Technical Memorandum

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To	Kari Svanstrom & Dante Del Prete (City of Sebastopol)	**MSA No.**	2010-01-36
From	Corey Hayes & Jeremy Svehla, PE (GHD)	**Task Order No.**	27
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Project Name	Calder Creek Modifications at Ives Park – Hydrologic and Hydraulic Modeling Assessment		

1. Introduction

This technical memorandum (TM) summarizes methods and results for development and analysis of flood reduction alternatives and improvements for Calder Creek in the vicinity of Ives Park in the City of Sebastopol, California. The purpose of this TM is to support technical findings and discussion for project alternatives to better understand the system hydraulic response and inform future maintenance and project improvements.

1.1 Structure of Technical Memorandum

This TM presents the hydrologic and hydraulic analyses that were performed to evaluate the existing condition and a range of proposed, project conditions within the study area. Some of the proposed improvements described below were developed and presented in the Waterways Restoration Institute (WRI) Stream Restoration Basis of Design Report for Calder Creek (WRI, 2022). A summary of the existing condition, along with the existing hydrologic condition for Calder Creek within the study area, is described in Sections 2 and 4, respectively. Hydraulic analysis methodology and results are later summarized in sections 5, 5 and 6, respectively. The final section of this TM summarizes the opinion of probable costs to implement the various improvements.

1.2 Study Area

The study area for this analysis encompasses the region between the 60-inch Calder Creek Outfall at Ives Park and the Joe Rodota trail footbridge, approximately 350 feet downstream of the Calder Creek storm drain outfall at the Laguna de Santa Rosa floodplain. For this analysis, Calder Creek was separated into four (4) discrete, numbered reaches within the study area. Reach 1 encompasses the Calder Creek channel from the 60-inch CMP concrete storm drain pipe at the upstream end of the park nearest Jewell Ave. to the Ives Park outfall nearest S. High St. flow from Ives Park then splits into two underground storm drain pipes until the pipes converge at a single junction structure at S. Main St. This reach was assigned as Reach 2. Reach 3 begins after the flow splits again from the S. Main St. junction structure end ends at the Calder Creek storm drain outfall at the Laguna de Santa Rosa floodplain. Reach 4 consists of the Calder Creek length between the Calder Creek storm drain outfall to the downstream model boundary condition near the Joe Rodota Trail footbridge (See Figure 1).

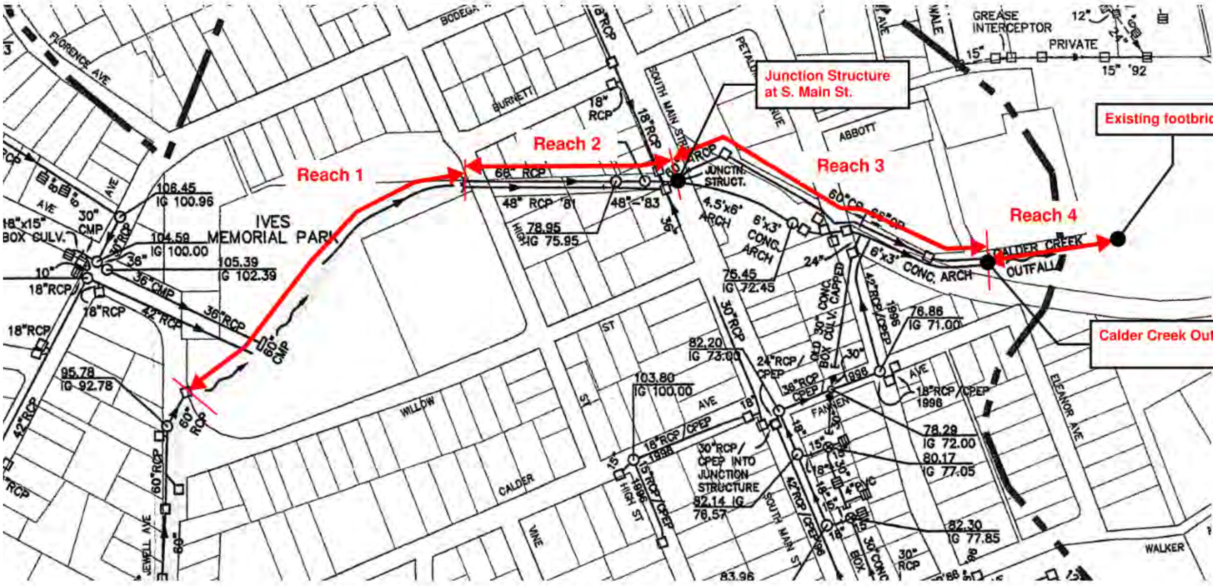

Figure 1 Reaches at Calder Creek within study area (Background image provided by City of Sebastopol storm drain mapping, 2022)

2. Existing Conditions

The Calder Creek drainage area consists of an approximate 667-acre watershed draining both rural-suburban and denser urban areas (WRI, 2022). Drainage enters the study area from the upstream Calder Creek subdrainages at various input locations. These discrete locations are discussed in Section 5.2, Boundary Conditions. The portion of Calder Creek within the study area consists of a highly urbanized and modified network of channels and storm water conveyance conduits that drain water from surrounding neighbourhoods and lands, conveying stormwater toward the Laguna de Santa Rosa to the east. Based on site and geomorphic assessment conducted by WRI (2022) and GHD, sediment sources from the upper watershed in combination with the release of stored sediment from the former Ives Park pond has caused the lower reaches (Reaches 2-4) to aggrade with sediment and effectively clog the lower Calder Creek storm drain system resulting in significant flooding near S. Main St and Petaluma Ave from surcharged drain inlets and manholes. Additionally, a single rootwad obstruction exists approximately 350 feet downstream from the Calder Creek storm drain outfall where Calder Creek drains into the Laguna de Santa Rosa floodplain. This rootwad and the resultant sediment accumulation within the lower reaches has caused the bed elevation to increase reducing the overall capacity of the storm drain system.

A significant storm event occurred on October 24, 2021 and caused Calder Creek to flow overbank and flood portions of Petaluma Ave. and adjacent private properties. According to the National Weather Service (NWS, 2022) total precipitation accumulation for that event was 6.09 inches over a 24-hour time period (NWS, 2022 from the Sonoma County Airport Rain Gauge). According to the intensity, duration, frequency data provided by the National Oceanic and Atmospheric Association (NOAA) this event was approximately a 10-year recurrence interval storm event (NOAA, 2022), or an event that has a 10% chance of occurrence in any given year. An image taken near the peak flooding event is provided below (Figure 2).

Figure 2 Calder Creek flooding at Petaluma Avenue during the October 24th, 2021 10-year recurrence interval storm event.

2.1 Site Topographic Survey and Geomorphic Assessment

As presented in Section 2, a topographic survey and geomorphic assessment was conducted during a series of site visits by GHD staff between October 19, 2021 and January 7, 2022. This assessment also references findings contained in the Calder Creek Stream Restoration Basis of Design Report by WRI (2022). The primary focus of the assessment was to capture channel conditions such as change in channel slope, form or geometry, identify breakpoints in the channel such as placed rock, root structures, infrastructure or any feature that would affect flow regimes within Calder Creek. Exhibit 1.1 attached to this Technical Memo provides locations for each of the observed channel conditions described in this section.

Sediment yield estimates for the Calder Creek watershed have not been quantified nor have analyses been completed to assess the transport capacity of Calder Creek through its variable reaches, i.e. the creeks ability to transport the watershed's total load (bed and suspended loads). The descriptions of the study reaches below provide indicators of Calder Creek's geomorphic conditions and the processes contributing to sediment deposition and/or scour.

2.1.1 Ives Park (Reach 1)

Calder Creek drains into Ives Park through an existing 60-inch diameter concrete storm drain pipe where flow immediately becomes channelized (Figure 3, left) into a trapezoidal, concrete lined channel with stone surface texturing that extends through Ives Park. Central to Ives Park is a widened, naturalized, earthen portion of the channel with Inset floodplains (also known as in-channel benches consisting of narrow floodplain "benches" which lie 1-2 feet above the existing low flow channel thalweg but below the bankfull width. A single weir and flashboard system downstream to this widened channel was constructed to create a pond feature (Figure 3, right). Overtime, this backwater effect has slowed velocities, which has allowed

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sediment to accumulate behind the weir structure and collect along the streambed and inset floodplain areas. The flashboard weir was later removed which caused geomorphic response along Reach 1, effectively dropping the thalweg profile, re-mobilizing the stored sediment to downstream reaches during large flow events.

Figure 3 Left: Calder Creek at upstream end of Ives Park (looking toward the southwest); Right: Calder Creek at the central flashboard weir system within the heart of Ives Park.

2.1.2 Storm Drain System Downstream of Ives Park (Reaches 2 and 3)

Reaches 2 and 3 consist of underground storm drain pipes extending from the east end of Ives Park to the outfall at the Laguna de Santa Rosa floodplain. Portions of these pipes lie directly under S. High St., S. Main St., and Petaluma Ave. Reach 2 consists of the portion of underground, parallel, reinforced concrete pipe (RCP) between Ives Park and the Junction Structure at S. Main St. Reach 3 consists of the portion of underground pipe that splits once again from the Junction Structure at S. Main St. and runs parallel to the storm drain outfall in the Laguna de Santa Rosa floodplain.

Figure 4: Left: Calder Creek at downstream end of Ives Park at the inlet of the parallel, underground pipes. Right: Calder Creek outfalls at the Laguna De Santa Rosa floodplain.

Sediment has accumulated within the Reach 2 and 3 storm drain system as a result of a) upstream sediment loads, b) the removal of the flashboard weir system at Ives Park that released sediment into the receiving storm drain system and c) a “rootwad” that has grown within the channel, downstream of the Calder Creek outfall at the Laguna de Santa Rosa floodplain, which has created a backwater effect, slowing water velocities and accelerating sediment accumulation. These contributing factors have resulted in sediment accumulation where, in some cases pipes are 75 – 90% clogged. Underground storm drain pipes at the upstream end of Reach 2, near the Ives Park outfall are generally free of sediment due to the steep slopes where velocities are high enough to maintain sediment transport to downstream reaches. These observations were made during onsite surveys by a GHD surveyor where nearly all manholes between Ives Park and the storm drain outfall at the Laguna de Santa Rosa were uncovered and surveyed.

According to the hydrology study performed by Coastland Civil Engineering (2005), under a sediment-free (unplugged) condition, the Reach 2 storm drainage system has sufficient capacity to convey the 10-year storm. However, because of the large sediment accumulation within Reaches 2 and 3, hydraulic capacity in the system has been significantly reduced resulting in flooding during the 10-year event, especially near the area where Calder Creek crosses Petaluma Ave. (see Figure 2 and Figure 5).

Figure 5 GHD staff at a manhole upstream from Petaluma Ave. with sediment accumulation at the manhole rim along the southern run of Reach 3 along a run of 6'x3' arched concrete conduit.

2.1.3 Reach Between Calder Outfall and Joe Rodota Trail Footbridge

An existing channel rootwad consisting of a large non-native Mayten tree (*Maytenus boaria*) has grown directly in the creek channel, approximately 125-feet downstream of the storm drain outfall (Figure 6). This rootwad has created an obstruction in the conveyance channel and has caused considerable backwater in the storm drain system, slowing water velocities thus allowing sediment to deposit and collect, upstream of the rootwad. Based on on-site investigation by GHD field crew, a considerable quantity of sediment was observed at a manhole along the southern leg of Reach 3, just upstream of the Calder / Petaluma Ave. crossing (Figure 5).

The rootwad creates an approximate 1.7-foot drop in creek bed elevation. Calder Creek then flows toward the Laguna de Santa Rosa through a series of shallow channels. For this report, geomorphic and hydraulic conditions were characterized to the footbridge at the Joe Rodota Trail.

Figure 6 Non-native Mayten trees in Calder Creek channel approximately 125 ft downstream of the storm drain outfall. Rootwad obstruction causes approximate 1.7' drop in the bed elevation.

2.2 FEMA Flood Analysis

The downstream end of the study area lies within the10-year or 10% annual chance FEMA flood elevation of 70.2 feet (NAVD88-ft). A larger portion of the study area (up to Petaluma Ave) lies within the 100-year or 1% annual chance FEMA flood zone (Zone AE). The area between Petaluma Ave. and S. Main St. lies within the 500-year FEMA flood zone (Zone X). The 1% annual chance FEMA flood elevation is 77.8 feet within the study area (FEMA, 2017).

3. Conceptual Design and Phasing Scenarios

A total of seven (7) separate scenarios (Existing Condition and Proposed Scenarios A-F) were modelled within the study area (Reaches 1 – 4). These scenarios are discussed in further detail below. Each of the seven scenarios were developed to better understand the hydraulic response of varying proposed conditions compared to the system's existing condition. Three (3) additional scenarios presented by WRI, Inc. (2022) are further described at the end of this section (Section 3.8). These scenarios were not modelled in this analysis, however the City of Sebastopol may consider these in future planning. The additional three scenarios were beyond the scope of this preliminary modelling effort and the results of the seven modelled scenarios demonstrate significant flood reduction. The scenarios below are present in the potential sequence they could be implemented; however additional planning and design are necessary as some scenarios could be combined for funding, design and regulatory permitting efficiencies.

3.1 Existing Condition Scenario

This scenario assesses the existing hydraulic conditions within the study area. This option represents existing channel conditions in Reach 1 through Ives Park, partially clogged storm drain pipes within Reaches 2 and 3, and the existing rootwad and channel conditions within Reach 4.

3.2 Proposed Scenario A – Removal of Tree Rootwad at Calder Outfall

Proposed Scenario A removes the single rootwad obstruction and lowers the bed elevation 1.7 feet between the storm drain outfall and rootwad (see Figure 6). The rootwad occurs approximately 100 feet downstream of the Calder Creek storm drain outfall. Given the backwater condition created by the rootwad, removal of rootwad and lowering of the channel could allow some accumulated sediment in the upstream storm drain pipes to remobilize and therefore, an additional assumption was made for this scenario that accounted for approximately 1 vertical foot of stored sediment remobilizing during the first high winter flow, slightly increasing the storm drain capacity. This model condition assumed the remobilized sediment would transport out of the system and redistribute throughout the Laguna.

3.3 Proposed Scenario B – Deepen and Widen Calder Creek Outfall

This scenario extends the deepening and widening within Reach 4 by expanding 375 feet of Calder Creek downstream from the storm drain outfall from the Calder Creek storm drain outfall to the Joe Rodota trail footbridge. The Reach 4 channel thalweg was lowered to match the storm drain outfall inverts while maintaining the existing channel slope through this reach. The modified Reach 4 was graded into the LiDAR surface and used in the PCSWMM 2D modelling using the channel geometry proposed by WRI (2022). The channel geometry included a trapezoidal channel with 8-ft bottom width, 3-ft channel depth and 1.5H:1V side slopes (WRI, 2022).

3.4 Proposed Scenario C – Unplug Storm Drains and Deepen / Widen Calder Creek Outfall

This scenario includes Scenario B described above in addition to complete removal of all debris and sediment that has collected in the storm drain system. This option would fully restore the storm drain infrastructure to its full capacity.

3.5 Proposed Scenario D –Ives Park Improvements Only

The Calder Creek Improvement concept was incorporated and analysed in Proposed Scenarios, D-F. This concept through Ives Park was designed and generated by WRI, Inc. and was provided to GHD as a 3D surface model. This design incorporates a new creek realignment of Calder Creek through the Ives Park Reach (Reach 1), new pedestrian pathways, bridges and other facilities. Further description of how this model was developed is described in the Calder Creek Restoration Basis of Design Memo by WRI (2022).

Proposed Scenario D includes the WRI improvements to Calder Creek through Ives Park based on the proposed Calder Creek realignment preferred by the City (the "Updated Charrette" alignment). Proposed Scenario D does not incorporate any improvements to Reaches 2–4 described in Condition A and B above.

3.6 Proposed Scenario E –Ives Park Improvements, Unplug Storm Drains and Deepen / Widen Calder Outfall

This scenario includes Scenarios C and D described above.

3.7 Proposed Scenario F - With Ives Park Improvements, Unplug Storm Drains and Deepen / Widen Calder Outfall – During 10-year Backwater Elevation

This scenario includes Scenario E and applies a 10-year FEMA water level to the downstream model boundary condition to simulate a coincident flood occurrence in the Laguna de Santa Rosa.

3.8 S. High St. to S. Petaluma Ave. Improvements

This option would remove the parallel underground storm drain pipes and daylight Calder Creek east of Calder Creek in downtown (between S. High St. to Petaluma Ave). This design option was explored by WRI, Inc. as an option to consider in future studies however was not modelled in this study as the results from Scenario C described below will reduce the flooding during a 10-year event if implemented.

4. Hydrologic Model Development

Peak runoff was estimated at the project boundary locations from data provided by the 2005 City of Sebastopol Storm Drain System Utility Master Plan (SSUMP) by Coastland Civil Engineering, Inc. This study utilized a hydraulic model that analysed the City's stormwater infrastructure during a 10-year storm event. This study was generated according to Sonoma County Water Agency (SCWA) Flood Control Design Criteria Manual for Waterways, Channels and Closed Conduits (1983) using the Rational Method and computer aided software StormCAD v5.5 (Coastland Civil Engineering, 2005). Comparisons of these data were made in the WRI Basis of Design Report (2022) which compared peak runoff values by Coastland Civil to other estimates obtained with regional regression equations. The 2005 Storm Drain System Utility Master Plan included the most up-to-date information available to GHD at the time of this study. Should the City conduct future hydrologic studies, use of the Flood Management Design Manual (2020) should be considered however given the watershed size and methods, the results are not anticipated to vary from those described above.

4.1 Coastland Civil Engineering Inc. 2005 Storm Drain System Utility Master Plan

GHD obtained model data from the 2005 SSUMP by Coastland Civil Engineering, Inc. from City of Sebastopol staff which included 10-year recurrence interval peak flow values, estimated time of concentration at each location in the system along with pipe sizes and geometries. All of this data was utilized in this modelling effort. Table 1 summarizes peak flow rate estimates at each of the seven (7) boundary condition locations within the study area.

Table 1: Peak runoff estimates from the 2005 City of Sebastopol Storm Drain System Utility Master Plan by Coastland Civil Engineering, Inc. (See Exhibit 4.1 for boundary locations)

Boundary Location ID (See Exhibit 4.1)	10-year Peak Flow (cfs) (Coastland Civil, 2005)	Storm Drain Size (inches)	Location Description
BC1	175	60" CMP	Upstream end of Ives Park
BC2	83	42" RCP	Northern Drainage from Bodega Ave
BC3	31	36" RCP	Northern Drainage from Bodega Ave
BC4	17	18" RCP	Northern Drainage from S. Main St.
BC5	61	42" RCP	Southern Drainage from Fannen Ave.
BC6	117	66" RCP	Downstream end of Ives Park (Ives Park Outfall)
BC7	128	60" RCP	Downstream end of Ives Park (Ives Park Outfall)

The 10-year peak runoff values, along with the corresponding time of concentration to that discrete location were used to generate synthetic, triangular hydrographs for inputs into each hydraulic model. Exhibit 4.1 in the Attachments provides locations of each boundary condition, along with other inputs that were assumed in each hydraulic model. Triangular synthetic hydrographs were developed at each boundary location from the data contained in the SSUMP study data by Coastland Engineering, Inc. (2005). Each hydrograph assumed that the time of concentration (tc) is equal to the time to peak (tp) (tc = tp). A 10-minute peaking period was applied to each hydrograph. The duration of the receding limb of each hydrograph was assumed to be 1.67*tp. Plots showing each of the boundary condition synthetic hydrographs are provided in Exhibits 3.1 through 3.7.

