



## TECHNICAL MEMORANDUM

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### 2017 Coyote Creek and Nyhan Creek Topographic and Bathymetric Survey and Hydraulic Analyses

**Prepared For:** County of Marin

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#### 1. Introduction

County of Marin (County) has been working on flood protection at the Coyote Creek watershed since the 1950s. In 1965, under partnership with the County as a local sponsor, the Coyote Creek Local Flood Protection Project was constructed by the U.S. Army Corps of Engineers (USACE) to protect a portion of the Tamalpais Valley community from periodic flooding. The project consists of a concrete channel and an earth channel, plus a system of earthen levees along an approximately 7,800' section of Coyote Creek, extending from just upstream of Maple Street downstream to the Mill Valley Sausalito Pathway at Richardson Bay. In addition, the project also later included an earth channel and an approximately 450' segment of earthen levees along Nyhan Creek, from Marin Avenue downstream to Coyote Creek confluence.

After the construction, the project ownership was transferred to the County for operation and maintenance, subject to the USACE Rehabilitation and Inspection Program (RIP) per Public Law 84-99. As a part of the RIP, the USACE requires the County to maintain the project to its original design specification, which is to convey the 5-percent annual exceedance probability (AEP) flow that was the basis of the original design of the channel. Over the years, the County maintains the project by periodically remove accumulated sediment from the creeks. In addition, the County has also added fill material to earthen sections of the levee crown in order to maintain levee elevations and installed slurry cut-off walls within certain levee sections to address seepage.

The earth channels in Coyote Creek and Nyhan Creek have historically been periodically surveyed and most recently were surveyed in 2013 and 2015 (Meridian Surveying Engineering, 2013 and 2015). In 2013, the County completed a hydraulic model of the project in order to assess current conditions and inform sediment removal needs. In 2016, the County prepared an engineering evaluation of the levee system in Coyote Creek, which included comprehensive geotechnical and structural assessment of the levee system conditions to develop recommendations for both short- and long-term levee improvements that meet the USACE and Federal Emergency Management Agency (FEMA) regulations, standards, policies, and guidance. As a part of the project, the County also completed a hydraulic study (HDR 2016a) on Coyote Creek and Nyhan Creek to assess its hydraulic performance under a series of flood protection alternatives, based on the 2013 survey data.

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In 2017, Cinquini & Passarino and GHD are under contract with the County to provide topographic and bathymetric survey, and hydraulic analyses services for Coyote Creek and Nyhan Creek. This project is a part of the long term creeks monitoring and management efforts, with the survey data and the hydraulic evaluation providing a snapshot of the existing condition. The goal of this project is to monitor the creeks flood protection level of services and to identify maintenance and improvement needs. Specific objectives of this project:

- Update the existing HEC-RAS model (HDR 2016b) and evaluate hydraulic performance of Coyote Creek and Nyhan Creek, to estimate the creek water surface elevations under five scenarios of design flows and tidal conditions.
- Identify the creeks' sediment removal needs if the levees and floodwalls do not meet the 1 foot freeboard criteria under a 5-percent annual exceedance probability (AEP) event and Mean Higher High Water (MHHW) tidal condition, as per the USACE design parameters for the Coyote Creek Local Flood Protection project (USACE 1965).
- Propose Enterprise Concourse Bridge design elevation criteria to remove hydraulic restriction for creek flow passage.

This technical memorandum documents the survey and hydraulic analyses prepared by the project team, and findings on creek sediment deposition, sediment management and Enterprise Concourse Bridge improvement needs.

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## 2. Topographic and Bathymetric Survey

Cinquini & Passarino conducted the topographic and bathymetric survey of the earthen channels on middle and lower reaches of Coyote Creek and Nyhan Creek in September 2017. The survey extent, as shown in Figure 2, covers Coyote Creek from the downstream of trestle bridge at the Mill Valley Sausalito Path upstream to the concrete channel confluence (Stations 10+44 to 50+00), and Nyhan Creek from the Coyote Creek confluence to approximately 150' upstream of the Enterprise Concourse Bridge crossing (Stations 1+46 to 10+54).

Survey control and monument locations for this project are shown in Figure 1. Control Monuments for this project were set in ½" iron pipes with a plastic control plug as indicated by points 1, 40, 41, and 42. Points 23, 24, 29, 30 and 10 were found control points or monuments established by Meridian Surveying Engineering (Meridian).

