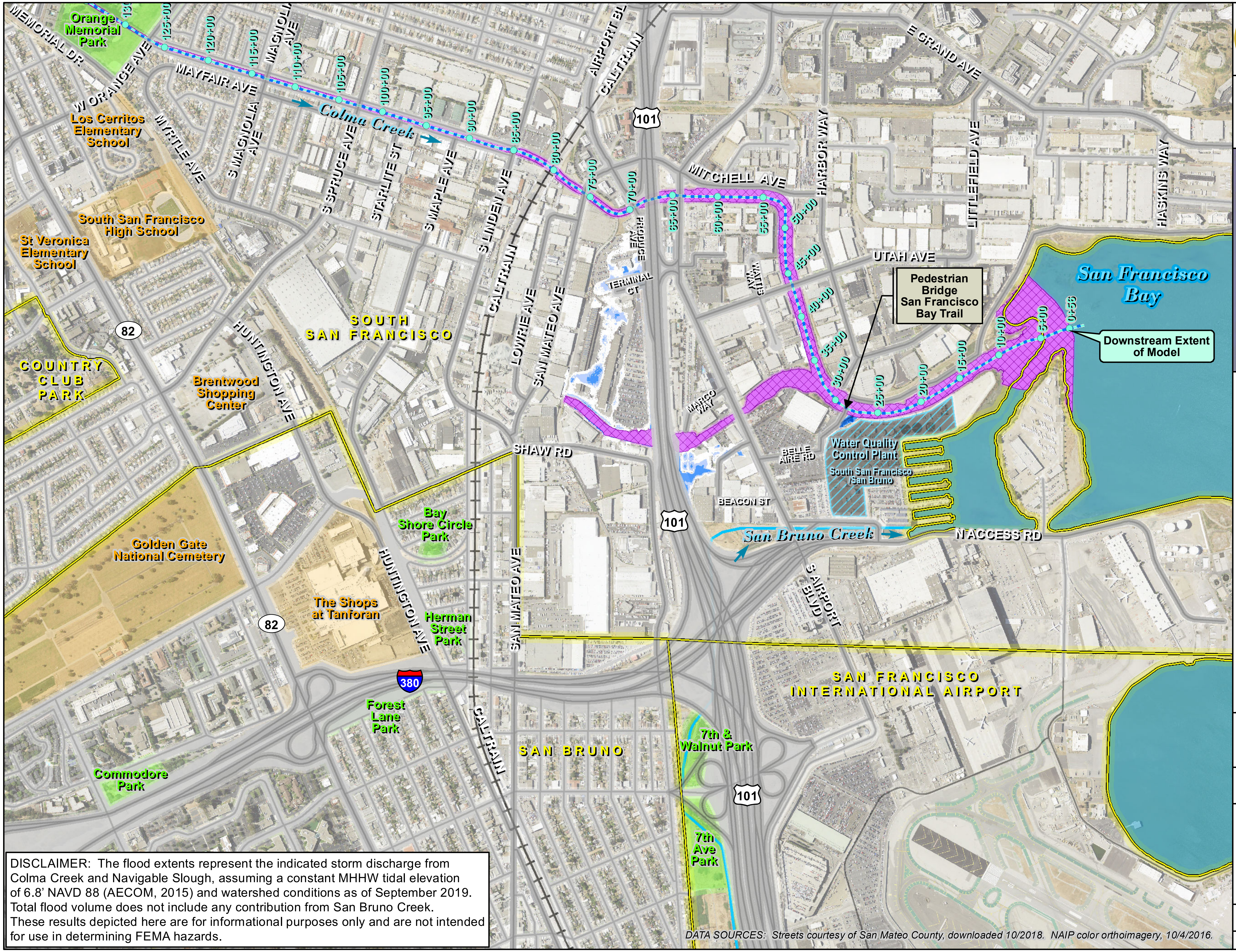
Colma Creek Watershed

Inundation Extent
2-year 12-hr Event
Future Climate
with Green Infrastructure

FIGURE A-16

Job: 5004303 | Date: DECEMBER 2019

ABC_P:\5004303-Colma_Creek\GIS\2_MXD_Workmaps\Staff_Workmaps\Dawn_Lasprugato\5004303-Colma-Inundation-Maps_DL_Rev4.mxd



DISCLAIMER: The flood extents represent the indicated storm discharge from Colma Creek and Navigable Slough, assuming a constant MHHW tidal elevation of 6.8' NAVD 88 (AECOM, 2015) and watershed conditions as of September 2019. Total flood volume does not include any contribution from San Bruno Creek. These results depicted here are for informational purposes only and are not intended for use in determining FEMA hazards.

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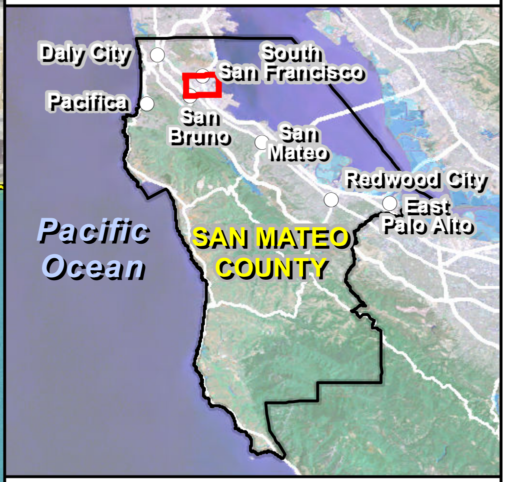

Legend

HEC-RAS Model Alignment and Stationing

Depth (in ft)

- 0.0 - 0.5
- 0.5 - 1.0
- 1.0 - 3.0
- 3.0 - 5.0
- 5.0 - 10.0
- 10.0 +

Flow in Channel

Railroads

Streets

Jurisdiction

Water Quality Control Plant

SCALE - 1:12,000

0 500 1,000 Feet

N

Coordinate System: CA State Plane, Zone III
Horizontal Datum: NAD 83

Colma Creek Watershed

Inundation Extent
5-year 12-hr Event
Future Climate
with Green Infrastructure

FIGURE A-17

Job: 5004303 | Date: DECEMBER 2019