4.2 FEMA Flood Studies

The 10-year or 10% annual chance water surface elevation was obtained from the FEMA Flood Insurance Study (FIS) report for Sonoma County and Incorporated Areas (See Exhibit). This study determined the 10-year water surface elevation (WSE) to be at 70.2 feet (NAVD88). The 100-year or 1% annual chance WSE was much higher at 77.8 feet NAVD88 (Table 2, FEMA, 2017). Exhibit 6.1 presents the project reach within the Laguna de Santa Rosa FEMA FIS report showing the model results from the FEMA flood study.

Table 2: Storm event and corresponding boundary condition for Calder Creek (FEMA, 2017)

Calder Creek Storm Event	Downstream Boundary Condition	WSE (ft)
10-year (10% annual chance)	Calder Creek 10-year Backwater	70.2 ft (NAVD88)
100-year (1% annual chance)	Calder Creek 100-year Backwater	77.8 ft (NAVD88)

5. Hydraulic Model Development

Given the combination of both open channel and storm drain pipes, two separate 2D hydraulic modelling software platforms were utilized to analyse hydraulics through the study area. Model runs analysed the system under the 10-year recurrence interval storm event.

Version 6.1 of the US Army Corp of Engineers HEC-RAS 2D model was utilized to assess hydraulics through Ives Park. PCSWMM hydraulic modeling software was utilized downstream of Ives Park because of its capabilities to model flow in closed conduits, and route overland flow from surcharged inlets using a 3D DEM surface model. Each of these models are further described below.

The HEC-RAS model domain encompassed the Ives Park area (Reach 1) from the upstream 60-inch RCP Pipe outfall, to the lower Ives Park dual headwall condition which flows into two, parallel, underground pipes towards Reach 2 – 4. Existing and proposed surface models were compiled and formatted in AutoCAD Civil 3D from onsite survey data conducted by BKF, Inc. dated June 2011 and data provided to GHD by WRI, Inc for the proposed Ives Park condition. Each data source was used to generate a 2D mesh within HEC-RAS 2D. Boundary conditions were inserted at each boundary location (See Section 5.2). Inline structures were used at existing bridges. A single rectangular weir inline structure was used within HEC-RAS at the central weir structure, to model hydraulics through this streambed stabilizing structure. Roughness coefficients presented in the WRI (2022) report were utilized in the model to simulate ground cover characteristics.

5.1 PCSWMM

The PCSWMM Model domain started at the Ives Park outfall where the double, parallel RCP pipes begin. The downstream model domain limit ended at the footbridge along the Joe Rodota Trail near the Laguna de Santa Rosa floodplain. PCSWMM is ideal for this application due to its capability to perform full dynamic modelling of natural rivers, culverts, bridges, storm water utilities and much more. The 1D and 2D connectivity allows water to be routed overland over a 2D mesh. The model is also ideal for analysing systems that are partially or fully clogged with sediment.

Topographic survey data was used to estimate the size and horizontal geometry of the storm drain system as well as estimated depth of accumulated sediment. These data were used in the geometry inputs of the PCSWMM model.

5.2 Boundary Conditions

Flow input locations into the HEC-RAS 2D model domain existed at three discrete locations. BC1, BC2 and BC3 were all assigned as boundary condition inputs into the HEC-RAS 2D model (See Exhibit 4.1). Boundary conditions BC6 and BC7 were located where the two hydraulic models converged. Flow hydrographs were shared at these locations between the two models.

The outflow hydrograph from the HEC-RAS 2D model were used as inputs into the upstream boundary condition for the PCSWMM model. Two additional boundary conditions were applied to the PCSWMM model. One near the Junction Structure at S. Main St. from the northern drainage (BC-4) and the second from southern drainage from flow originating from Fannen Ave. and entering the system near Petaluma Ave. (BC5).

The downstream boundary condition was set as a normal depth for all model runs except Scenario F (described below). The computed 10-year normal depth elevation at the model downstream boundary condition is similar to that of the 10-year Laguna de Santa Rosa backwater elevation (FEMA) and therefore use of the normal depth boundary condition appears appropriate. Additionally, due to the size of the Laguna de Santa Rosa watershed in comparison to the Calder Creek watershed, it is assumed for this study that the time to peak in the Laguna is much longer than the time to peak within the Calder Creek watershed, and thus coincident 10-year events is unlikely.

6. Hydraulic Modelling Results

For each of the seven scenarios described above, hydraulic modelling results showing both inundation extents along with longitudinal hydraulic grade line (water surface elevation) for each modelling scenario are presented the attached Exhibits 2.1 through 2.7 and 5.1 – 5.13, respectively.

6.1 Model Verification

The October 24, 2021 storm event and resulting flooding extent was the only available verification of model accuracy and used to calibrate the model (see Figure 1). Inundation extent during the time of peak runoff was observed for this 10-year recurrence interval storm event. Sediment depth in the existing pipe network was adjusted between the topographic surveyed elevations to match the observed water levels as a calibration variable for the model.

6.2 Existing Condition Scenario

The combined hydraulic models were successful in modelling the existing conditions through the study area (Reaches 1-4). The existing condition within the study area resulted in flooding in both Ives Park (Reach 1) and the downstream storm drain system (Reaches 2 and 3) for the 10-year recurrence interval design storm events. Exhibit 2.1 provides flood inundation extents for this scenario. Exhibit 5.2, 5.3 and 5.7 present longitudinal profiles and velocity information through each reach.

6.2.1 Channel and Storm Drain Capacity

Portions of the Ives Park channel through Reach 1 overtopped during the 10-year storm event. The HEC-RAS 2D analysis showed water overtopping on river right (looking downstream) near the 60-inch RCP culvert near the area where the Jewel Ave. drainage enters the park. Additional overtopping occurred near the existing playground on river right, along the right hand side, inset floodplain, just upstream of the flashboard weir structure. According to the model, stormwater re-enters the Calder Creek channel downstream of the overtopping location. The concrete, trapezoidal channel downstream of the flashboard weir structure did not overtop during the 10-year storm. The model predicted higher velocities (5-10 ft/s) within this reach which corroborates the absence of observed sediment in the channel through this reach (See Exhibit 5.2 for velocity profile). Lower velocities (1-5 ft/s) were observed through the reach upstream of the flashboard weir system where the channel slope is not as steep, structures exist which act to slow velocities and cause flow to back up behind each structure.

Correspondence with City of Sebastopol staff confirm that flooding occurs during large storm events at the playground. This serves as an additional verification point for model accuracy through Ives Park.

While the existing condition exhibited some overtopping, the system's ability to transport sediment through and maintain a stable channel exists due to the quantity of grade control structures within earthen portions of the Ives Park reach and the stable, concrete lined channel that make up approximately 74% of Reach 1. Historically sediment would accumulate behind the flashboard weir system when the flashboard was installed and bed elevations were approximately 4-ft higher upstream of the weir system. Since the removal of the flashboard weir, the bed has mobilized to the invert of the existing concrete below the flashboard. The bed profile has since stabilized to its current elevation after the release of sediment and post-removal of the flashboard weir.

Storm drain capacity was exceeded within Reaches 2 and 3 due to the factors described in section 2.1.2 and resulted in overtopping of storm water at manhole structures and flooding within the lower area near Petaluma Ave. Exhibits 2.1 and 5.7 provide both inundation extents for flooding within Reaches 2 and 3 along with velocity and hydraulic grade line information through the storm drain system. Conduit C1 and C23 (60" and 66" RCP pipes, Exhibit 5.7) show velocities at 7.96 ft/s and 5.47 ft/s, respectively. These velocities will be used as a comparison for later scenarios and a gauge for understanding sediment re-entrainment from higher velocities.

6.2.2 Flood Inundation

Exhibit 2.1 presents flood inundation for the Existing Condition Scenario. Under this scenario portions of Ives Park become inundated from channel overtopping. Further extensive inundation occurs near S. Main St. and Petaluma Ave. due to surcharging at manholes and drain inlets within the existing storm drain system. The area most impacted by flood inundation is the Post Office parking area adjacent to where the Calder Creek storm drains cross Petaluma Ave. Flood inundation is also observed at the S. Main St. manholes and drain inlets. This flood inundation extent is similar to peak flooding conditions observed during the 10-year storm that occurred on October 24, 2021 (Figure 1).

6.3 Scenario A – Removal of Tree Rootwad at Calder Outfall

The modelling results for this scenario are described below and Exhibits 2.2, 5.2, 5.3 and 5.8 provide inundation mapping, velocity and water surface elevation profiles.

6.3.1 Channel and Storm Drain Capacity

This scenario did not increase channel capacity through Ives Park (Reach 1) but did provide minor additional flow capacity and resultant flood reduction through the Reach 2 and 3 storm drain system. This additional capacity was caused by a lower bed elevation at the outlet and a slightly reduced quantity of sediment within the storm drain system. Conduit C1 and C23 (60-inch and 66-inch RCP pipes, Exhibit 5.8) show velocities at 7.96 ft/s and 7.1 ft/s, respectively which is an observed higher velocity compared to existing conditions. This increase in velocity and additional capacity through the lower reaches could promote remobilization of deposited sediment in the storm drain system during high flow events.

6.3.2 Flood Inundation

Exhibit 2.2 provides inundation mapping for this scenario which shows a light reduction of flooding compared to the Existing Condition especially in the vicinity of Petaluma Ave. where an approximate ~0.25' depth flood reduction was observed.

6.4 Scenario B – Deepen and Widen Calder Outfall

The modelling results for this scenario are described below and Exhibits 2.3, 5.2, 5.3 and 5.9 provide inundation mapping, velocity and water surface elevation profiles.

6.4.1 Channel and Storm Drain Capacity

Similar to Proposed Scenario A, this scenario did not increase channel capacity through Ives Park but did generate additional capacity and resultant flood reduction through the Reach 2 and 3 storm drain system. This option resulted an approximate additional 0.5' depth reduction in flooding compared to Proposed Scenario A and a 1.0-foot depth reduction in flooding compared to the Existing Condition. Conduit C1 and C23 (60-inch and 66-inch RCP pipes, Exhibit 5.9) show velocities at 8.01 ft/s and 8.25 ft/s, respectively which is an observed higher velocity compared to both Proposed Scenario A and the Existing Condition. This increase in velocity and additional capacity through the lower reaches will assist in transporting sediment through the system and reducing flooding.

6.4.2 Flood Inundation

A significant reduction in flooding was observed under this scenario. Manholes and drain inlets remain surcharged near the S. Main St. and Petaluma Ave. but depths of surcharges are significantly reduced. Exhibit 2.3 provides inundation mapping for this scenario which shows a reduction of flooding compared to the Existing Condition where an approximate ~0.73' depth flood reduction was observed in the vicinity of Petaluma Ave.

6.5 Scenario C – Unplug Storm Drains and Deepen / Widen Calder Creek Outfall

The modelling results for this scenario are described below and Exhibits 2.4, 5.2, 5.3 and 5.10 provide inundation mapping, velocity and water surface elevation profiles.

6.5.1 Channel and Storm Drain Capacity

Removal of the deposited sediment within the storm drain system and deepening/widening the channel downstream of the storm drain outfall results in full recovery of the system's conveyance capacity and elimination of flooding during the 10-year storm event. A slight reduction in water surface elevation was observed near the Ives Park outfall due to the increase in system capacity through Reaches 2 and 3 (Exhibit 5.3). Conduit C1 and C23 (60" and 66" RCP pipes, Exhibit 5.10) show velocities at 7.78 ft/s and 9.19 ft/s, respectively which is an observed higher velocity compared to both Proposed Scenario B and the Existing Condition.

6.5.2 Flood Inundation

This scenario eliminated the 10-year flooding in Reaches 2 and 3. While the downstream reach near the Ives Park dual headwall outfall resulted in slightly lower water surface elevations locally, inundation and overbank flow still occurred at the same locations as scenarios A and B (Exhibit 5.3). This shows flooding at Ives Park is independent of sediment removal within the storm drain system in Reach 2 and 3 due to the inlet controlled condition of the culvert entrance at the eastern end of Ives Park at High Street.

6.6 Scenario D – Ives Park Improvements Only

The modelling results for this scenario are described below and Exhibits 2.5, 5.4, 5.5 and 5.11 provide inundation mapping, velocity and water surface elevation profiles.

6.6.1 Channel and Storm Drain Capacity

The WRI concept improvements through Ives Park were based on a stable channel geometry and included widening the channel corridor, which effectively provided increased flow capacity through Reach 1 reducing overtopping of the channel compared to the Existing Condition Scenario. This option provides sufficient capacity to convey the 10-year storm event. While the low flow channel overtops within the channel corridor as it is designed to do - it is sized for lower recurrence interval storm events, the 10-year event remains within the inset floodplains. Additionally, due to the gentle meander of the channel, constant slope along the channel thalweg and relatively uniform cross section through the modified Reach 1, velocities also remain relatively constant (5.0-8.0 ft/s) (Exhibit 5.4 and 5.11 show velocity information within Reaches 1-4).

6.6.2 Flood Inundation

With this Scenario, no inundation was observed outside of the Calder Creek channel area (Exhibit 2.5) however flooding throughout Reaches 2 and 3 remain similar to Existing Conditions.

6.7 Scenario E – With Ives Park Improvements, Unplug Storm Drains and Deepen / Widen Calder Outfall

The modelling results for this scenario are described below and Exhibits 2.6, 5.4, 5.5 and 5.12 provide inundation mapping, velocity and water surface elevation profiles.

6.7.1 Channel and Storm Drain Capacity

This scenario results providing Reach 1 through 4 with the highest level of storm water conveyance capacity due to the incorporation of the Ives Park improvements by WRI, the clearing of sediment through the Reach 2 through 4 storm drain and channel systems and the deepening / widening of the Calder Creek outfall at the Laguna de Santa Rosa floodplain area. No surcharging or overtopping of channels are observed within the study area under this scenario.

Exhibits 5.4 and 5.5 show a decrease in water surface elevation compared to the Existing Condition was observed near the Ives Park outfall due to the clearing of sediment within Reaches 2 – 4. Consequently, an increase in velocity is observed at the downstream end of Reach 1.

6.7.2 Flood Inundation

No flood inundation was observed outside of the Calder Creek corridor for this Scenario. Similar flood inundation was observed within Ives Park compared to the Proposed Scenario D with a slight reduction near the Ives Park outfall. Water surface remained within the Calder Creek channel for this option. A similar observation was made to Scenarios A – C where inundation at Ives Park were largely independent of sediment removal within the storm drain system in Reach 2 and 3 due to the inlet controlled condition of the culvert entrance at the Ives Park outfall. No flood inundation was observed with this scenario within Reaches 2 or 3.

6.8 Scenario F - With Ives Park Improvements, Unplug Storm Drains and Deepen / Widen Calder Outfall – During 10-year Backwater Elevation

This scenario was incorporated into the analyses to assess what (if any) backwater effects of incorporating the 10-year FEMA flood elevation of 70.2 feet (NAVD88) to the downstream boundary as a “fixed boundary”. Exhibits 2.7, 5.4, 5.5 and 5.13 provide inundation mapping, velocity and water surface elevation profiles for Scenario F.

6.8.1 Channel and Storm Drain Capacity

Channel and storm drain capacity with Reaches 1 through 3 were similar to results from Proposed Condition E. slightly deeper depths were observed in Reach 4 under this scenario due to the lower outfalls being partially submerged (inundated) throughout the model run. This created slightly increased backwater into the Reach 2 and 3 storm drain system but did not result in surcharging or flooding at any area within Reaches 1 though 3.

6.8.2 Flood Inundation

No flood inundation was observed outside of the Calder Creek drainage way for this Scenario. Slightly deeper channel depth was observed near the Calder Creek outfall within Reach 4 but the channel did not overtop.

6.9 Flood Reduction Results Summary

Based on the summaries above, Table 3 represents the percent reduction in flooding relative to existing conditions within the study area (Reaches 1 through 4) for the 10-year or 10% annual chance. Additionally, the percent reduction of maximum flooded depth at Petaluma Ave. is reported as an additional metric of project benefit for each scenario. This information is also provided in Section 7 which compares the percent reduction in flooded area to the project cost (Table 4).

Table 3: Flood Reduction Summary from modelled results A – E within study area (Reaches 1 – 4)

Flood Reduction Summary - Model Results - Scenarios A through E				
	Area of Flood Inundation (ac)	Percent Reduction in Flooded Area from Existing Conditions	Max Depth Flooding at Petaluma Ave. (ft)	Percent Reduction in Flooding Depth at Petaluma Ave.
Existing Condition (No Action)	4.09	-	0.73	-
Scenario A	3.24	21%	0.63	14%
Scenario B	2.32	43%	0.51	30%
Scenario C	1.10	73%	0.00	100%
Scenario D	3.10	24%	0.72	1%
Scenario E	0.00	100%	0.00	100%

7. Opinion of Probable Construction Cost

Class 4 rough order of magnitude construction costs (ROM) were developed for the scenarios (Table 4). The opinion of construction cost range consists of a combination of estimated labor, equipment and materials necessary to implement the alternatives. Typical accuracy ranges for Class 4 estimates are -15% to -30% on the low side, and +20% to +50% on the high side. The scenario costs reflect an estimating contingency of +50% to account for material and construction cost volatility and uncertainties given the early planning phases of this study. Scenario costs are based on recent bid results of similar projects and professional judgement. Construction costs associated with instream projects are difficult to estimate given the unique nature of work and lack of applicable industry standard construction estimating resources such as R.S. Means data. Site conditions such as a high groundwater, presence of sensitive species and seasonal work windows increase construction costs. The risks associated with working in these environments are much higher relative to typical public works construction projects. Construction costs are subject to variations in contractor bidding, labor rates, material costs, availability, permitting conditions, site accessibility, general economic pressures and other unforeseen costs associated with a project in the current planning level. Given these potential variations, GHD makes no warranty, express or implied, that actual scenario costs will not vary from the provided cost. Remaining planning, engineering, regulatory compliance and construction management services were not included in the cost estimate, however these costs can be included in future project planning and budgeting.

Table 4: Class 4 rough order of magnitude construction costs (ROM) for Proposed Scenarios A - E.

Scenario	Cost	Cost +50% Contingency	Percent Reduction in Flooded Area from Existing Conditions
A - Removal of Tree Rootwad at Calder Creek Storm Drain Outfall	$134,000	$201,000	21%
B - Deepen and Widen Calder Creek Below Storm Drain Outfall	$460,000	$690,000	43%
C - Unplug Storm Drains and Deepen / Widen Calder Creek Outfall	$1,815,000	$2,722,500	73%
D - Ives Park Improvements	$5,249,000	$7,873,500	24%
E - Ives Park Improvements with Unplugged Storm Drains / Deepened & Widened Calder Creek Outfall	$6,689,000	$10,033,500	100%

Cost includes: permit compliance, water management, creek bypass, fish exclusion in addition to construction costs.

8. Conclusions and Next Steps

The conclusions from this study are summarized below and can be used to support future restoration and maintenance activities on Calder Creek.

1. The existing storm drain capacity in Reaches 2-4 is limited by the quantity of deposited sediment within the system and the outfall condition. Removal of the deposited sediment from within the storm drain system in combination with deepening/widening the channel downstream of the storm drain outfall (Scenario C) will reduce flood risk and eliminate flooding throughout the Petaluma Ave. area during the 10-year event. While Scenario A and B provide some flood reduction benefits in the Petaluma Ave. area, these Scenarios could result in some remobilization of sediment from the storm drain pipes and re-deposition into Reach 4.

   Alternatively, daylighting the storm drain system in Reach 2 through 4 which was conceptualized by WRI however not modeled in this study, could be assessed comparatively and would require additional feasibility assessments beyond the scope of this study. The remaining planning, design and implementation for the daylighting concepts could take 3-10 years and would be subject to available grant funding and right-of-way acquisition.