The horizontal datum used for this control network is based upon California Coordinate System of 1983 as referenced by epoch 2011.00. The vertical datum is based upon North America Vertical Datum 1988 (NAVD 88). All coordinates derived from this survey are grid values, we found that the values utilized by Meridian in the 2013 survey is different than the values as published by the USACE for the Coyote Creek project. Therefore, to provide consistent horizontal datum and vertical datum, the project team utilized the control from Meridian's survey work to establish the horizontal and vertical control for the project. We utilized tidal monuments 941 3819 Tidal 32 (HT1067) and N501 as established by the USACE to determine the bearing references. This data was then shifted South 31°49'42", East 1.985', to match the coordinate system utilized by Meridian. No new benchmark was set, but multiple permanent control points were set to mark the survey, as shown in Figure 1. The vertical datum utilized an average of the various Meridian control points used in their survey works. These points averaged -0.283' below the elevation datum established by USACE on Tidal 32 (HT1067), N500 and N501. We recalculated the NAVD 88 datum elevation to be 0.283' higher than the elevations shown on this drawing, Mean Higher High Water (MHHW) datum elevation is at 2.032' and Mean Lower Low Water (MLLW) datum elevation is at 0.283' based on this drawing, as shown in the datum list below:

- MHHW + 2.032'
- MLLW & NAVD 1988 + 0.283'
- Project Datum 0.000'

Field work for this project was completed using static GNSS surveys to establish the project control. These surveys were reduced in Trimble Business Center version 3.81. RTK GNSS surveys were used to collect the majority of the creek cross sections as well as the hydrographic data. Terrestrial total station surveys were used to collect the data in the areas where the hillsides or tree canopy obscured the use of GNSS equipment, in those areas we utilized GNSS established control to provide a basis for the terrestrial surveys. For data processing, all of the field data was processed using Trimble Business Center version 3.81. The Aerial Orthographic Photo, used as a background in Figure 2 and to determine the vegetation limits for this project, was collected using a Sensefly eBee + fixed wings UAS system. This image was then processed using Pix4D software to prepare the orthographic photo. Figure 3 shows the survey data collected for this project.

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## 3. Hydraulic Analysis

GHD developed an updated one-dimensional (1D) unsteady state HEC-RAS hydraulic model (2017 model) based on the topographic and bathymetric survey data collected in 2017. The 2017 model was built based on the HEC-RAS hydraulic model (HDR 2016b) developed in HDR 2016a (2013 model), reflecting the creek elevations and hydraulic performance in 2013. A Digital Elevation Model (DEM) was created for the surveyed creek corridor based on the 2017 survey data. In the model and this technical memorandum, the left and right banks are defined based on the viewpoint looking downstream in the channel, a typical HEC-RAS cross sections orientation. For example, the left bank of Nyhan Creek refers to the west bank along the creek.

Creek cross sections, consistent with the location and stationing in the 2013 model, were extracted from the DEM and imported to the HEC-RAS hydraulic model, with the following exceptions:

- Between Coyote Creek stations 10+44 and 20+50, topographic data along the left overbank at Bothin Marsh is based on the 2013 model.
- The concrete channel geometries at Coyote Creek station 50+00 and upstream are extracted from the 2013 model.

The 2017 HEC-RAS model included five scenarios as summarized in Table 1. Model setups, including flow hydrographs and stage boundary conditions at the Richardson Bay outfall, creek crossing structures, and analytical setup, are reproduced from the 2013 model. The lateral structures in the 2013 model were not included in the 2017 model, since the weir coefficients were set to 0 in the 2013 model (HDR 2016a), so no lateral weir flow was estimated in the 2013 model. Therefore, the entire design flow is contained within the channel corridor in all scenarios.

In each scenario, the model estimated the hydraulic grade line (HGL) along Coyote Creek, from downstream of the Mill Valley Sausalito Path (Station 10+44), to the upstream extent of the concrete channel at Ash Street (Station 7632). The model also included Nyhan Creek from the downstream confluence with Coyote Creek (Station 1+46) to upstream of Enterprise Concourse Bridge (Station 1054). The Coyote Creek / Nyhan Creek confluence is located at the downstream of the Flamingo Road Bridge, between Coyote Creek stations 40+38 and 42+00.

