Sausalito Willow Creek Daylighting – Phase 1A
Basis of Design Report - PRELIMINARY

Prepared For:
Friends of Willow Creek

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1 INTRODUCTION

Willow Creek is a perennial creek that passes through the northern part of the City of Sausalito, CA. Since the early 1900s, development in the city has encroached on the riparian corridor, and today almost the entire length of the channel from Hwy 101 to Richardson Bay has been filled in. The creek is currently contained in a stormdrain that passes underneath Hwy 101, through the center of a K-8 public school campus known as Willow Creek Academy, and under City-owned residential and commercial buildings where it empties into Richardson Bay (Figure 1).

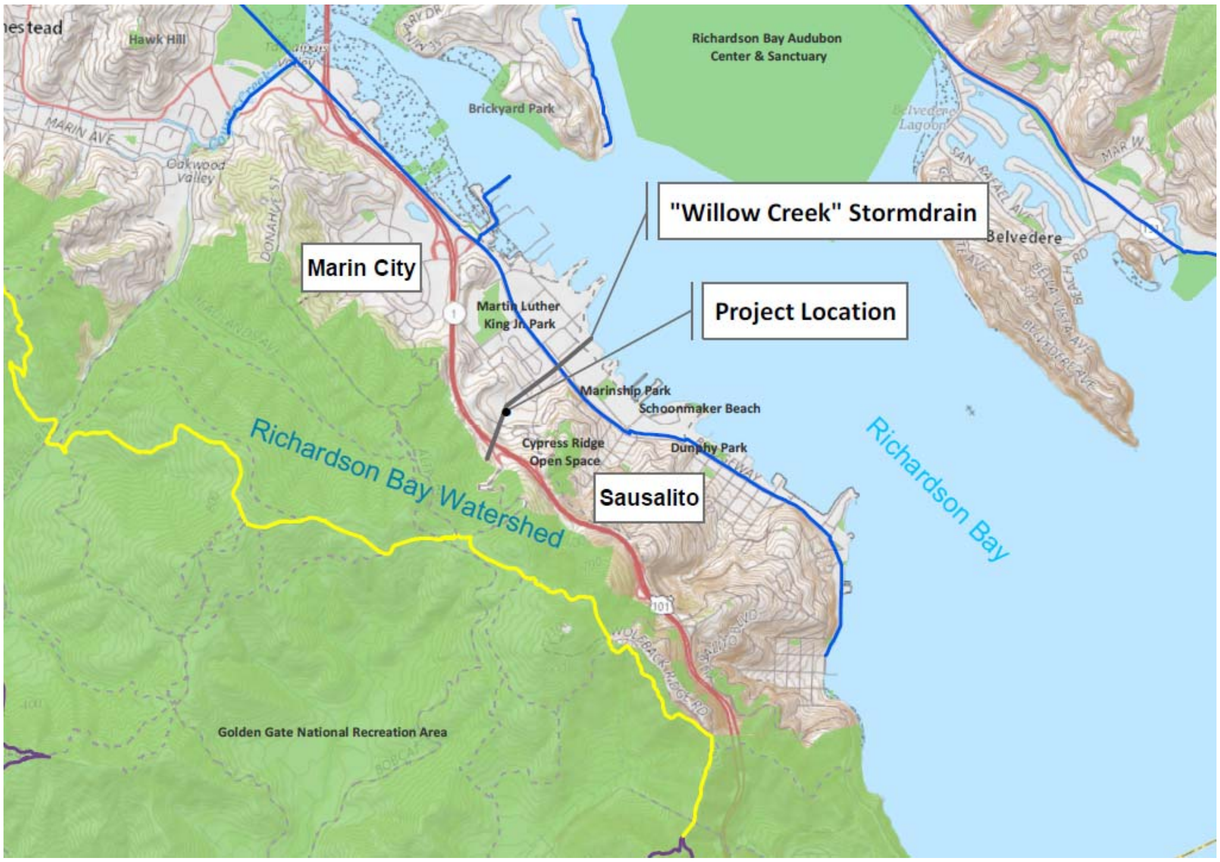


Figure 1. Regional map of project site.