Flood reduction improvements in Reaches 2 through 4 were identified in the City's Hazard Mitigation Plan. Should the City move forward with sediment removal from the storm drain pipes in the short term, which will provide immediate flood risk reduction, future Hazard Mitigation Grant Program (HMGP) Applications may not achieve a Benefit-Cost-Analysis (BCA) greater than one which is the minimum for eligibility of FEMA's HMGP. Additional hydraulic model runs could be conducted now to assess flood risk and damage at more extreme events (i.e. 1% and 2% annual chance) storms. The City will need to consider the urgency to unplug the storm drains relative to the potential long-term feasibility of daylighting the creek as it relates to HMGP funding.

2. Ives Park improvements (Scenario D) will reduce flood inundation locally within Ives Park by 24% during the 10% annual chance flood, however it had little effect on flood reduction within Reaches 2 through 4 (i.e. Petaluma Ave). Additionally, the modelling results indicate removal of sediment from Reaches 2 and 3 have a minor effect on the water surface elevations at the eastern end of Ives Park and therefore Scenario C could be implemented independent of Scenario D. The next phase of Ive's Park creek restoration design should consider upper watershed sediment yield relative to the sediment transport capacity of the design reach. This will provide a better understanding of the change in sediment transport conditions, i.e. will the restored reach transport more or less sediment to downstream reaches 2-4.
3. Obtaining grant funding to conduct maintenance activities is often challenging and therefore securing funds to only remove sediment from the storm drain pipes in Reaches 2 and 3 may be difficult. Including the widening/deepening of Reach 4 which would include invasive species removal, instream habitat features and re-vegetation of natives would improve the competitiveness of a grant application by demonstrating multi-benefits of flood reduction and habitat enhancements.

9. References

BKF Engineers, (2013). Existing Conditions topographic survey data provided to GHD, Inc. by the City od Sebastopol.

Coastland Civil Engineering Inc. (2005). Storm Drain Utility Master Plan

Ives Park Master Plan (2013). Prepared for the City of Sebastopol by Royston Hanamoto Ally & Abey, Landscape Architects and Planners.

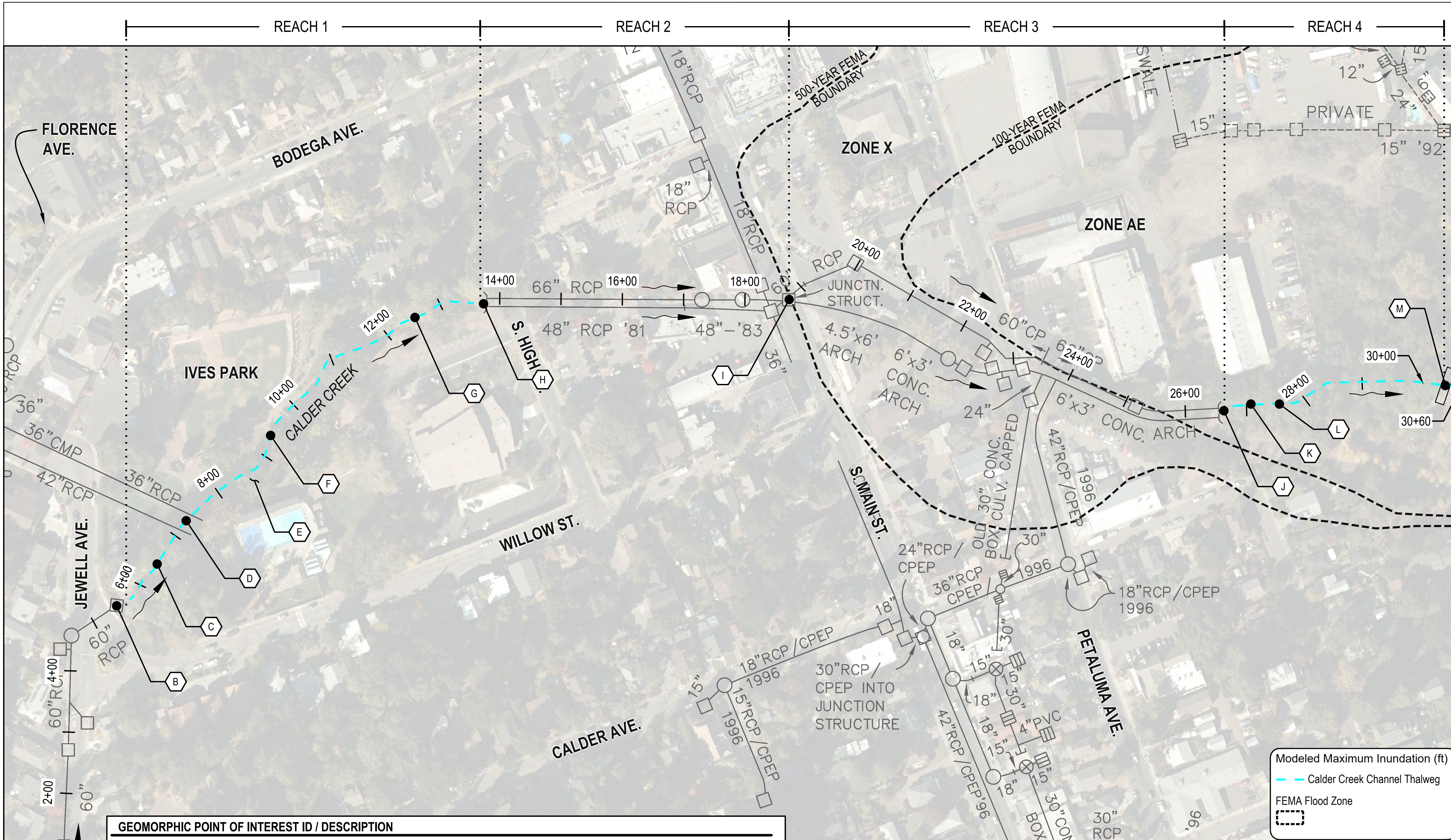
Sonoma County Water Agency (SCWA) Flood Management Design Manual (2020). Prepared for SCWA by Horizon Water and Environment, LLC.

Stream Restoration Basis of Design for Calder Creek in Sebastopol, CA (April 15, 2022). Prepared for the City of Sebastopol by Waterways Restoration Institute, Inc. (WRI) in collaboration with Wildling Design Studio.

National Oceanic and Atmospheric Administration (NOAA), (2022). Noaa Atlas 14 Point Precipitation Frequency Estimates. Retrieved online 7/15/2022: https://hdsc.nws.noaa.gov/hdsc/pfds/pfds_map_cont.html?bkmrk=ca

National Weather Service (NWS), 2022. Online Weather Data Climatological Data for SANTA ROSA SONOMA CO AP, CA October 2021. Retrieved online 7/15/2022: https://www.weather.gov/wrh/Climate?wfo=mtr

Exhibits



GEOMORPHIC POINT OF INTEREST ID / DESCRIPTION

ID	Description
A	CONCRETE LINED "CHUTE"
B	CALDER CREEK OUTFALL AT IVES PARK
C	CONCRETE LINED, TRAPEZOIDAL CHANNEL
D	60" RCP CULVERT
E	NATURAL CHANNEL WITH INSET FLOODPLAIN
F	CONCRETE STRUCTURE WITH WEIR (REMOVED)
G	CONCRETE LINED, TRAPEZOIDAL CHANNEL
H	CONCRETE HEADWALL ENTRANCE AT 2 PARALLEL RCP PIPES
I	STORM DRAIN JUNCTION STRUCTURE
J	CALDER CREEK OUTFALL AT LAGUNA DE SANTA ROSA FLOODPLAIN
K	SEDIMENT ACCUMULATION AT OUTFALL
L	EXISTING ROOTWAD DOWNSTREAM OF OIUTFALL
M	TRAIL/FOOTBRIDGE

N

0 75' 150'

Paper Size 11" x 17" (Ansi B)

Map Projection: Lambert Conformal Conic
Horizontal Datum: North American 1983
Grid: NAD 1983 StatePlane California II FIPS 0402

GHD

CITY OF SEBASTOPOL
CALDER CREEK MODIFICATIONS AT IVES PARK

PROJECT AREA MAP WITH IDENTIFIED PROJECT REACHES, AND GEOMORPHIC POINTS OF INTEREST ALONG LOWER CALDER CREEK

Project No. 12566276
Date 7/15/2022

Exhibit 1.1

Filename: \\ghdnet\ghd\US\Eureka\Projects\561\12566276\Digital_Design\ACAD\Figures\12566276_Calder_Crk_Inundation_Maps.dwg
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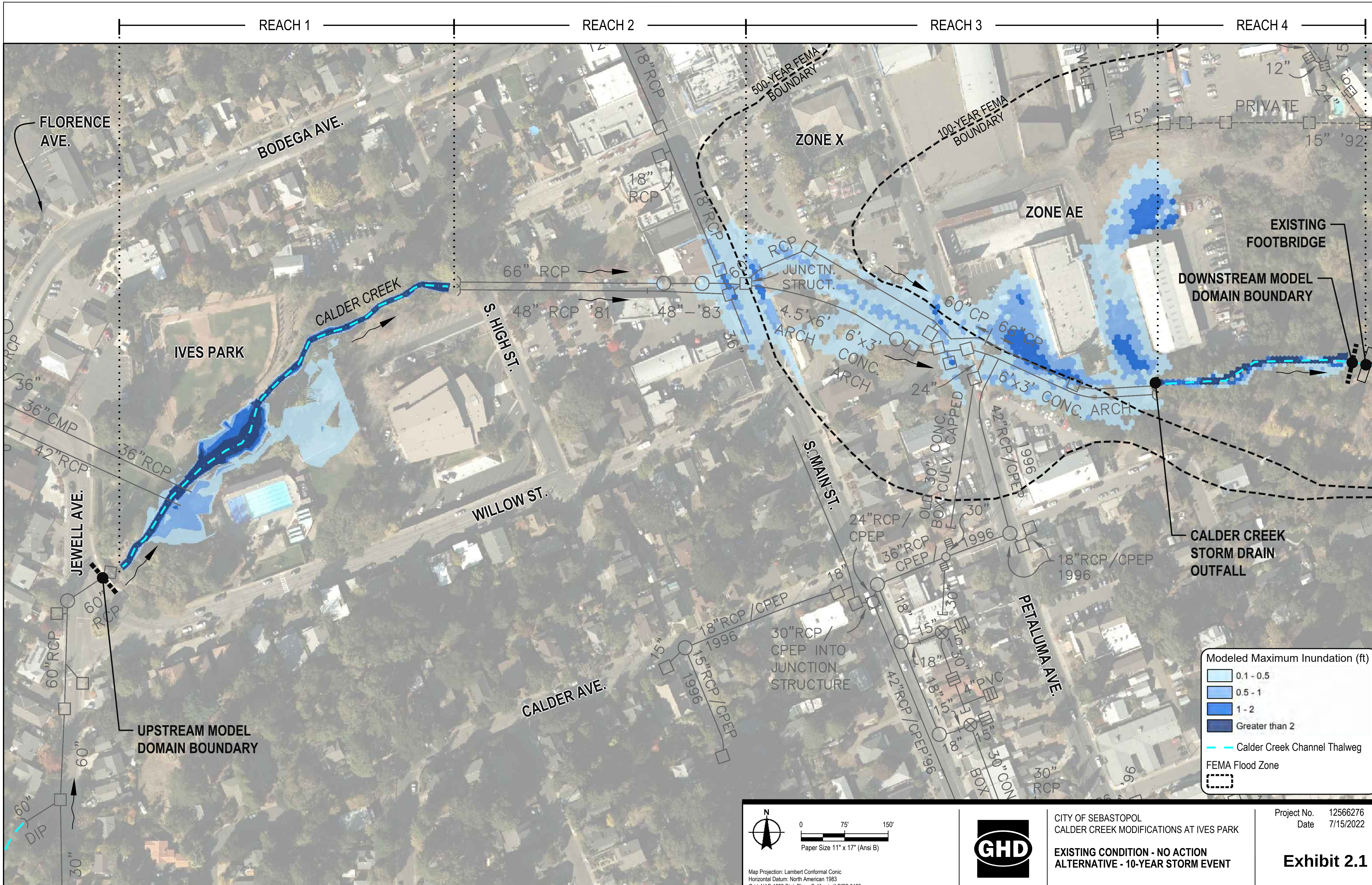

CITY OF SEBASTOPOL
CALDER CREEK MODIFICATIONS AT IVES PARK

EXISTING CONDITION - NO ACTION ALTERNATIVE - 10-YEAR STORM EVENT

Project No. 12566276
Date 7/15/2022

Exhibit 2.1

Filename: \\ghdnet\ghd\US\Eureka\Projects\561\12566276\Digital_Design\ACAD\Figures\12566276_Calder_Crk_Inundation_Maps.dwg
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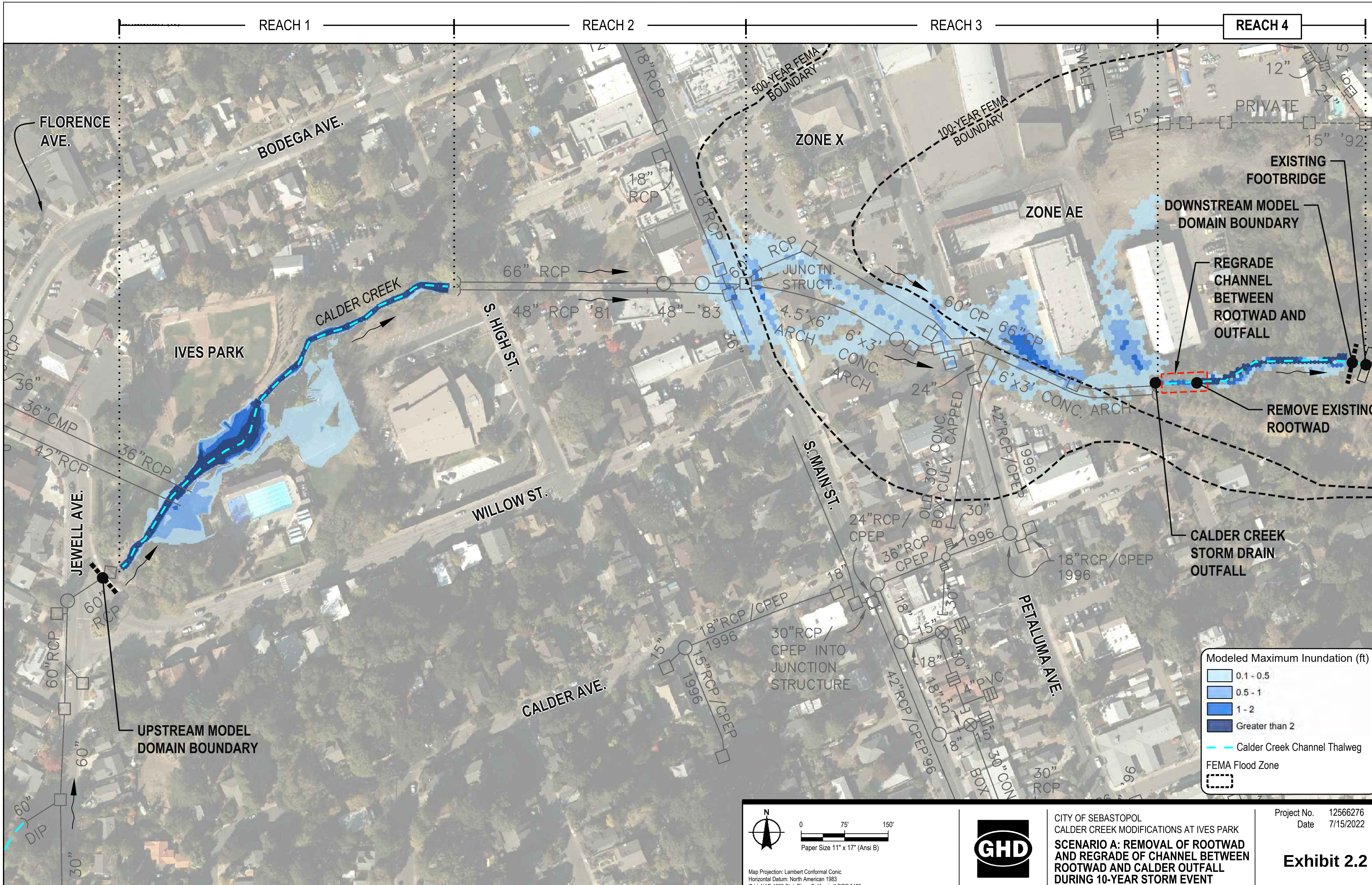

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Horizontal Datum: North American 1983
Grid: NAD 1983 StatePlane California II FIPS 0402

GHD

CITY OF SEBASTOPOL
CALDER CREEK MODIFICATIONS AT IVES PARK

SCENARIO A: REMOVAL OF ROOTWAD AND REGRADE OF CHANNEL BETWEEN ROOTWAD AND CALDER OUTFALL DURING 10-YEAR STORM EVENT

Project No. 12566276
Date 7/15/2022

Exhibit 2.2

Filename: \\ghdnet\ghd\US\Eureka\Projects\561\12566276\Digital_Design\ACAD\Figures\12566276_Calder_Crk_Inundation_Maps.dwg
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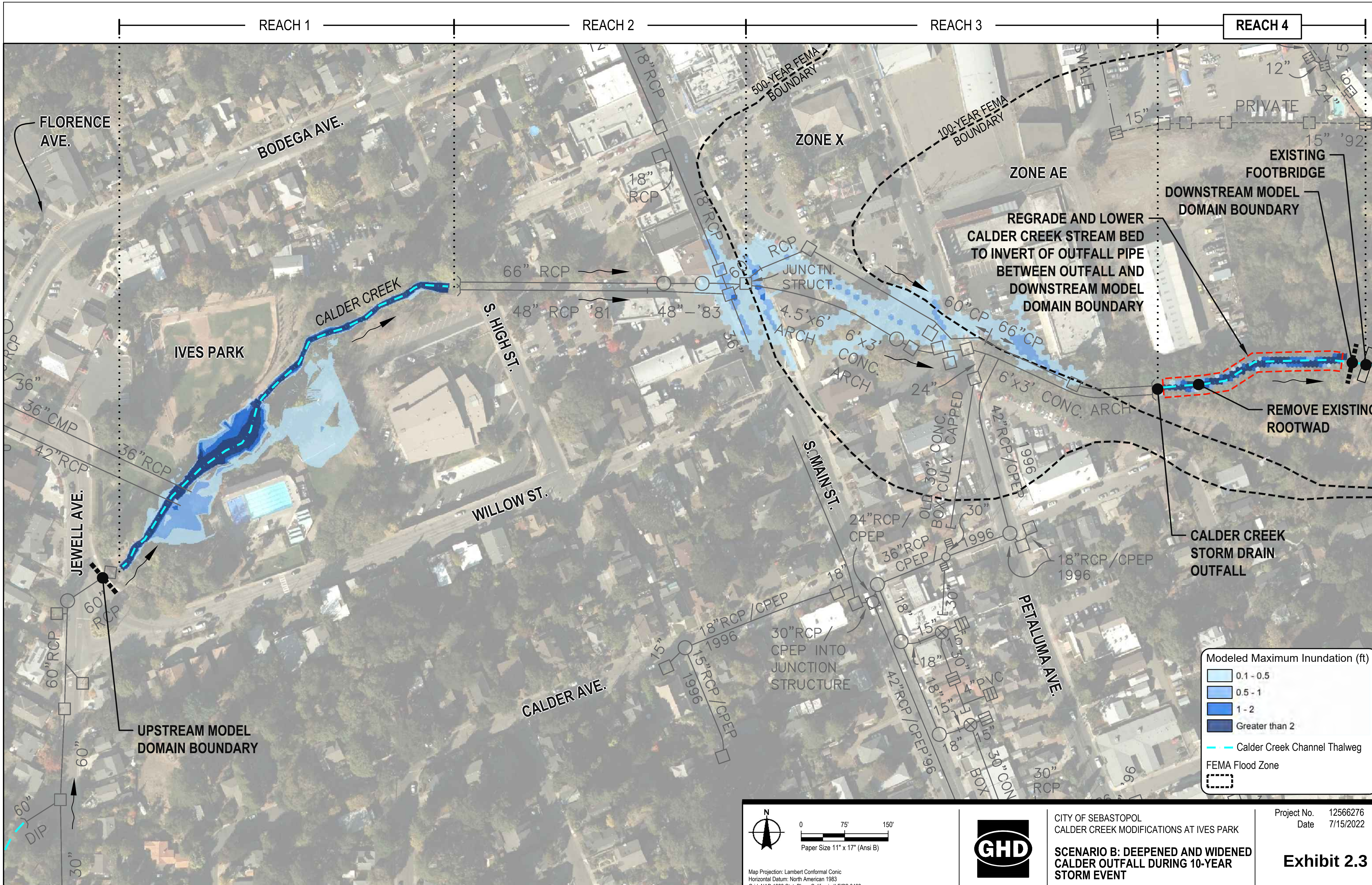