Figures 4 to 8 show the HGL, channel flowline elevations, levee and floodwalls elevations and freeboards at Coyote Creek and Nyhan Creeks, under 2013 and 2017 conditions. The extent of the levees and floodwalls for freeboard evaluation is based on HDR 2016a, as listed in follow:

- Coyote Creek, Left Bank, Stations 25+00 to 76+32
- Coyote Creek, Right Bank, Stations 42+00 to 76+32
- Nyhan Creek, Left Bank, Stations 1+46 to 4+96

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Table 1 - Hydraulic Analysis Modeling Scenarios					
Scenario	1	2	3	4	5
Scenario Name	Baseline	4% Annual Exceedance	2% Annual Exceedance	1% Annual Exceedance	1% FEMA Annual Exceedance with SLR
Geometry Data	Topographic and Bathymetric Survey, September 2017				
Flow Input					
Description	1960s USACE Design Flow	District Flow + 15%	District Flow + 15%	District Flow + 15%	FEMA Flow
Annual Exceedance Probability (AEP)	5%	4%	2%	1%	1%
Coyote Creek Flow Upstream Limit	900 cfs	473 cfs	555 cfs	641 cfs	910 cfs
Coyote Creek Flow At Confluence	1,100 cfs	555 cfs	650 cfs	753 cfs	1,120 cfs
Nyhan Creek Flow Upstream Limit	650 cfs	356 cfs	420 cfs	489 cfs	920 cfs
Nyhan Creek Flow At Confluence	650 cfs	473 cfs	559 cfs	651 cfs	920 cfs
Downstream Boundary Conditions					
Fluvial - Description	MHHW at 1960s	MHHW at Present Day			MHHW at 2050
Fluvial - Elevation	5.4'	5.9'			8.9'
Tidal - Description	MHHW at 1960s	MHHW at Present Day	FEMA 1% AEP event and Still Water Elevation		FEMA 1% AEP event and Still Water Elevation + Sea Level Rise
Tidal - Elevation	5.4'	5.9'	9.7'		12.7'

The following summarizes the hydraulic analysis findings in each scenario. A summary table of the hydraulic analysis results is in Appendix A.

**Scenario 1:** This scenario is the baseline scenario based on USACE's 5% AEP design flow. The Coyote Creek HGL in 2017 condition is close to 2013 condition, with lower HGL up to approximately 0.15', as compares with the 2013 condition. Figure 4a shows that there are two locations in Coyote Creek which do not meet the 1' freeboard criteria. They are located at the Nyhan Creek confluence between stations 39+71 and 42+00, and upstream of the Flamingo Road Bridge between stations 44+00 and 45+50. In addition, the section of the concrete channel between station 49+00 and 67+50 does not have 1' freeboard, and HGL overtops about 750 linear feet of concrete channel section located upstream of Ross Drive, between stations 52+50 and 60+00. Note that USACE 1959 stated that flow in the concrete channel would be supercritical, with hydraulic jump at the earth channel transition. However, the hydraulic analysis estimated that the overtopping concrete channel section is in subcritical flow condition, as evidence by less than 1.0 Froude numbers. Subcritical flow HGL is always higher than supercritical flow HGL, it may partly explain the difference between the hydraulic analysis results and the design description in USACE 1959. At Nyhan Creek, HGL in 2017 condition is up to approximately 0.35' higher than the 2013 condition. Figure 4b shows that Nyhan Creek flow overtops Marin Avenue and Enterprise Concourse bridges. In addition, a 50' section of earth levee along the left bank, between stations 4+62 and 4+92, at the downstream of Marin Avenue have less than 1' freeboard.

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**Scenario 2:** This scenario is the 4% AEP design flow based on the District's estimate, which is lower than the USACE's estimates as applied in Scenario 1. At Coyote Creek, HGL in 2017 condition is close to 2013 condition, with lower HGL up to approximately 0.15', as compared with the 2013 condition. Figure 5a shows that Coyote Creek contains the design flow and meets the 1' freeboard criteria. At Nyhan Creek, HGL in 2017 condition is up to approximately 0.35' higher than the 2013 condition. Figure 5b shows that Nyhan Creek flow overtops Marin Avenue and Enterprise Concourse bridges. However, the creek HGL meets the 1' freeboard criteria along the left bank earth levee at the downstream of Marin Avenue.