A local non-profit organization known as “Friends of Willow Creek” (Friends) has established a vision of daylighting the entire length of the creek, from its headwaters to the bay, and has undertaken the formidable challenge of procuring funding for the effort. To help accomplish this ambitious vision, a phased approach has been selected whereby the overall project will be divided into smaller reaches of daylighted channel, with additional phases being implemented as funding becomes available (Figure 2).

Figure 2. Willow Creek Daylighting Project overall phase map.

In 2017, Friends received a private grant to begin planning and design for the daylighting of Phase 1A. Prunuske Chatham, Inc. was retained to design and prepare preliminary construction documents. This report describes the existing project site, presents the proposed design, and documents the engineering analyses to support the design.

2 EXISTING SITE CONDITIONS

The upstream end of Phase 1A begins at an existing fire road that provides access around the back side of the Willow Creek Academy Nevada Street campus (Figure 3). The fire road has a drop inlet that is the connection point for the upstream extent of the Phase 1A reach. Downstream of the fire road is a eucalyptus grove with tree diameters ranging from approximately 8 inches to 5 feet (Figure 4). The existing stormdrain passes directly through this eucalyptus grove. The proposed design will involve removing the eucalyptus trees and reestablishing native plant species through the project reach. The eastern edge of the eucalyptus grove is bordered by a paved staff parking lot, with a path and stairs leading down to the school buildings. In the eucalyptus grove, just downstream of the fire road, is a concrete water tank and associated pumping infrastructure (Figure 5). This water tank is not currently utilized by the Academy; however, preserving and restoring its function is a desirable element of the proposed design.

Downstream of the eucalyptus grove is grassy area with a paved path that provides access from the main campus to the staff parking lot and a school classroom (Figure 6). The proposed daylighted channel would pass through this grassy area and between these buildings. Access to the classroom would be maintained with a pedestrian bridge. The downstream connection point for Phase 1A is located at a covered walkway next to a paved patio area (Figure 7). The proposed design would conform back to the stormdrain system at this location. The total straight line length of the Phase 1A reach is approximately 270 feet, with an overall slope of 5.8%.

Figure 3. Photo looking downstream at existing fire road near the upstream extent of Phase 1A. Note staff parking lot on right side of photo.

Figure 4. Photo looking upstream from the classroom at the eucalyptus grove.

Figure 5. Existing water tank infrastructure in eucalyptus grove.

Figure 6. Photo looking downstream at path between school buildings.

Figure 7. Photo looking downstream at downstream extent of Phase 1A.

3 PROPOSED PROJECT DESIGN

The proposed channel design for Phase 1A will daylight and create 340 feet of new meandering stream channel with cascades, riffles and pools and a recreated riparian corridor with a diverse native plant palate; create multiple new gathering areas for outdoor education; provide an amphitheater for an outdoor classroom; connect the features with a new accessible trail system along the creek with a pedestrian bridge to the adjacent classroom; and provide new treatment and retention for existing stormwater runoff (Figure 8).

Figure 8. Phase 1A proposed design

3.1 Channel Geometry

The proposed channel alignment, profile, and cross-sectional geometry were designed to mimic natural stream conditions to the extent possible while protecting existing critical infrastructure at the site. This means that the new channel is designed to remain grade and laterally stable through the school grounds while providing for as much natural function as feasible in an urban environment. A sinuous plan view alignment was selected to add stream length and reduce the overall channel profile slope. The ultimate vision for this reach of the project is to facilitate human interaction with the stream channel by creating natural spaces where kids and adults can safely interact with the riparian corridor. To promote this vision, the overall depth of the channel was minimized to allow easier access to the creek bed as well as to reduce the footprint of the project and the necessity for extensive retaining walls. This goal was balanced with the requirement for the channel to convey the 100-year design storm with adequate freeboard. Ultimately, a design profile for the new channel was selected to roughly match the existing valley slope and led to three different channel types with varying average slopes: Riffle Pool, Cascade, and Boulder Chute (Figure 9).