CITY OF SEBASTOPOL
CALDER CREEK MODIFICATIONS AT IVES PARK

SCENARIO B: DEEPENED AND WIDENED CALDER OUTFALL DURING 10-YEAR STORM EVENT

Project No. 12566276
Date 7/15/2022

Exhibit 2.3

Filename: \\ghdnet\ghd\US\Eureka\Projects\561\12566276\Digital_Design\ACAD\Figures\12566276_Calder_Crk_Inundation_Maps.dwg
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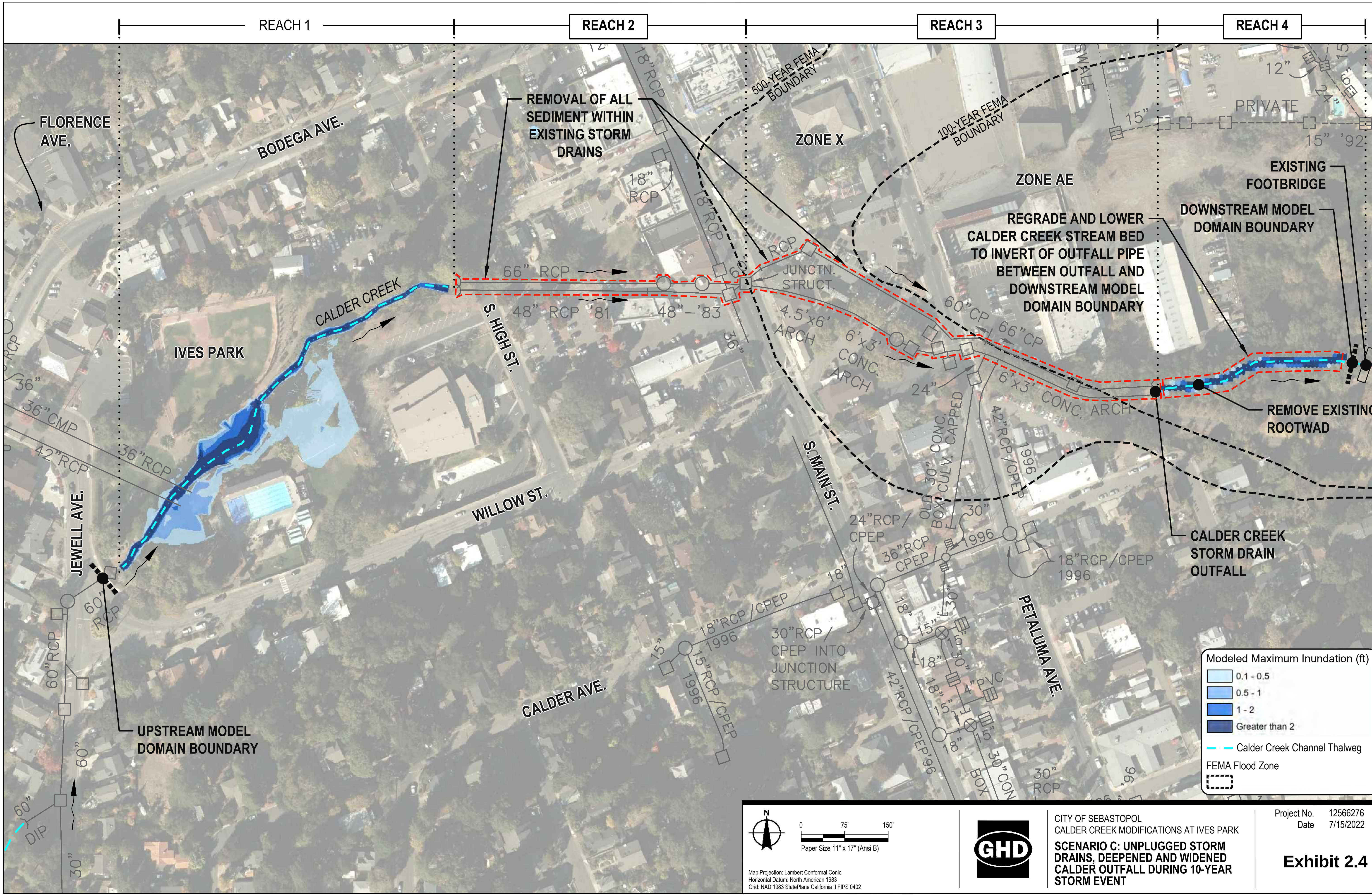

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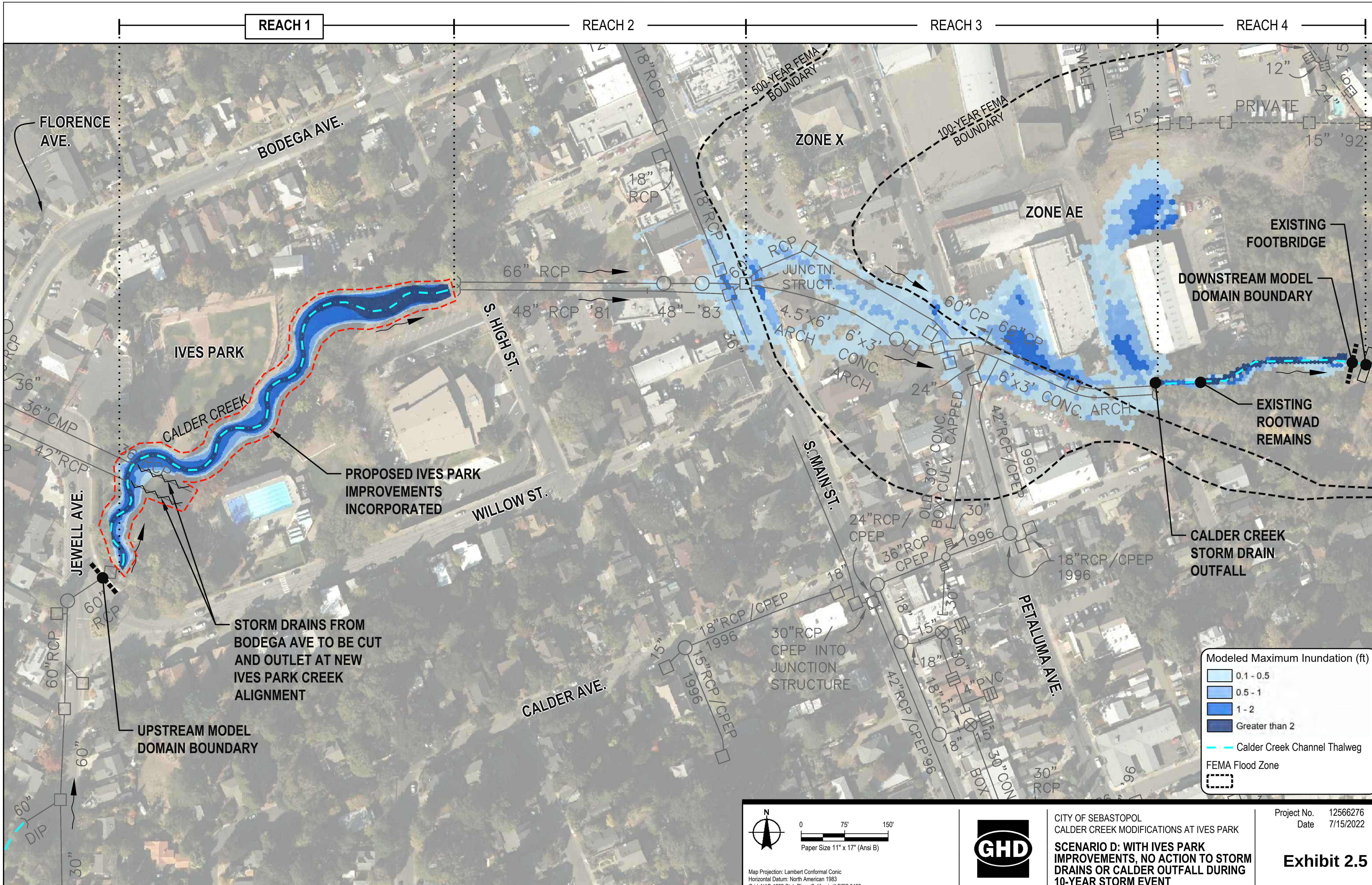

CITY OF SEBASTOPOL
CALDER CREEK MODIFICATIONS AT IVES PARK

SCENARIO D: WITH IVES PARK IMPROVEMENTS, NO ACTION TO STORM DRAINS OR CALDER OUTFALL DURING 10-YEAR STORM EVENT

Project No. 12566276
Date 7/15/2022

Exhibit 2.5

Filename: \\ghdnet\ghd\US\Eureka\Projects\561\12566276\Digital_Design\ACAD\Figures\12566276_Calder_Crk_Inundation_Maps.dwg
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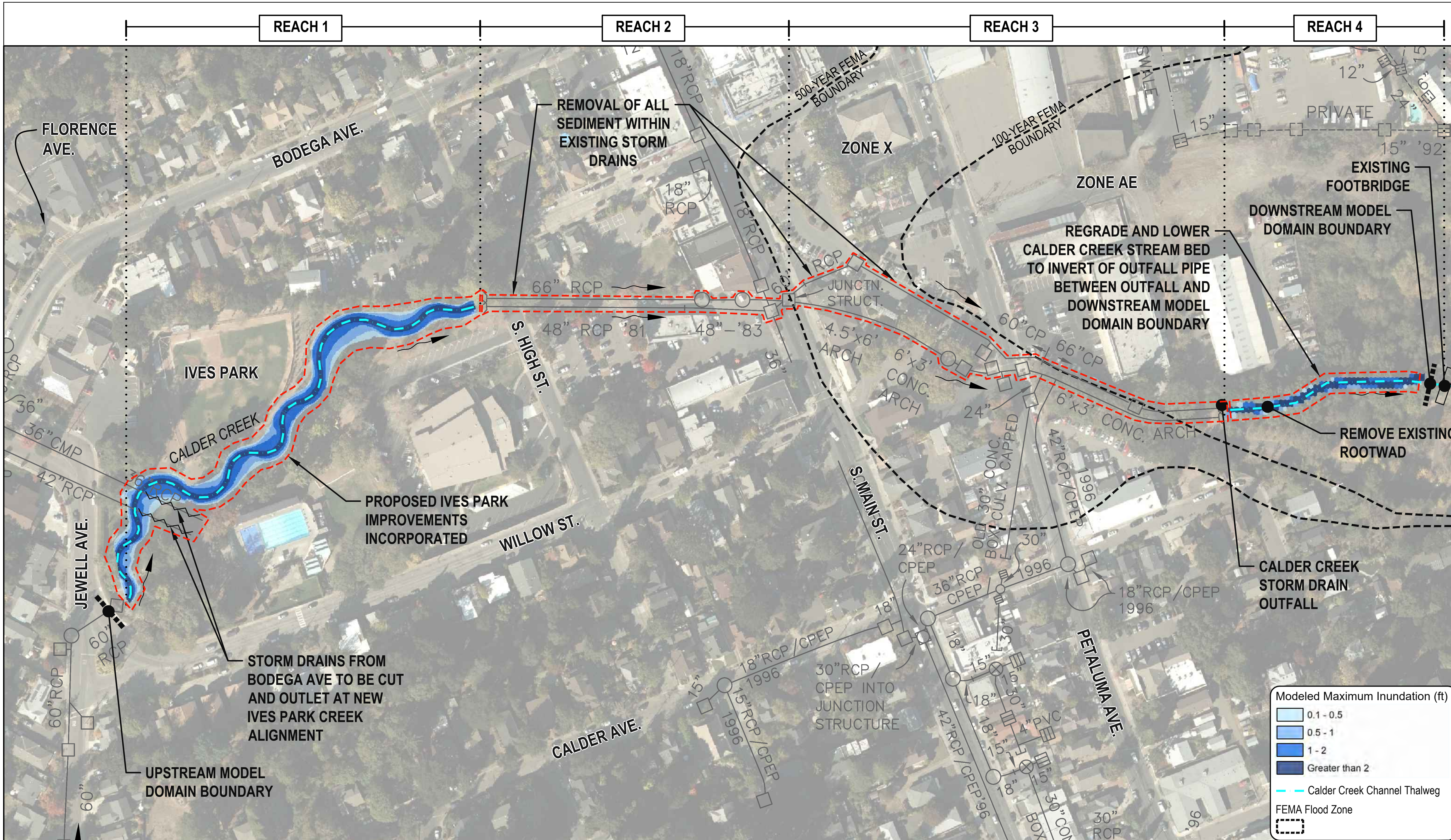

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Paper Size 11" x 17" (Ansi B)

Map Projection: Lambert Conformal Conic
Horizontal Datum: North American 1983
Grid: NAD 1983 StatePlane California II FIPS 0402

GHD

CITY OF SEBASTOPOL
CALDER CREEK MODIFICATIONS AT IVES PARK

SCENARIO E: WITH IVES PARK IMPROVEMENTS, UNPLUGGED STORM DRAINS, DEEPENED & WIDENED CALDER OUTFALL DURING 10-YEAR STORM EVENT

Project No. 12566276
Date 7/15/2022

Exhibit 2.6

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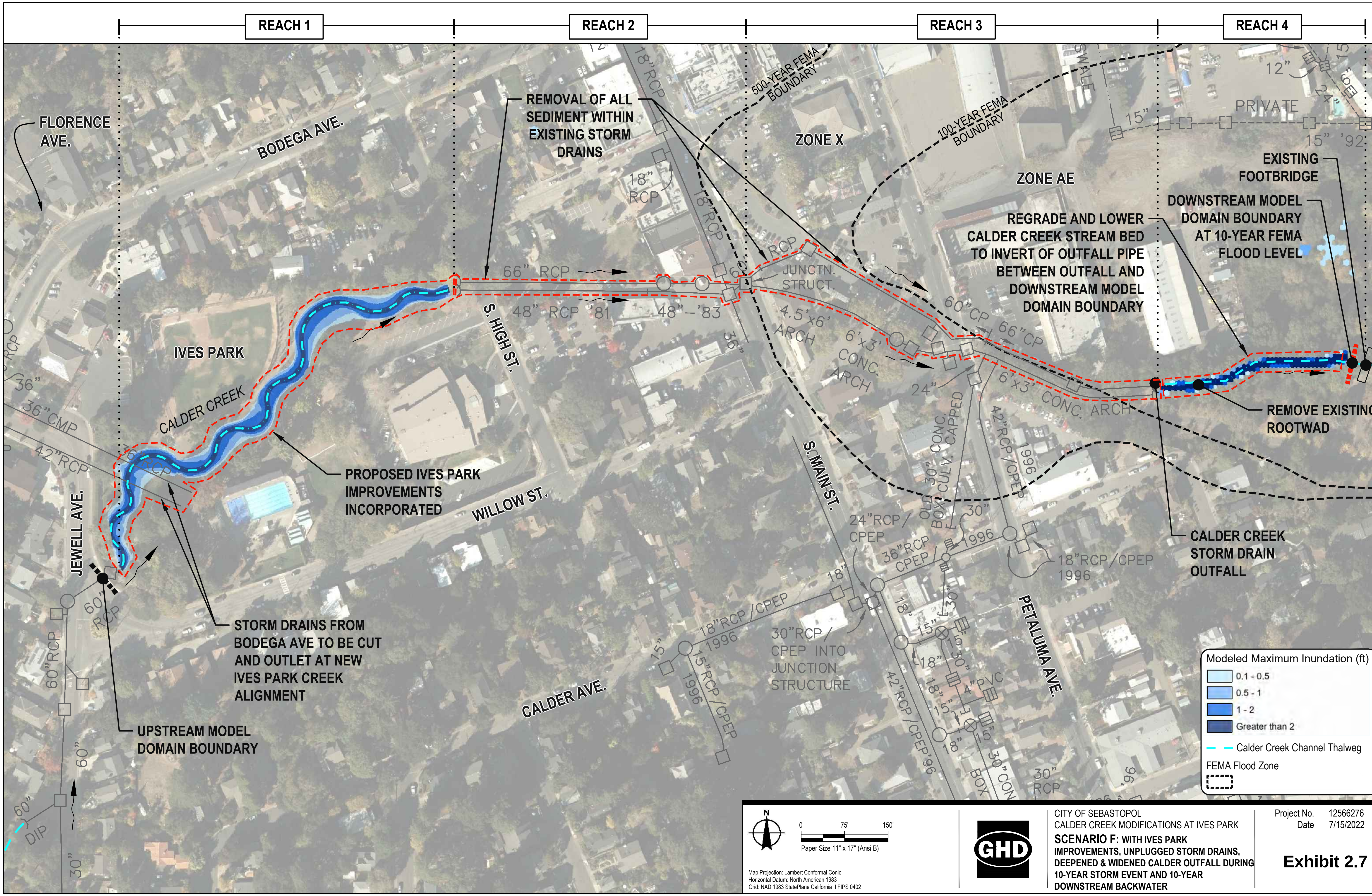

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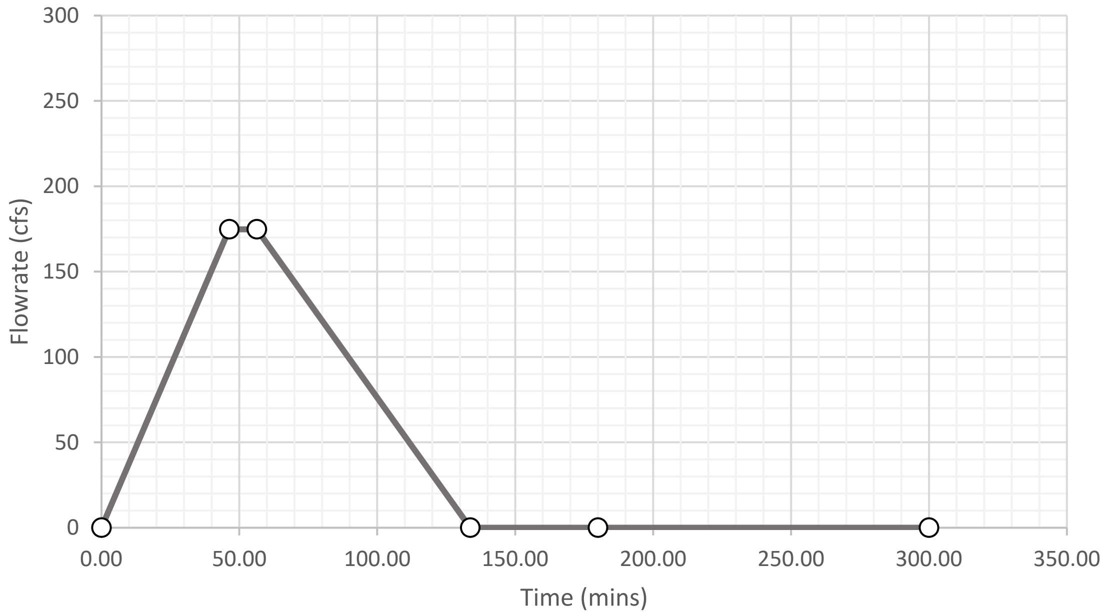
Q10 Peak Runoff =	174.83 cfs	1.67 * tc =	77.3878
Time of Concentration =	46.34 mins	end of receding limb =	133.7278