**Scenario 3:** This scenario is the 2% AEP design flow. The Coyote Creek HGL in 2017 condition is close to 2013 condition, with lower HGL up to approximately 0.15', as compared with the 2013 condition. Figure 6a shows that Coyote Creek contains the design flow and meets the 1' freeboard criteria, except for a 500' section of concrete channel upstream of Ross Drive. The Nyhan Creek HGL in 2017 condition is up to approximately 0.45' higher than the 2013 condition. Figure 6b shows that Nyhan Creek flow overtops Marin Avenue and Enterprise Concourse bridges. However, the creek HGL meets the 1' freeboard criteria at the left embankment downstream of Marin Avenue except for a short segment right downstream of Marin Avenue. Under the tidal dominated backwater condition with a tide level of 9.7', levees and floodwalls on Coyote Creek and Nyhan Creek do not meet the 1' freeboard criteria, and tidal flow overtops levees and floodwalls at multiple locations.

**Scenario 4:** This scenario is the 1% AEP design flow. The Coyote Creek HGL in 2017 condition is close to 2013 condition, with lower HGL up to approximately 0.15', as compared with the 2013 condition. Figure 7a shows that Coyote Creek contains the design flow, but does not meet the 1' freeboard criteria upstream of Flamingo Road. The Nyhan Creek HGL in 2017 condition is up to approximately 0.35' higher than the 2013 condition. Figure 7b shows that Nyhan Creek flow overtops Marin Avenue and Enterprise Concourse bridges. However, the creek HGL meets the 1' freeboard criteria at the left embankment downstream of Marin Avenue except for a short segment right downstream of Marin Avenue. Under the tidal dominated backwater condition with a tide level of 9.7', levees and floodwalls on Coyote Creek and Nyhan Creek do not meet the 1' freeboard criteria, and tidal flow overtops levees and floodwalls at multiple locations.

**Scenario 5:** This scenario is the 1% AEP design flow with the project Year 2050 MHHW tide level of 8.9' as the downstream boundary condition. The Coyote Creek HGL in 2017 condition is close to 2013 condition, with lower HGL up to approximately 0.15', as compared with the 2013 condition. Figure 8a shows that Coyote Creek overtops at multiple locations, and most of the levees do not meet the 1' freeboard criteria. The Nyhan Creek HGL in 2017 condition is up to approximately 0.2' higher than the 2013 condition. Figure 8b shows that Nyhan Creek flow overtops Marin Avenue and Enterprise Concourse bridges, and do not meet the 1' freeboard criteria. Under the tidal dominated backwater condition with a tide level of 12.7', the earthen channel in Coyote Creek, the section of Nyhan Creek modeled, and the levees and floodwall along both creeks are inundated.

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**4. Sediment Deposition**

A sediment mapping analysis was completed to identify cumulative deposition and scouring changes between 2013 and 2017. Figures 9a to 9d show the change in creek bed elevations in plan views, based on the DEM comparison between the 2013 survey (HDR 2015) and the 2017 survey prepared for this project. The mapping shows deposition, in red color, at the confluence of Nyhan and Coyote Creeks, and upstream along Nyhan Creek. Deposition is also observed along Coyote Creek, especially along the flowline at the center of the channel. Figure 10 shows the range of elevation change in Coyote Creek between 2013 and 2017. The figure shows that close to 80% of the area has scouring or deposition that is 6" or less.

Figures 11a and 11b show the sediment deposition and erosion along Coyote Creek and Nyhan Creek, respectively. At Coyote Creek, the creek segments downstream of the Nyhan Creek confluence are mostly erosional, with negative net sediment volume. There is significant deposition at the Nyhan Creek confluence, and additional deposition at the upstream segments of the Coyote Creek earthen channel. At Nyhan Creek there is net deposition between 2013 and 2017, with higher deposition volume at the vicinity of the Coyote Creek confluence. Note that the sediment volume as shown in Figure 9b did not include the 220 cubic yard (cy) of sediment removed by the County in 2015, which would further increase the net deposition volume.