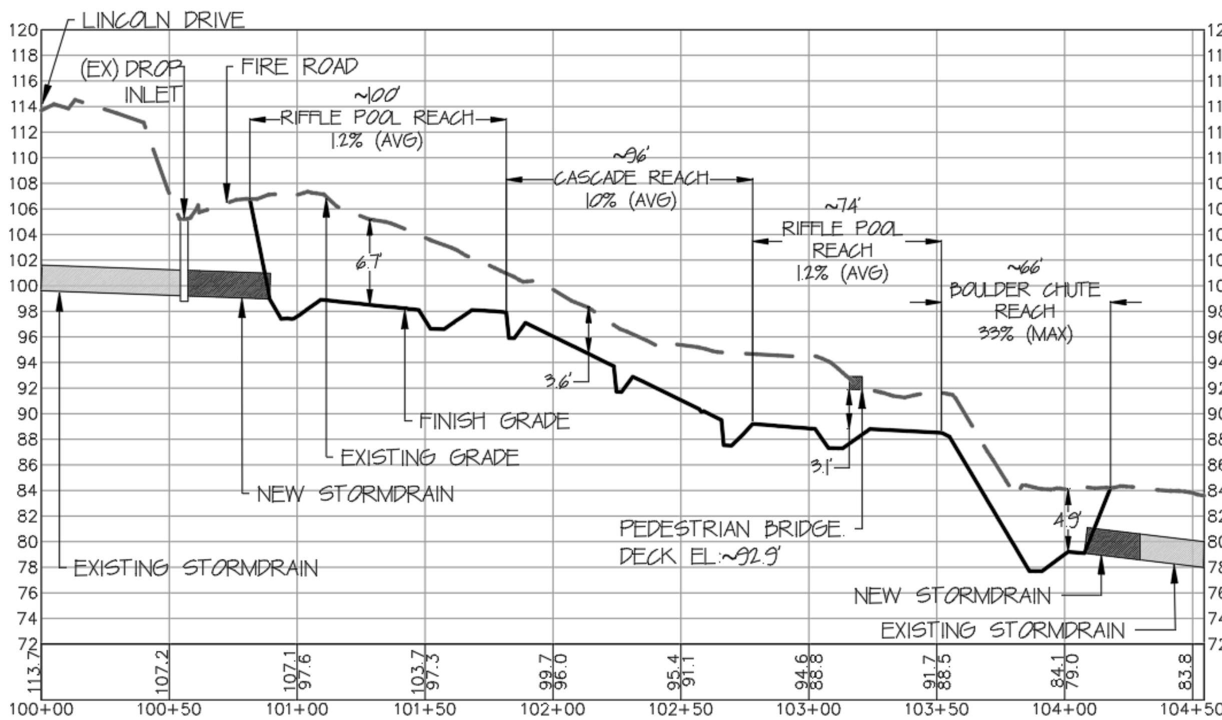


Figure 9. Existing ground and proposed channel profile (Note: 5x vertical exaggeration).

One consideration in developing both the active channel geometry and the design of the channel bed is the presence of what is effectively a detention basin upstream where the channel passes under Hwy 101. At this location, water flows into a 2' diameter stormdrain that outlets just upstream of Phase 1A near Lincoln Drive. During high flow events, this culvert inlet creates a restriction that limits the total rate of flow downstream. The excess flow volume creates a surcharge at the culvert inlet, effectively reducing the total peak and extending the duration of a given stormflow hydrograph downstream. The implication is that as long as the culvert under Hwy 101 remains, peak flows in the downstream channel will be reduced and sediment transport may be affected. Because Friends' ultimate goal is to daylight the entire watershed, the channel geometry and bed were designed assuming no detention upstream.