Time min	Flow cfs		
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56.34	174.83	0.939	0:56
133.73	0	2.2287967	2:13
180.00	0		3:00
300.00	0		0.2083333

GHD

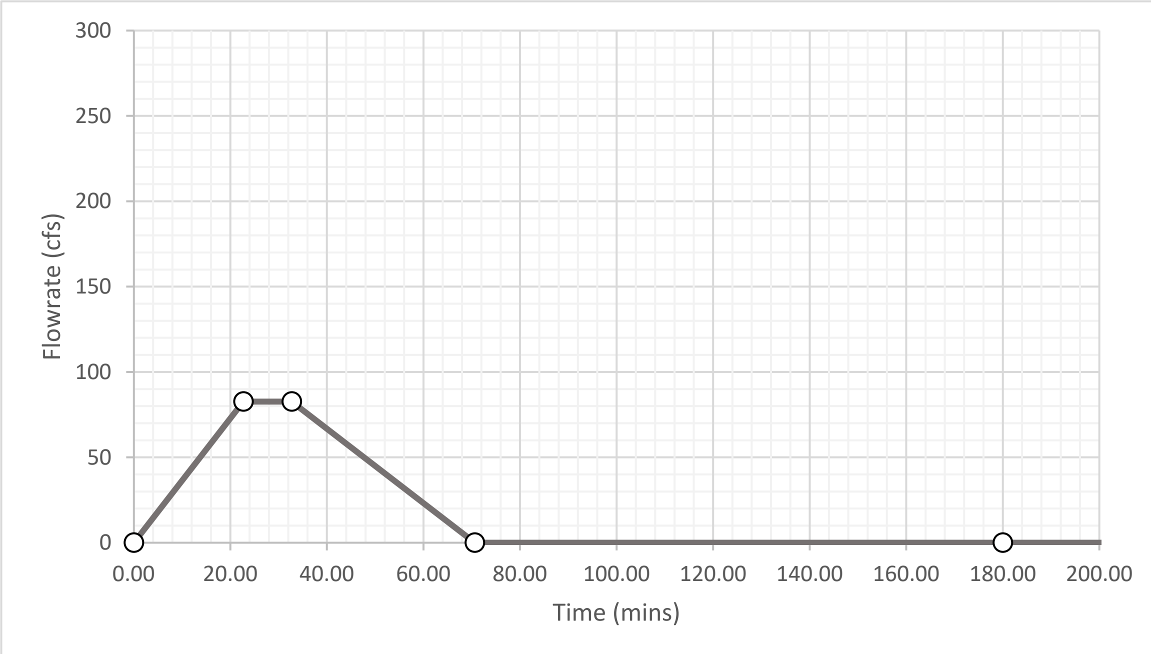
Calder Creek Stream Restoration Hydrologic and Hydraulics
Sebastopol CA

Boundary Conditions - BC1

PROJECT NO.
12566276
7/18/2022

EXHIBIT 3.1

Q10 Peak Runoff =	82.66 cfs	1.67 * tc =	37.9257
Time of Concentration =	22.71 mins	end of receding limb =	70.6357



Time min	Flow cfs
0.00	0
22.71	82.66
32.71	82.66
70.64	0
180.00	0
300.00	0

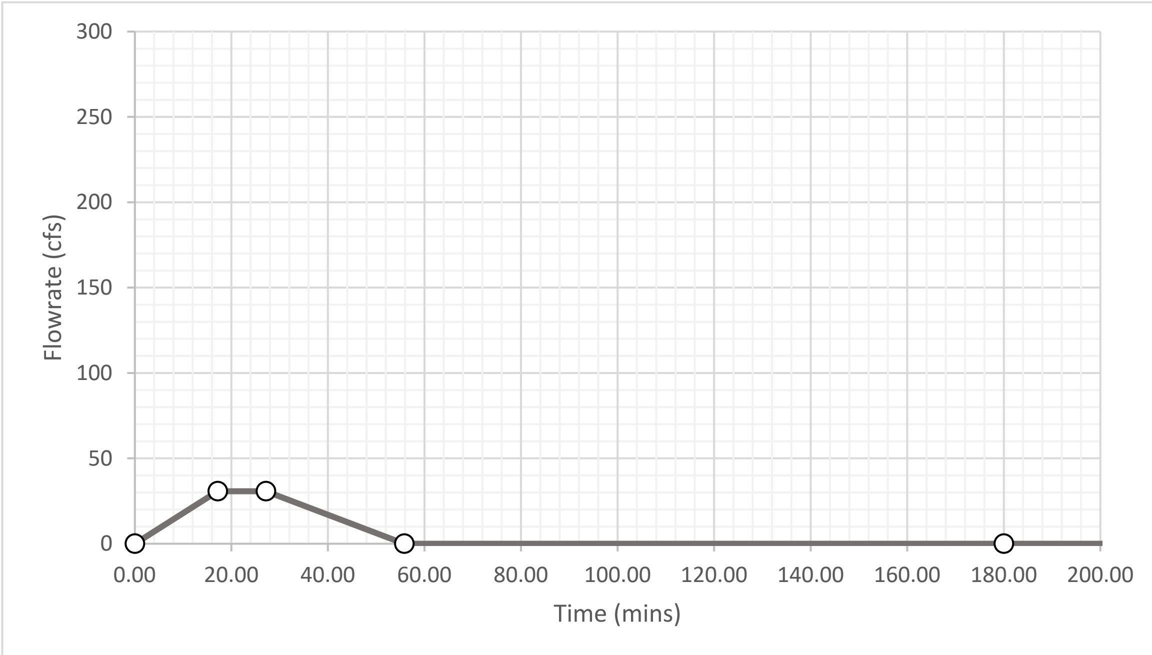
Calder Creek Stream Restoration Hydrologic and Hydraulics
Sebastopol CA

PROJECT NO.
12566276
7/18/2022

Boundary Conditions - BC2

EXHIBIT 3.2

Q10 Peak Runoff =	30.79 cfs	1.67 * tc =	28.6572
Time of Concentration =	17.16 mins	end of receding limb =	55.8172



Time	Flow
min	cfs
0.00	0
17.16	30.79
27.16	30.79
55.82	0
180.00	0
300.00	0

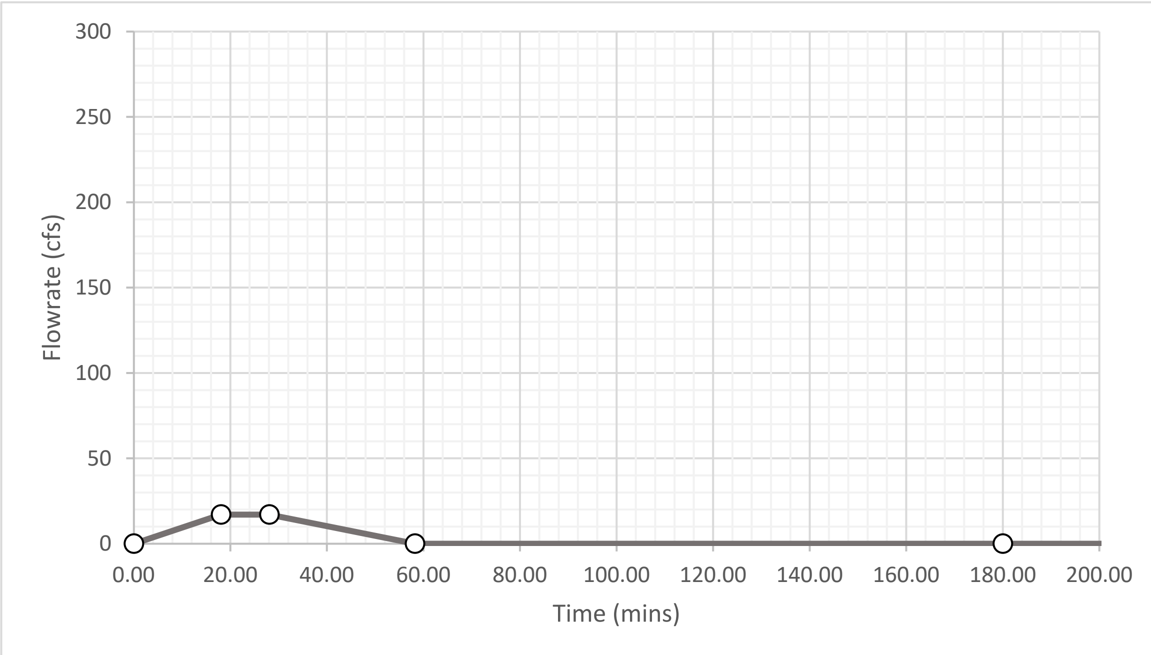
Calder Creek Stream Restoration Hydrologic and Hydraulics
Sebastopol CA

Boundary Conditions - BC3

PROJECT NO.
12566276
7/18/2022

EXHIBIT 3.3

Q10 Peak Runoff =	17.07 cfs	1.67 * tc =	30.1769
Time of Concentration =	18.07 mins	end of receding limb =	58.2469



Time min	Flow cfs
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18.07	17.07
28.07	17.07
58.25	0
180.00	0
300.00	0

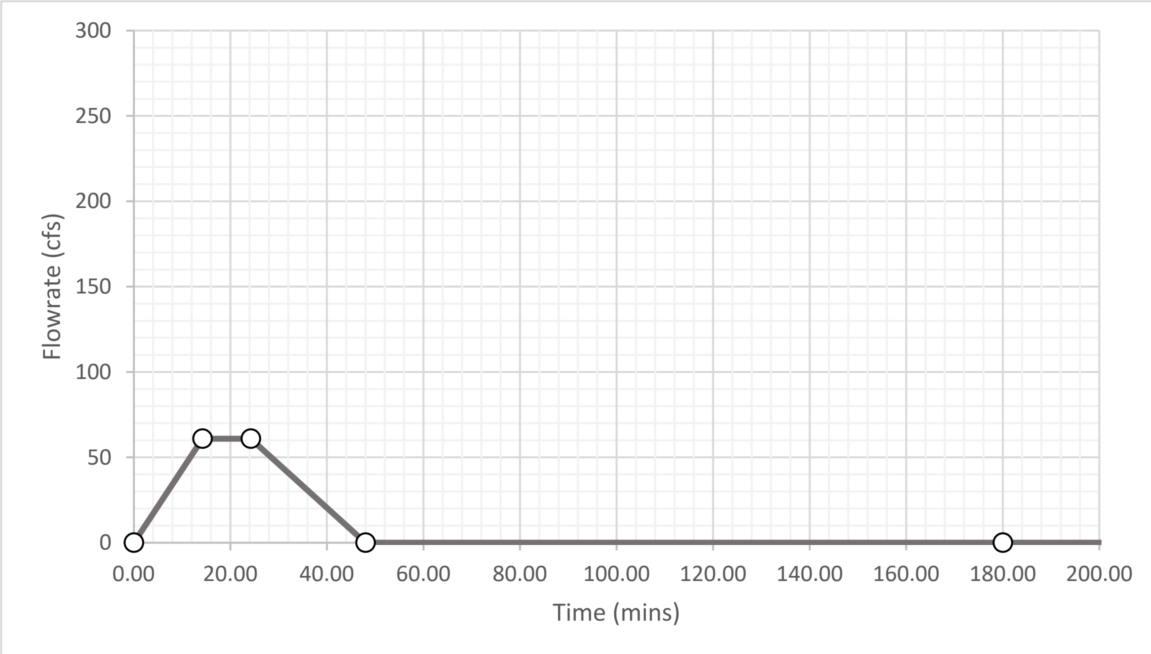
Calder Creek Stream Restoration Hydrologic and Hydraulics
Sebastopol CA

Boundary Conditions - BC4

PROJECT NO.
12566276
7/18/2022

EXHIBIT 3.4

Q10 Peak Runoff =	60.92 cfs	1.67 * tc =	23.7641
Time of Concentration =	14.23 mins	end of receding limb =	47.9941



Time min	Flow cfs
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14.23	60.92
24.23	60.92
47.99	0
180.00	0
300.00	0

GHD

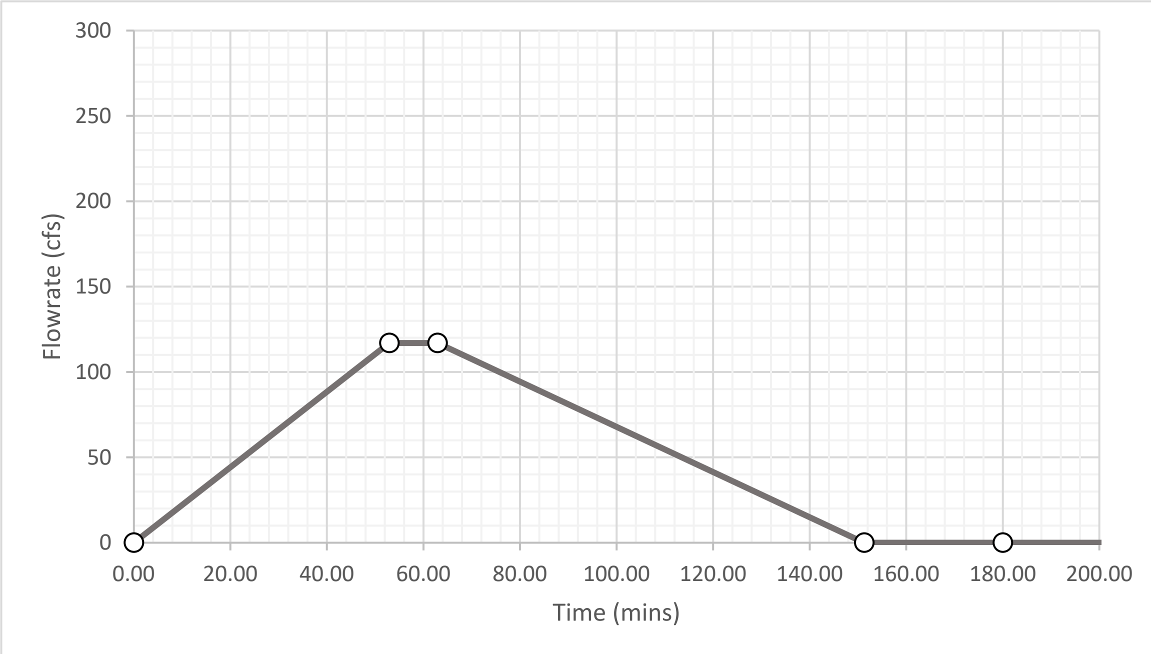
Calder Creek Stream Restoration Hydrologic and Hydraulics
Sebastopol CA

Boundary Conditions - BC5

PROJECT NO.
12566276
7/18/2022

EXHIBIT 3.5

Q10 Peak Runoff =	116.99	cfs	1.67 * tc =	88.3764	
Time of Concentration =	52.92	mins	end of receding limb =	151.2964	



Time	Flow
min	cfs
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52.92	116.99
62.92	116.99
151.30	0
180.00	0
300.00	0

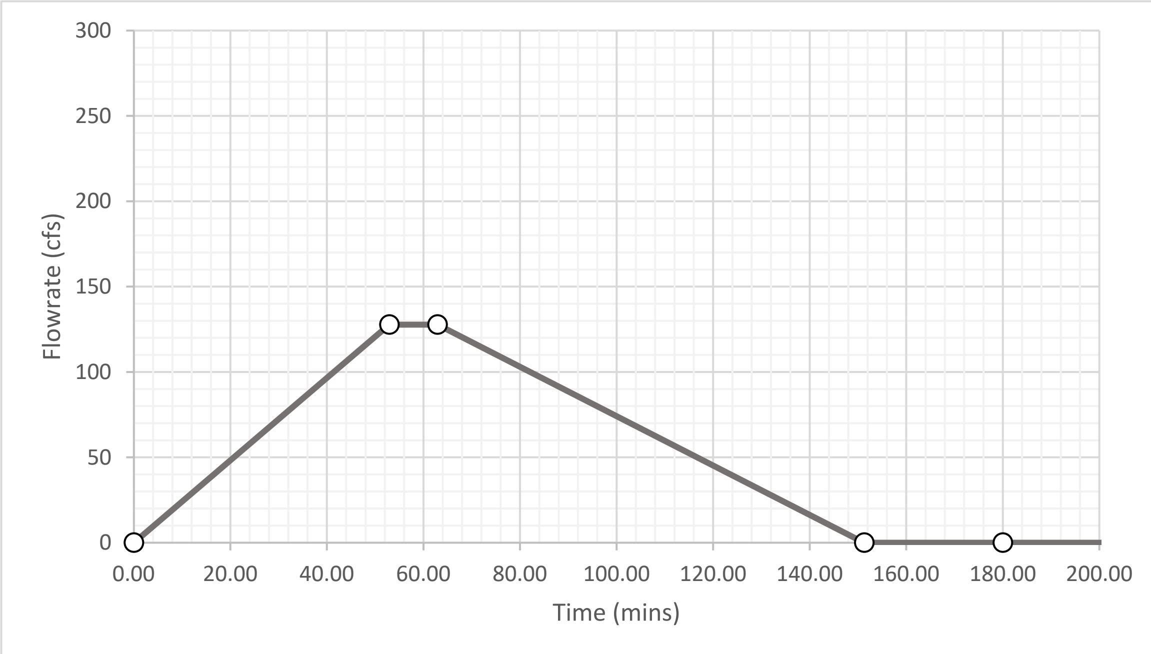
Calder Creek Stream Restoration Hydrologic and Hydraulics
Sebastopol CA

Boundary Conditions - BC6

PROJECT NO.
12566276
7/18/2022

EXHIBIT 3.6

Q10 Peak Runoff =	127.82 cfs		1.67 * tc =	88.3764
Time of Concentration =	52.92 mins		end of receding limb =	151.2964