Based on the sediment mapping analysis, Table 2 summarizes the sediment deposition estimates. The table shows that between 2013 and 2017, Coyote Creek and Nyhan Creek have 2170 cy and 1300 cy of sediment deposition, respectively. The estimate at Nyhan Creek included 220 cy of sediment removed in 2015. The shoaling rate in Table 2 was calculated based on the total deposition volume estimated in the sediment mapping analysis divide by the total water surface area in the creek, then divide by 4 years between 2013 and 2017. The estimated shoaling rate for Coyote Creek and Nyhan Creek are 0.4 in/yr and 2.7 in/yr, respectively. Similar to sediment deposition volume, the shoaling rate estimate for Nyhan Creek included 220 cy of sediment removed in 2015. The shoaling rate for Nyhan Creek would be 2.2 in/yr if excluding the 2015 sediment removal volume. The combined shoaling rate for both creeks is 0.5 in/yr. As a comparison, the shoaling rate reported in HDR 2016a is 0.8 in/yr.

<b>Table 2 - Sediment Deposition Estimates (2013 – 2017)</b>							
	Coyote Creek			Nyhan Creek			
	Scour Volume	Deposition Volume	Net Volume	Scour Volume	Removed Volume	Deposition Volume	Net Volume
2013 - 2017	-2390 cy	2170 cy	-220 cy	260 cy	220 cy	1070 cy	1030 cy
Deposition Volume	2170 cy			1290 cy			
	540 cy/yr			320 cy/yr			
Shoaling Rate	0.4 in/yr			2.7 in/yr			
	0.5 in/yr (weighted average of both creeks)						

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### 5. Sediment Management

As a part of the RIP, the USACE requires the County to maintain the project to its original design specification, which is to convey the 5-percent annual exceedance probability (AEP) flow that was the basis of the original design of the channel. As shown in Scenario 1 of the hydraulic analysis, the baseline scenario based on USACE's 5% AEP design flow, Coyote Creek and Nyhan Creek currently do not meet the 1' freeboard criteria at the following three levee and floodwall locations in the earth channel that are a part of the flood protection project:

- Coyote Creek at the Nyhan Creek Confluence, flood wall along left bank, between Stations 39+71 and 42+00. The available freeboard range from 0.78' to 0.99'
- Coyote Creek at Flamingo Road, earth levee along both banks, between Stations 44+00 and 45+50. The available freeboard range from 0.15' to 0.8' along left bank, 0.79' to 0.95' along right bank.
- Nyhan Creek at Marin Avenue, earth levee along left bank, between Stations 4+62 and 4+96. The available freeboard range from 0.09' to 0.87'.

In order to address the freeboard deficiency at these three levee and floodwall locations, we evaluated potential options for improvement by removing deposited sediment along Coyote Creek and Nyhan Creek. Development of the sediment removal concept is based on the following design criteria:

- Provide 1' freeboard along the existing levees and floodwalls in the earth channel that are a part of the flood protection project:
  - Coyote Creek, Left Bank, Stations 25+00 to 76+32
  - Coyote Creek, Right Bank, Stations 42+00 to 76+32
  - Nyhan Creek, Left Bank, Stations 1+46 to 4+96
- To the extent feasible, maintain positive slope along the entire earth channel alignment, including at the outfall to Richardson Bay. It is to ensure the proposed sediment removal concept does not create local sump area in the channel, susceptible to sediment trapping and deposition.
- To the extent feasible, avoid encroachment into existing marsh vegetation along the creeks, to minimize disturbance to the existing habitats.
- At Coyote Creek, maintain 3:1 side slope along the banks of the sediment removal areas, daylighting to the existing channel geometry.
- At Nyhan Creek, maintain at least 2:1 side slope along the banks of the sediment removal areas, daylighting to the existing channel geometry.
- At creek segments where the width of the sediment removal areas is wider than 20', grade a thalweg with 10' bottom width and 5:1 side slope along the thalweg banks.
- Minimize sediment removal volume while maximize water surface elevation reduction.

As a part of the evaluation, the project team tested multiple iterations of prototype sediment removal concepts in the 2017 model in HEC-RAS for its hydraulic performance. The following summarized a

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proposed sediment removal concept that meets the design criteria. Figures 12 and 13 shows the plan view and profile view of the proposed sediment removal concept. The profile view includes levees and floodwalls elevations, HGL, flowlines and freeboards comparisons between the 2017 conditions and the sediment removal concept. A summary table of the hydraulic analysis results is in Appendix A. Appendix B contains the proposed sediment removal concept cross section plots.

At Coyote Creek, the proposed concept set the upstream sediment removal limit at the riprap transition between earth channel and concrete channel, at station 49+22, elevation 2.47'. For the downstream sediment removal limit, the proposed concept hold the existing thalweg elevation at the downstream of the Mill Valley Sausalito Path at the creek outfall to Richardson Bay, at station 10+44, elevation 0.38'. The concept did not lower the flowline elevation at the creek outfall in order to not create a potential local sediment trap.