Time	Flow
min	cfs
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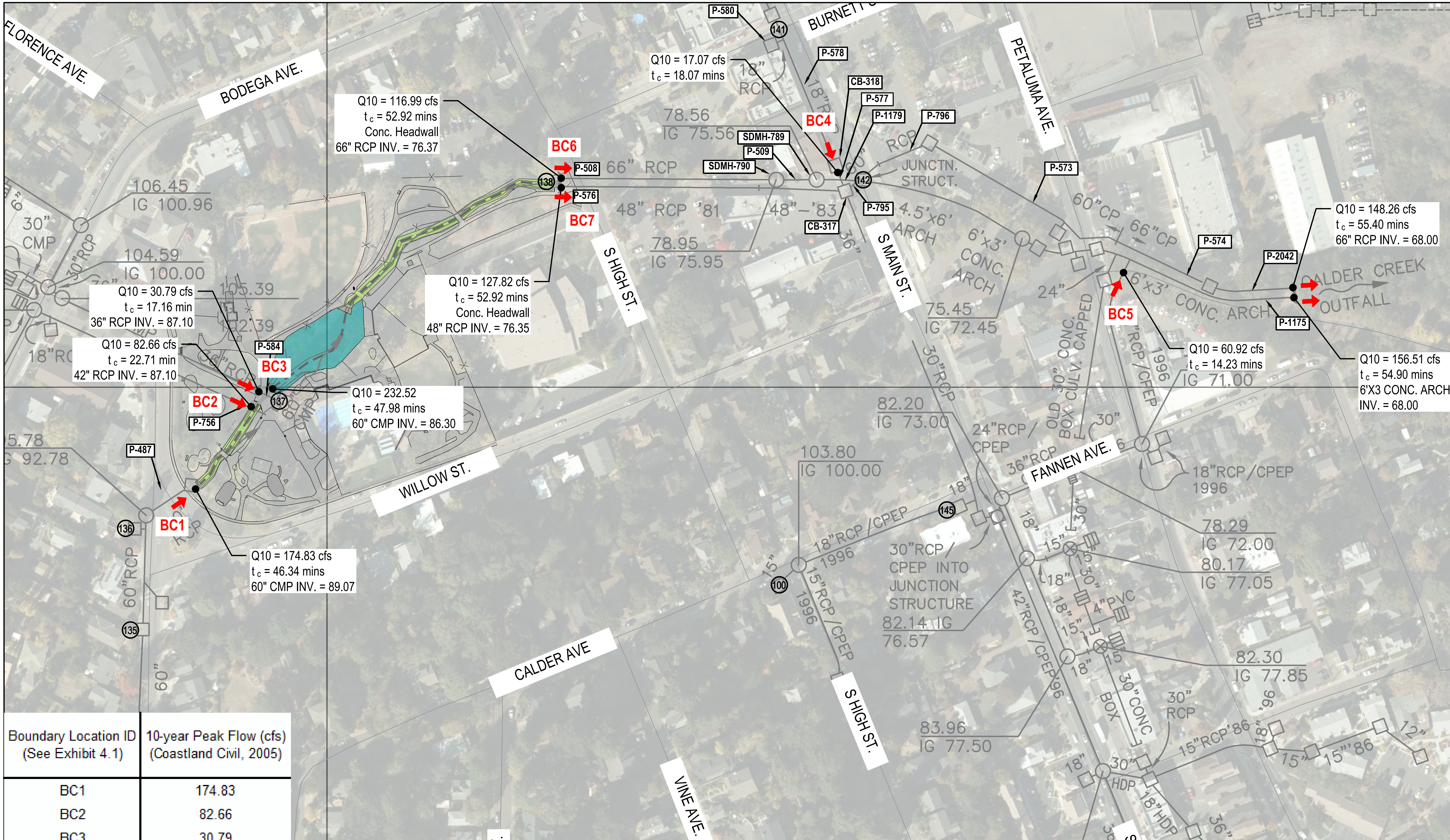
62.92	127.82
151.30	0
180.00	0
300.00	0



Boundary Location ID (See Exhibit 4.1)	10-year Peak Flow (cfs) (Coastland Civil, 2005)
BC1	174.83
BC2	82.66
BC3	30.79
BC4	17.07
BC5	60.92
BC6	116.99
BC7	127.82

0 75' 150'

Paper Size 11" x 17" (Ansi B)

Map Projection: Lambert Conformal Conic
Horizontal Datum: North American 1983
Grid: NAD 1983 StatePlane California II FIPS 0402

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CITY OF SEBASTOPOL
CALDER CREEK MODIFICATIONS AT IVES PARK

Hydrologic Inputs and Existing Storm Drain Utilities

Project No. 12566276
Date 7/15/2022

Exhibit 4.1

Filename: \\ghdnet\ghd\US\Eureka\Projects\561\12566276\Digital_Design\ACAD\Figures\12566276_Calder_Crk_data_figure.dwg
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HEC-RAS 2D Results - (Reach 1, Ives Park) - Longitudinal Profiles

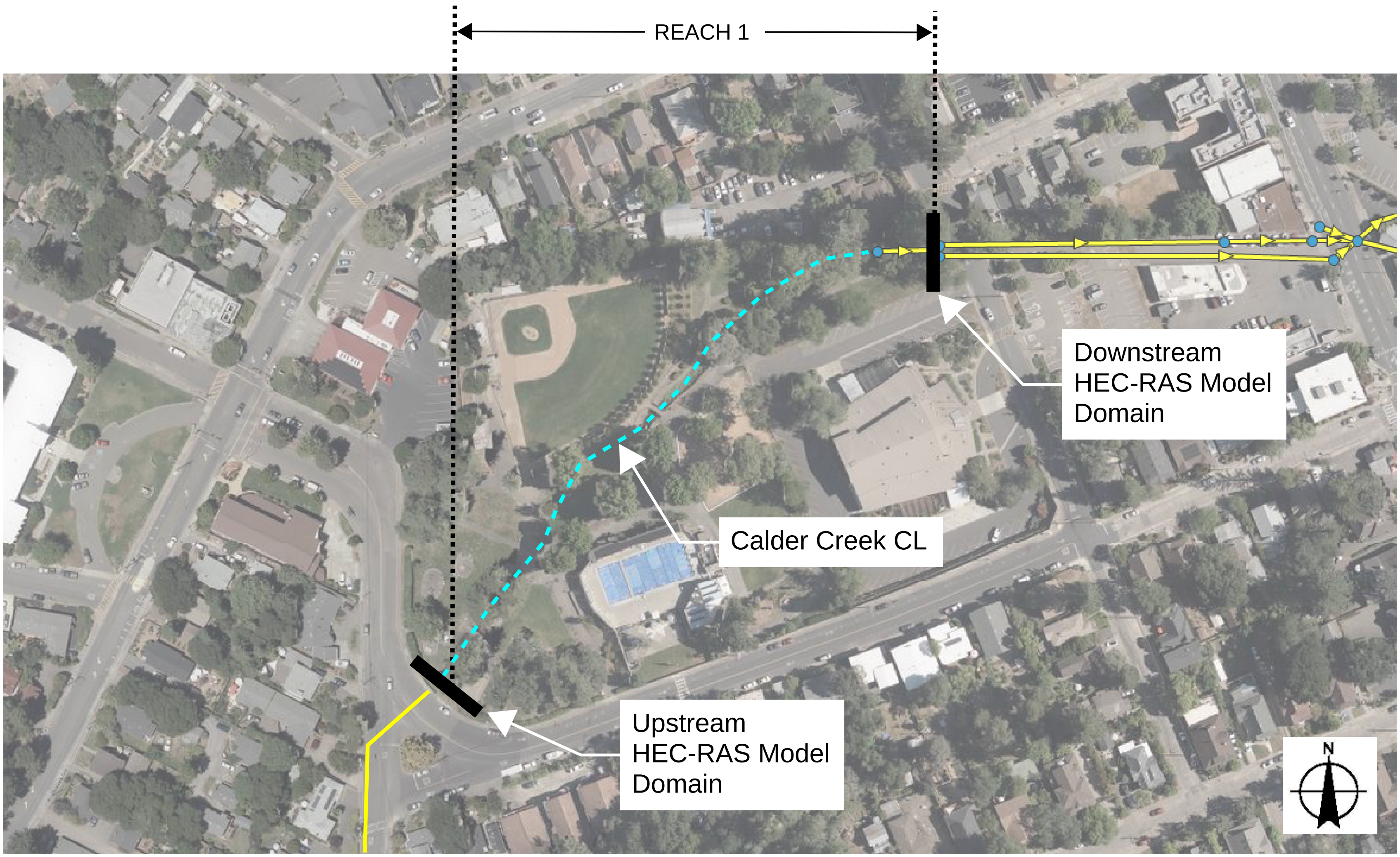


Exhibit 5.1

Velocity Profiles Through Reach 1 Without Ives Park Improvements
Model Scenarios: Existing Conditions (No Action) & Scenarios A - C)
HEC-RAS 2D Model Results

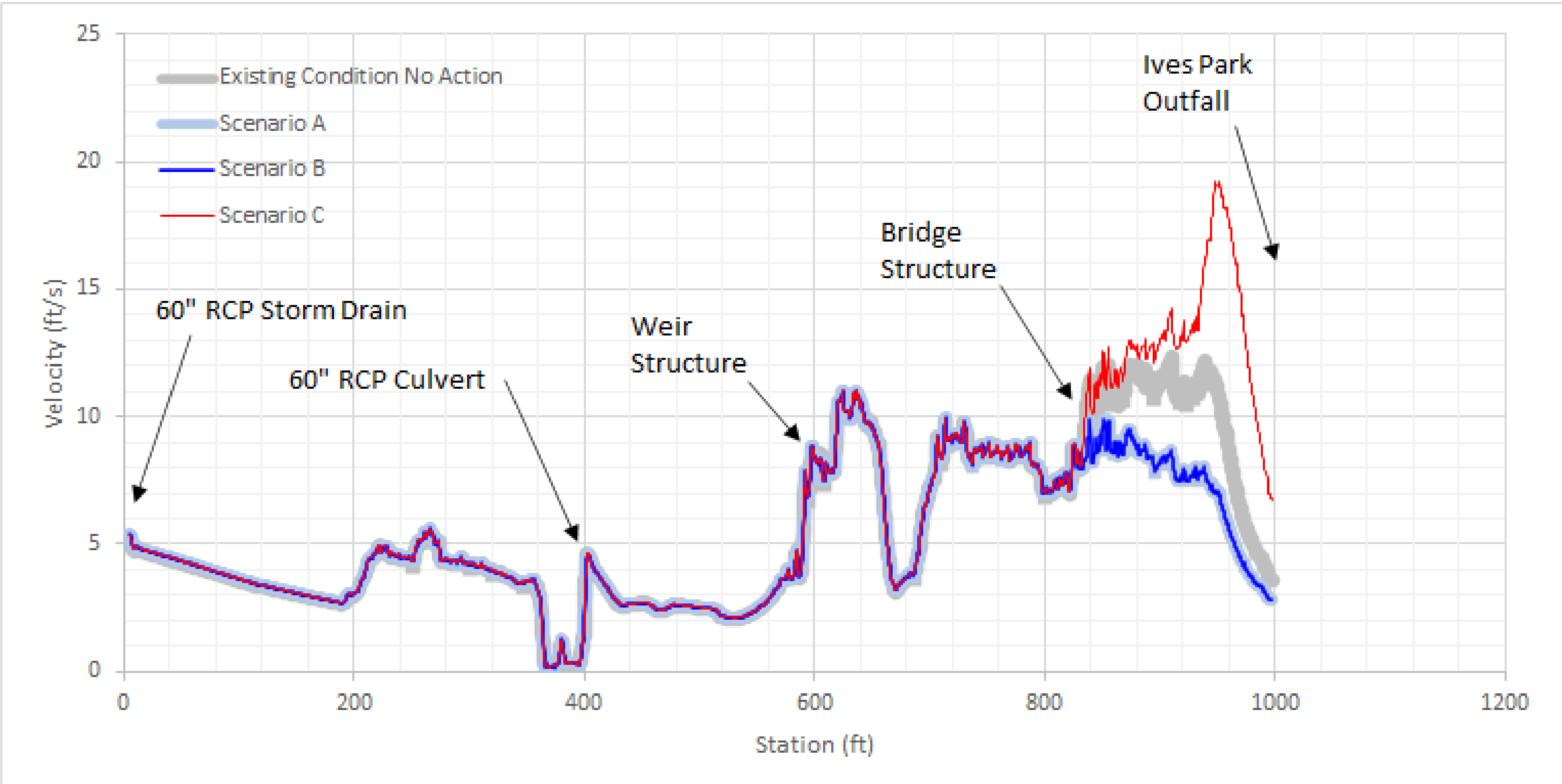


Exhibit 5.2

Water Surface Elevation Profiles Through Reach 1 Without Ives Park Improvements
Model Scenarios: Existing Conditions (No Action) & Scenarios A - C)
HEC-RAS 2D Model Results

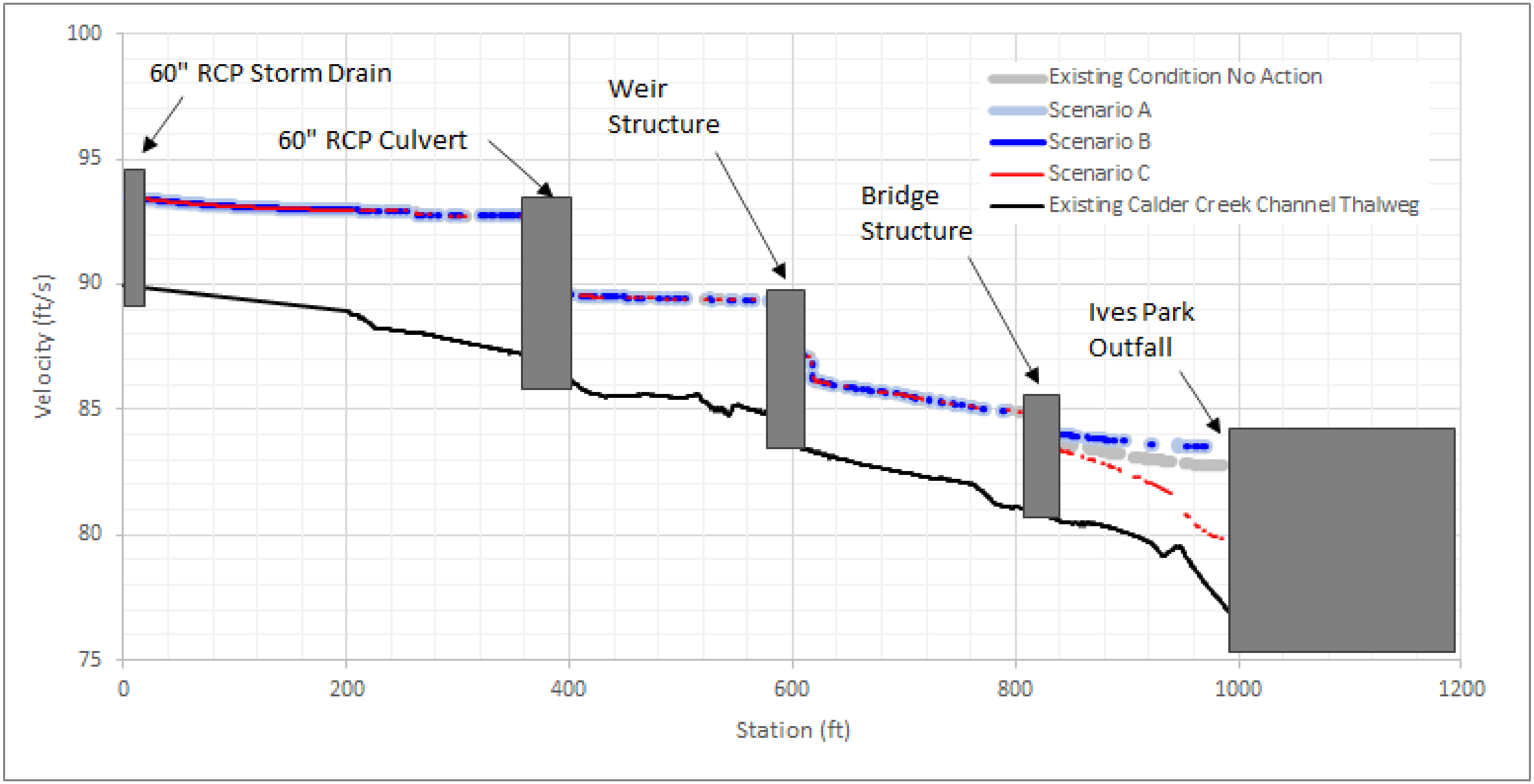


Exhibit 5.3

Velocity Profiles Through Reach 1 With Ives Park Improvements
Model Scenarios: Scenarios D - F)
HEC-RAS 2D Model Results

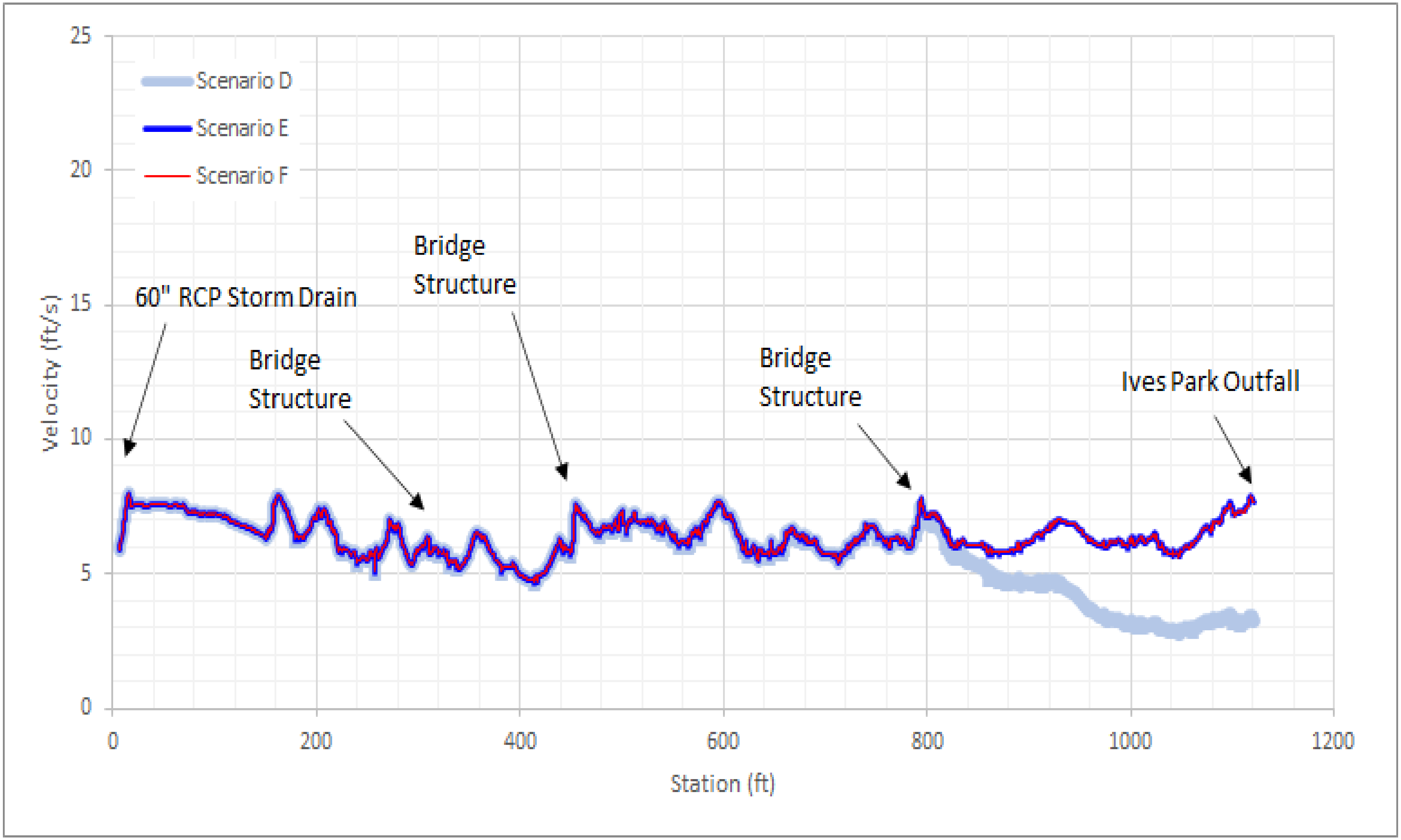


Exhibit 5.4

Water Surface Elevation Profiles Through Reach 1 With Ives Park Improvements
Model Scenarios: Scenarios D - F)
HEC-RAS 2D Model Results