The creek flowline has 0.005% slope between the Mill Valley Sausalito Path and the Nyhan Creek confluence, in order to lower the confluence flowline elevation to 0.53'. The confluence flowline elevation is needed to provide 1' freeboard at the confluence. Upstream of the confluence, a 0.266% longitudinal slope is set for the flowline profile, to the upstream limit of the earth channel at station 49+22, elevation 2.47'. The following is a list of channel cross section bottom widths at Coyote Creek.

- Stations 49+00 to 42+00: Earth channel upstream limit to Nyhan Creek confluence, the channel bottom width is between 5' to 15'.
- Stations 40+39.5 to 32+50: Nyhan Creek confluence to upstream of Highway 1, the channel bottom width is 15', except at the channel bend between stations 35+70 and 33+50, the channel bottom width is 20' to 25' and a thalweg with 10' bottom width.
- Stations 32+00 to 27+50: At the vicinity of Highway 1 crossing, the channel bottom width is between 25' to 30' and a thalweg with 10' bottom width.
- Stations 27+00 to 23+50: At the downstream of Highway 1 crossing, gradually widen from 35' at station 27+00, to 55' at station 23+50, and a thalweg with 10' bottom width.
- Stations 23+00 to 11+62: At the lower reach between stations 23+00 and the Mill Valley Sausalito Path at station 11+62, the channel bottom width is 50' and a thalweg with 10' bottom width.

As a comparison, the original design cross sections in the Coyote Creek Local Flood Protection Project has 22' bottom width in Coyote Creek at the upstream of the Nyhan Creek confluence, and 30' bottom width in Coyote Creek at the downstream of the Nyhan Creek confluence. To maximize water surface elevation lowering, the sediment removal concept proposed the channel bottom width to be wider than 30' at Coyote Creek between stations 27+00 and 11+62. During the sediment removal design, a geotechnical review should be included to assess if the sediment removal cross sectional width and bank slopes should be adjusted for levee and bank stability.

At Nyhan Creek, the sediment removal limit is bounded by the Coyote Creek confluence and the existing flowline elevation at the upstream of the Enterprise Concourse Road bridge, at station 10+54, elevation 5.37'. The longitudinal slope is 0.525%. The cross section geometries are mostly v-shaped or trapezoidal

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channel with up to 5' of channel bottom width. At the Enterprise Concourse Road Bridge, the creek cross sections have between 5' and 10' of channel bottom width and 3:1 bank slopes.

The proposed sediment removal concept requires approximately 2400 cy of sediment removal, it includes approximately 2050 cy of sediment removal between stations 10+44 to 49+22 at Coyote Creek, and approximately 350 cy of sediment removal between stations 1+46 to 10+54 at Nyhan Creek. The sediment removal concept lower the HGL at the Coyote Creek earth channel, between station 26+00 and the upstream limit, by about 0.30' to 0.34'. The HGL lowering taper down along the downstream reaches of Coyote Creek, from about 0.3' at station 26+00 to just matching the existing HGL at the Mill Valley Sausalito Path. At Nyhan Creek, the proposed sediment removal concept lower the HGL by about 0.3' to 0.4' at the downstream of Marin Avenue, and at the upstream of Enterprise Concourse Bridge. Between Marin Avenue and Enterprise Concourse Bridge, the HGL is lowered by about 0.7'.

At Coyote Creek, the proposed sediment removal concept provides 1.11' to 1.32' of freeboard along the left bank floodwall at the Nyhan Creek confluence, and 1.09' to 1.35' of freeboard along the right bank earthen levee at the Flamingo Road Bridge. However, the proposed sediment removal concept only provides 0.45' to 1.13' of freeboard along the left bank earthen levee at the Flamingo Road Bridge. At Nyhan Creek, the proposed sediment removal concept only provides 0.49' to 1.26' of freeboard along the left bank earthen levee between stations 4+62 and 4+96, at the downstream of Marin Avenue. Therefore, in addition to the proposed sediment removal concept, the following earthen levee segments would need to be raised to provide 1' freeboard:

- Coyote Creek at the upstream of Flamingo Road at stations 44+57 and 45+00. Raise the left bank earth levee by at least 0.55' to provide 1' freeboard.
- Nyhan Creek at the downstream of Marin Avenue at stations 4+62 and 4+96. Raise the left bank earth levee by at least 0.51' to provide 1' freeboard.

Also note that while the proposed sediment removal concept lowered the overall HGL profile at Coyote Creek and Nyhan Creek, the analysis suggested that the channel overtopping estimated in the hydraulic analysis Scenario 1 will persist along the concrete channel at Coyote Creek, and at Marin Avenue and Enterprise Concourse Bridge at Nyhan Creek.

In addition to the proposed sediment removal concept, the analysis also included a sensitivity evaluation to consider the effects of reducing the sediment removal extent at the lower reaches of Coyote Creek. The sensitivity evaluation considered two sediment removal alternatives:

**Alternative 1:** In this alternative, the downstream sediment removal limit at Coyote Creek is moved upstream from the Mill Valley Sausalito Path to station 33+00. As shown in the profile plots in Figure 14, the alternative matches the existing flowline elevation at station 33+00 such that it will not create local sump area along the creek. The analysis results show that Alternative 1 does not meet the freeboard criteria. Therefore, it is not to be considered as a viable sediment removal alternative.

**Alternative 2:** In this alternative, the downstream sediment removal limit at Coyote Creek is moved upstream from the Mill Valley Sausalito Path to station 28+00. As shown in the profile plots in Figure 15, the alternative set the Coyote Creek downstream sediment removal limit at station 28+00, at elevation 0.6'. It results in a much deeper channel than Alternative 1, but it created a local sump area at the

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downstream of Highway 1. Similar to the proposed sediment removal concept, the analysis result shows that Alternative 2 provides over 1' freeboard along the Coyote Creek left bank floodwall at the Nyhan Creek confluence, and the right bank earthen levee at Flamingo Road Bridge. However, it cannot provide 1' freeboard along Coyote Creek left bank earthen levee at Flamingo Road Bridge, nor along Nyhan Creek left bank earthen levee at the downstream of Marin Avenue.

In the context of the Coyote Creek, an ideal sediment removal design should balance conveyance constraints with sustainable operation and maintenance. PWA 2012 evaluated channel sustainability, and estimated the equilibrium channel cross sectional area at about 200 to 220 ft<sup>2</sup>. However, it is only about half of the Coyote Creek Local Flood Protection Project design cross sectional area. Designing the sediment removal channel geometries based on the equilibrium channel cross sectional area could significantly reduce channel capacity. It also means that the original project design and the proposed sediment removal concept will continue to require sediment removals in the future, as it has been experienced since the project was completed in the 1960s. On the other hand, while the sediment removal concept Alternative 2 reduces the sediment removal extent at the downstream reaches of Coyote Creek, the local sump area created in this alternative encourages sediment deposition. Hence Alternative 2 is not a sustainable option.

Considering this analysis identified three areas in the earth channel that do not provide a minimum of 1' freeboard, and two of the locations will require earthen levee improvements to raise the crest elevations, the County should consider the feasibility to raise the existing floodwall along Coyote Creek left bank at the Nyhan Creek confluence, and the existing earthen levee along Coyote Creek right bank at Flamingo Road Bridge. Such improvements plus the other two earthen levee improvement proposed in the analysis could alleviate or at least defer the needs of sediment removal at Coyote Creek.

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### 6. Enterprise Concourse Bridge Improvement

The hydraulic analysis shows that Marin Avenue Bridge and Enterprise Concourse Bridge create significant hydraulic restrictions at Nyhan Creek. The soffit elevation at Enterprise Concourse Bridge is about 8', but the Scenario 1 baseline HGL is over 11'. Bridge improvements by raising the bridge soffit will improve creek flow conveyance by eliminating the hydraulic restrictions. Figure 16 shows the creek HGL assuming the Enterprise Concourse Bridge is raised above the design HGL, and the proposed bridge abutments are setback from the creek corridor, so it does not create flow blockage along the creek. The analysis shows that the improvement will reduce the creek HGL by 0.43' under the Scenario 1 baseline condition. Note that the HGL listed in Table 3 assumes the 2017 creek bed elevations and also assumes Marin Avenue Bridge will be maintained as is. Since Marin Avenue Bridge creates significant hydraulic restriction on Nyhan Creek, raise or remove Marin Avenue Bridge from the creek flow path could reduce Nyhan Creek HGL at Enterprise Concourse Bridge and creek flooding in general.