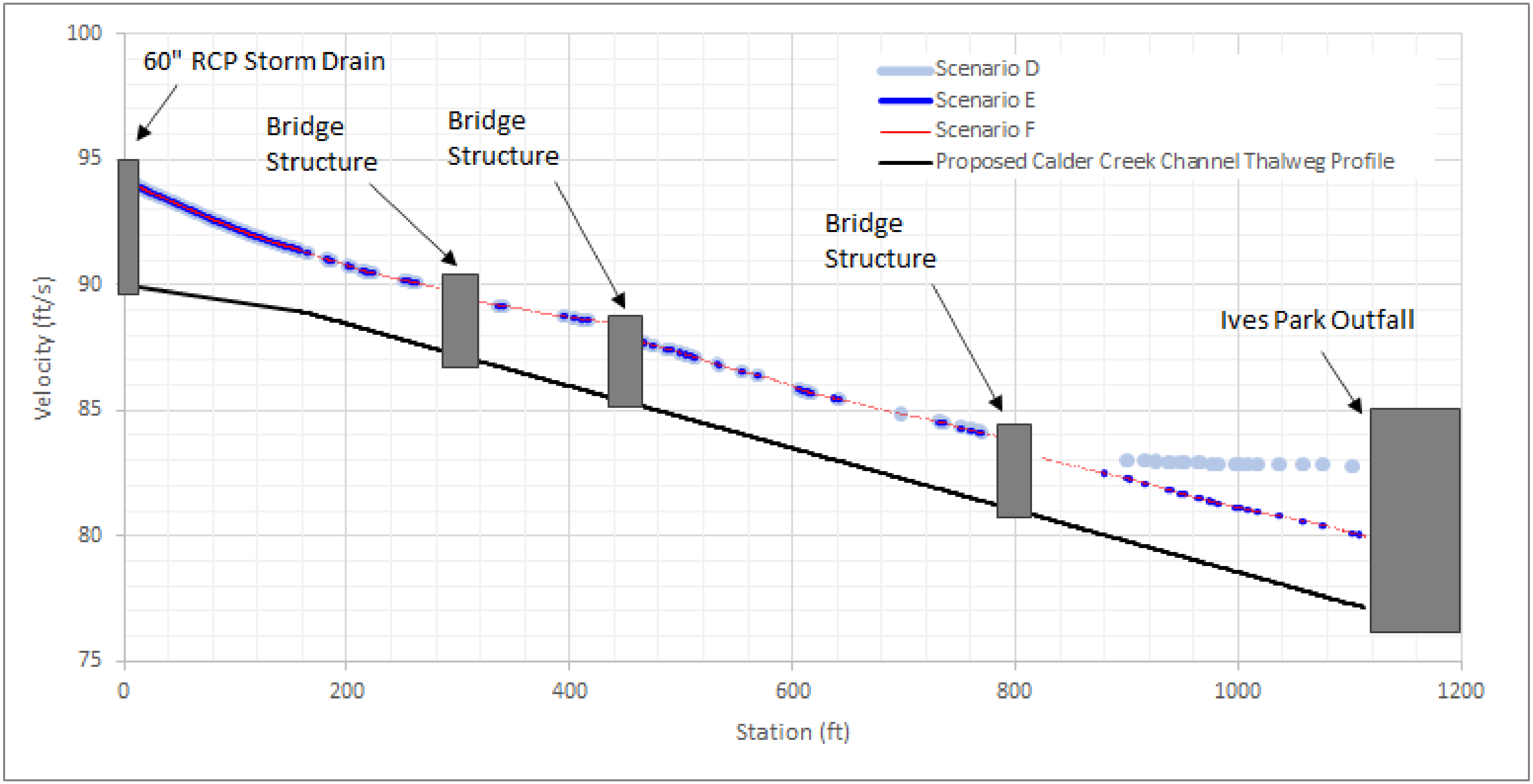


Exhibit 5.5

PCSWMM Results - (Reaches 2 - 4, Downstream of Ives Park) - Longitudinal Profiles

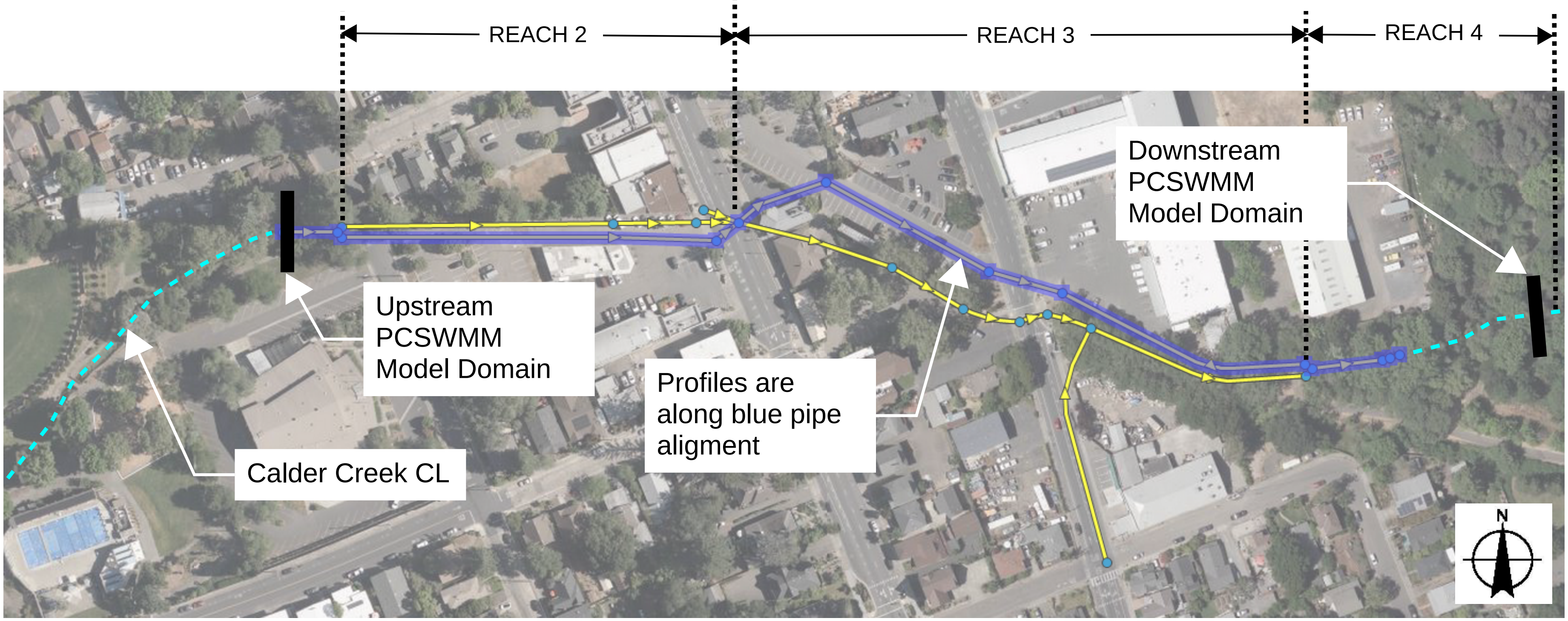


Exhibit 5.6

Existing Condition - No Action Alternative (10-year Storm Event)

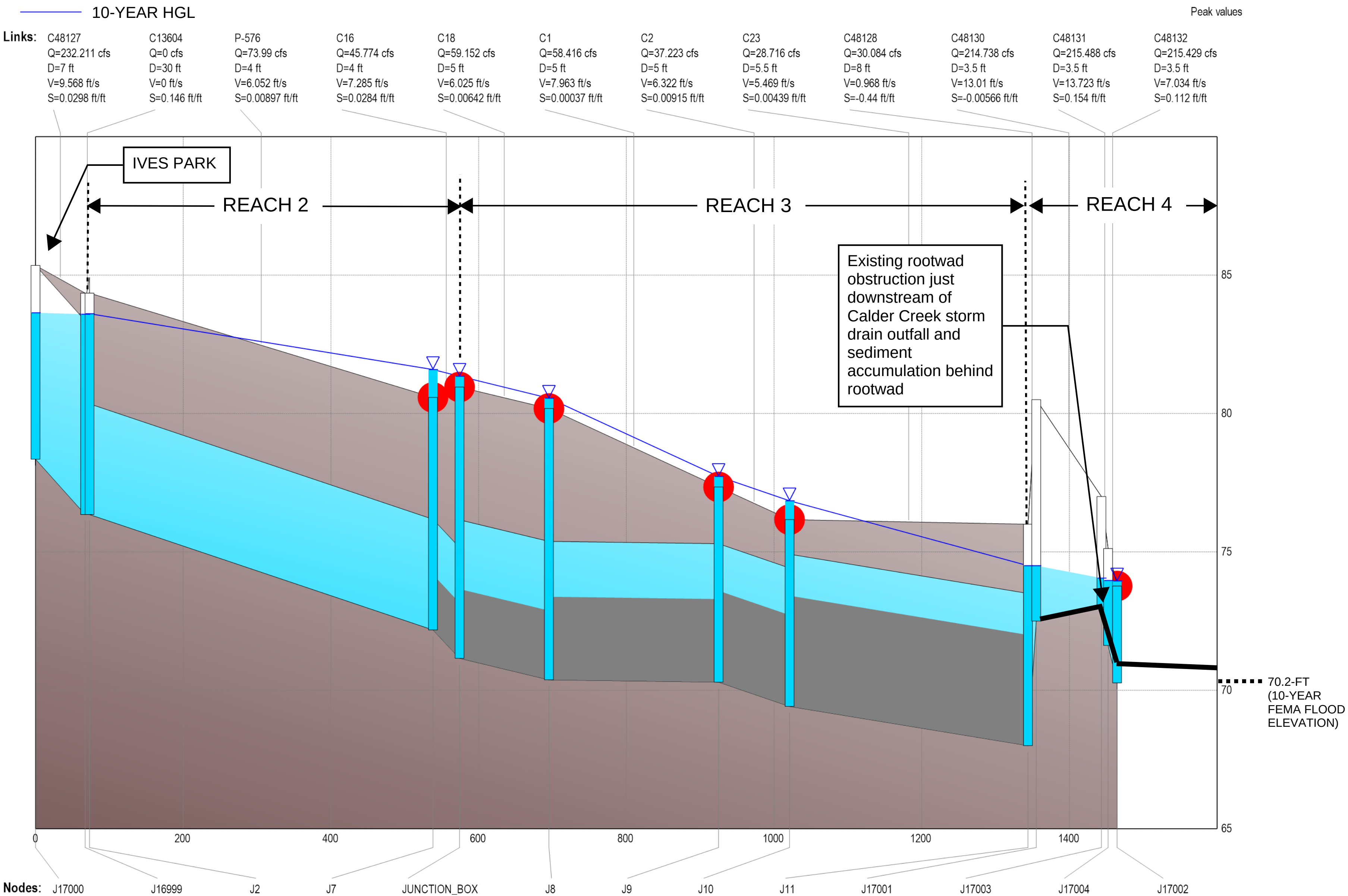


Exhibit 5.7

Proposed Condition A - Removal of Rootwad at Calder Outfall (10-year Storm Event)

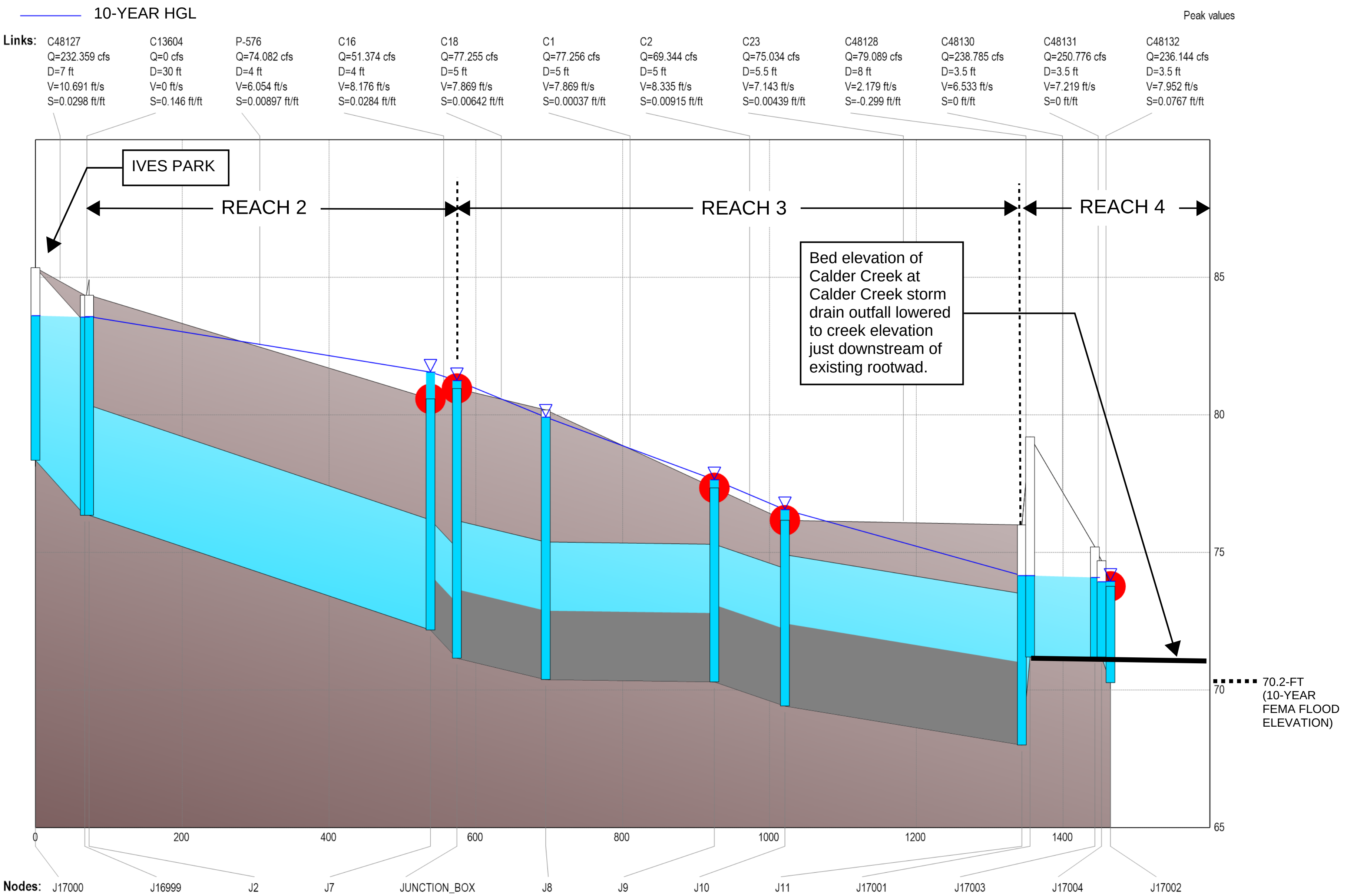


Exhibit 5.8

Proposed Condition B - Deepen and Widen Calder Creek Outfall (10-year Storm Event)

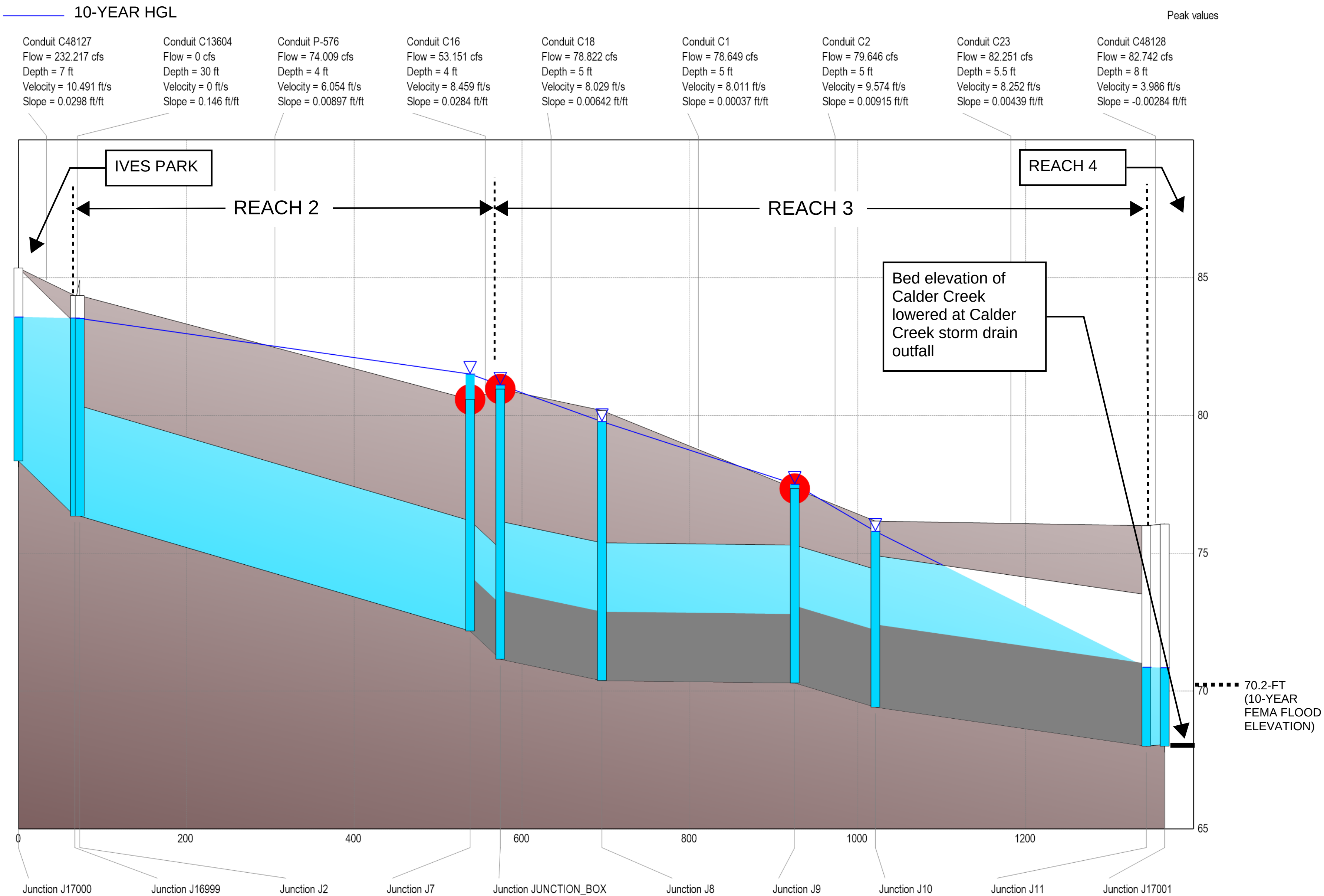


Exhibit 5.9

Proposed Condition C - Unplug Storm Drains and Deepen / Widen Calder Creek Outfall (10-year Storm Event)