Scenario	Description	HGL at Enterprise CC	HGL Reduction
1	Baseline	11.08'	0.43'
2	4% AEP	9.85'	0.90'
3	2% AEP	10.23'	0.74'
4	1% AEP	10.55'	0.61'
5	1% AEP+SLR	11.80'	0.16'

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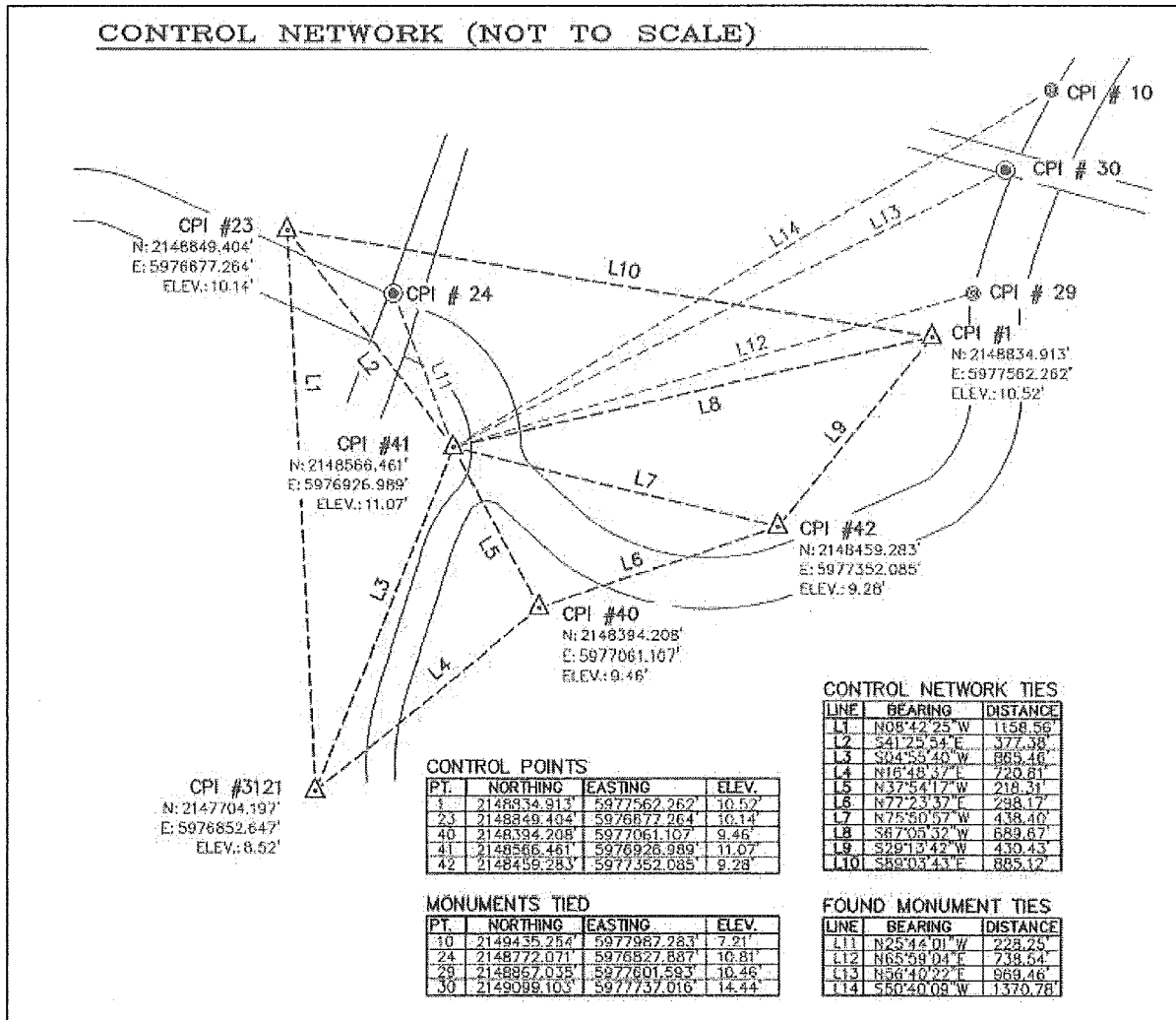


Figure 1: Survey controls and monuments at the study site