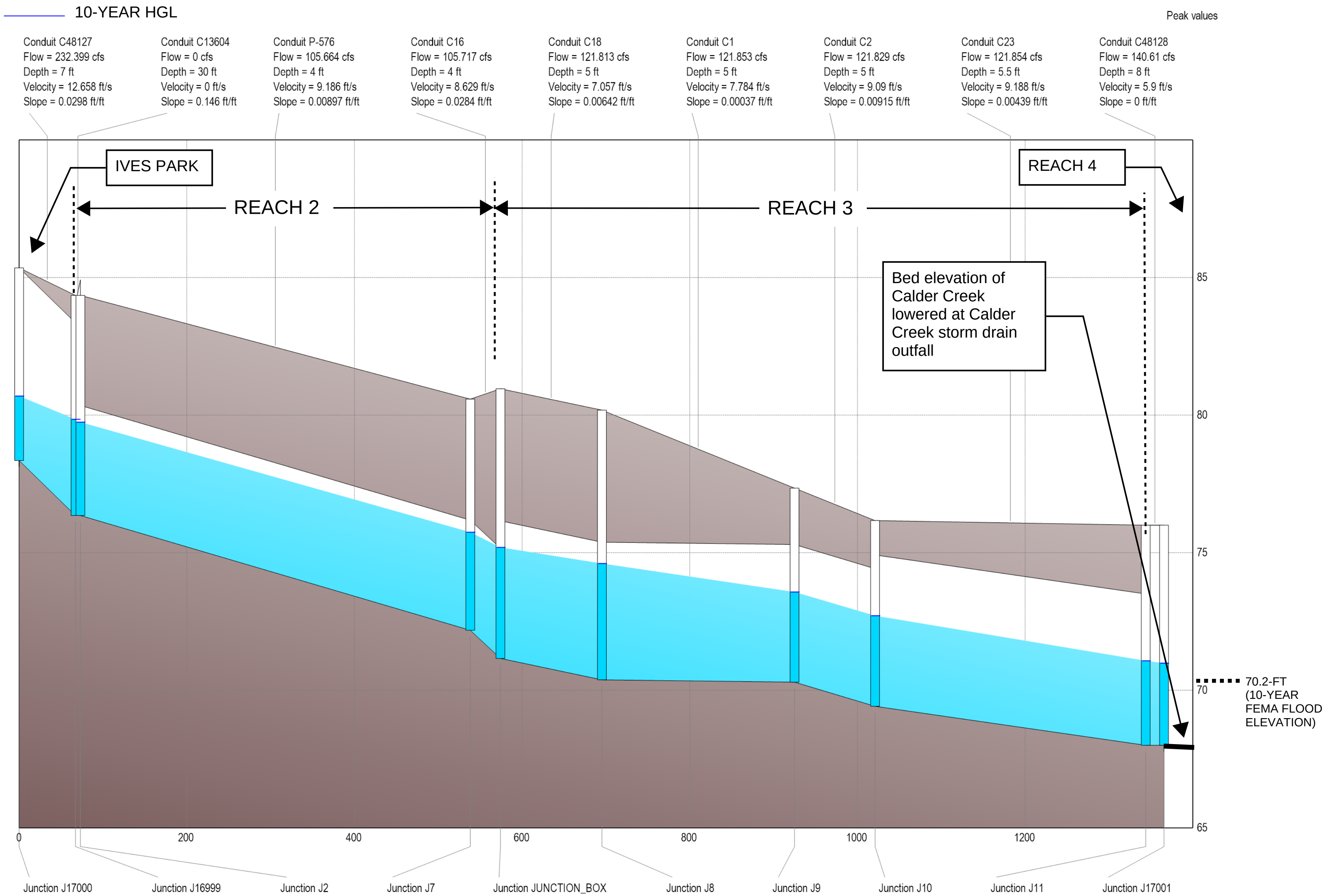


Exhibit 5.10

Proposed Condition D - With Ives Park Inmprovements, Unplug Storm Drains and Deepen / Widen Calder Creek Outfall (10-year Storm Event)

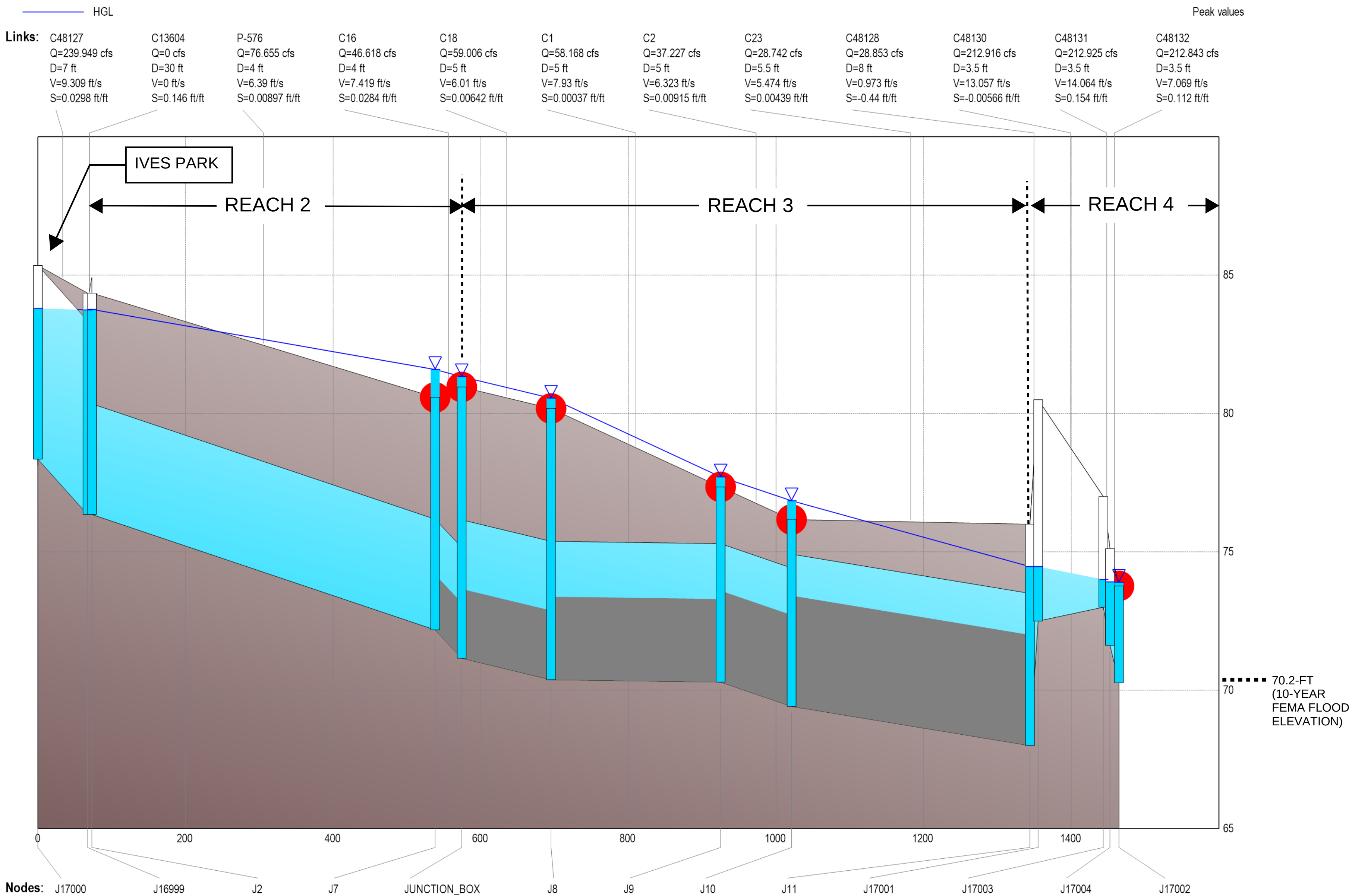


Exhibit 5.11

Proposed Condition E - With Ives Park Improvements, Unplug Storm Drains and Deepen / Widen Calder Outfall (10-year Storm Event)

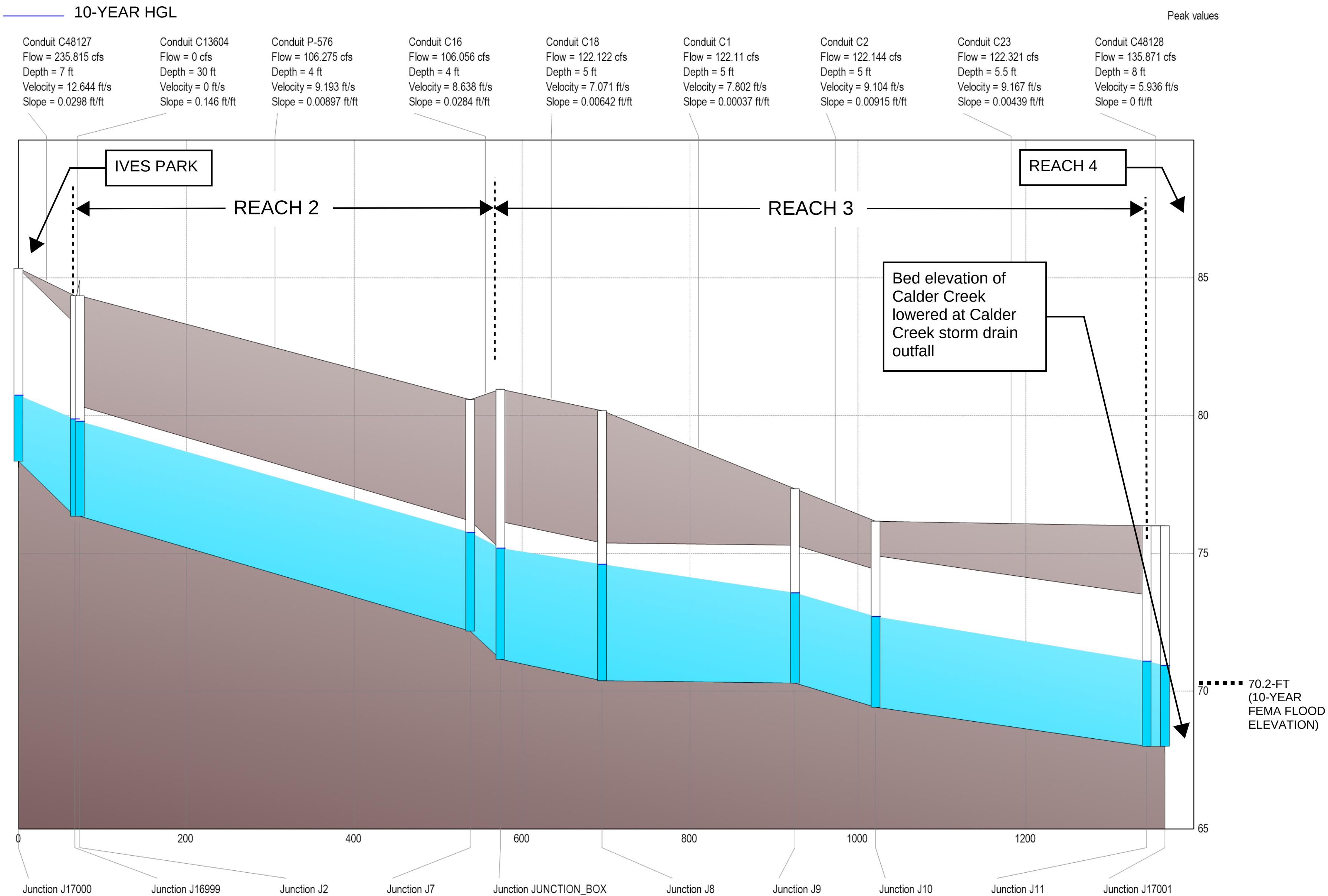


Exhibit 5.12

Proposed Condition F - With Ives Park Improvements, Unplug Storm Drains and Deepen / Widen Calder Outfall – During 10-year Backwater Elevation (10-year Storm Event)

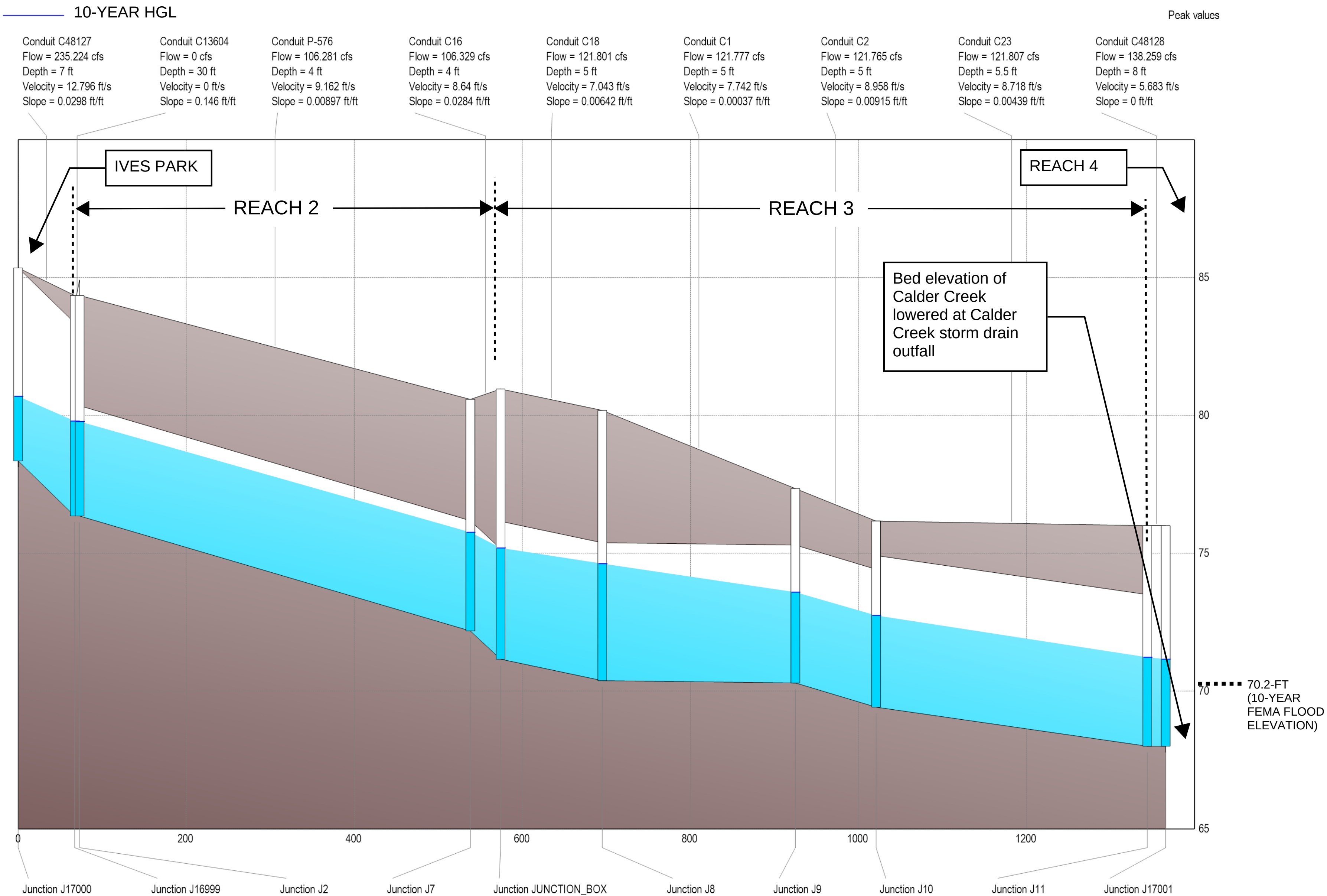
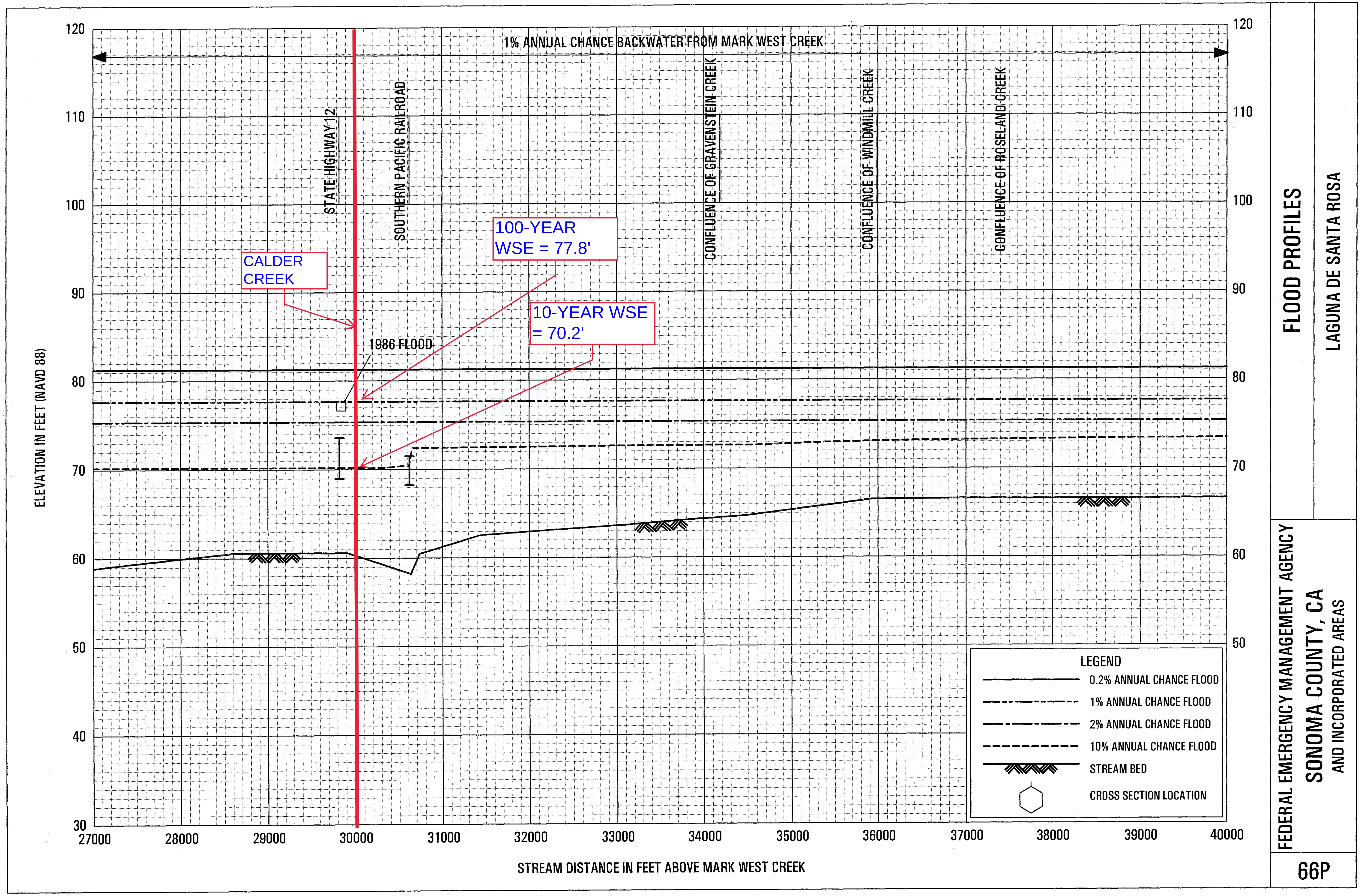


Exhibit 5.13



1% ANNUAL CHANCE BACKWATER FROM MARK WEST CREEK
STATE HIGHWAY 12
SOUTHERN PACIFIC RAILROAD
CONFLUENCE OF GRAVENSTEIN CREEK
CONFLUENCE OF WINDMILL CREEK
CONFLUENCE OF ROSELAND CREEK
100-YEAR WSE = 77.8'
CALDER CREEK
10-YEAR WSE = 70.2'
1986 FLOOD
ELEVATION IN FEET (NAVD 88)
STREAM DISTANCE IN FEET ABOVE MARK WEST CREEK
LEGEND
0.2% ANNUAL CHANCE FLOOD
1% ANNUAL CHANCE FLOOD
2% ANNUAL CHANCE FLOOD
10% ANNUAL CHANCE FLOOD
STREAM BED
CROSS SECTION LOCATION
FLOOD PROFILES
LAGUNA DE SANTA ROSA
FEDERAL EMERGENCY MANAGEMENT AGENCY
SONOMA COUNTY, CA
AND INCORPORATED AREAS
66P

Exhibit 3.1