The reduction in peak flows is likely beneficial for the daylighting project in terms of flood risk, but the floodplains may become inundated less frequently than under normal conditions. PCI strongly recommends against daylighting the portion of channel under Hwy 101 before all other phases have been daylighted, to prevent increasing the risk of flooding where the daylighted channel returns back to the stormdrain system (see Section 4.3 for hydraulic analysis). The current phased approach is in accord with this recommendation.

The cross-sectional geometry of the different channel reaches was determined using regional curve data, as well as measurements from a reference reach approximately 1,000 feet downstream near Bridgeway Street. Open channel flow hydraulics were then used to verify that the proposed channel design has adequate capacity to convey the 100-year design storm with at least 12" of freeboard with an unimpaired upstream condition (no detention).

Regional curve data have been developed for the San Francisco Bay Area to provide a relationship between drainage area and bankfull channel geometry (width, depth, XS area) (Leopold, 1994). Approximating the correct bankfull channel geometry is extremely important in natural channel design, as the bankfull flow (also known as the channel forming flow) does the most work overall in transporting sediment. If the bankfull width is too wide, aggradation can occur; too narrow and incision may occur. The San Francisco Bay Area Bankfull Discharge regional curve was used to determine a bankfull width and depth of 9 feet and 1 foot, respectively. Site measurements in the downstream reference reach match the regional curve data very closely (Figure 10).

Figure 10. Photograph of reference reach (looking downstream).

The two Riffle Pool reaches have a low profile gradient with approximately 20-foot-long pools near the apex of the channel meanders. The thalweg is pushed to the outside bend through these pools to create a slightly steeper outside bank and a more gentle point bar slope along the inside of the bend (Figure 11). Several large wood habitat structures will be installed in the pools to provide cover for riparian species, as well as to help maintain pool depth. These large wood structures will be anchored to boulders and are designed to remain stable. The upstream and downstream floodplains are 18 feet and 10 feet wide, respectively, and slope towards the channel at a 2% grade. The channel bed is a 1-foot-thick, partially stabilized mix of river run gravel and cobble, with larger key boulders scattered throughout to provide hard points and bed diversity. The bed structure through these reaches is expected to adjust somewhat over time as the pools develop a natural equilibrium, but the upstream and downstream limits of each reach have sub-surface rock sills to prevent larger critical erosion that could threaten overall site stability.

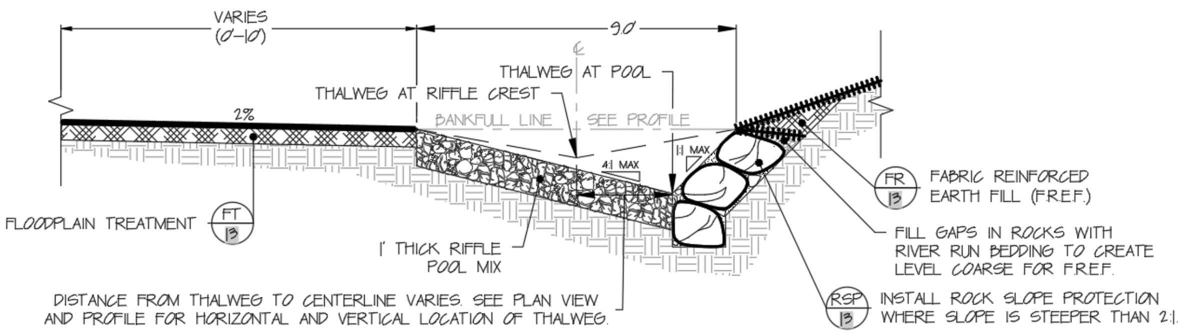


Figure 11. Typical Riffle Pool channel cross section

The Cascade and Boulder Chute reaches have much steeper profile gradients and will have an engineered streambed with material sizes ranging from sand up through 2-ton boulders. These reaches are designed to remain stable with little adjustment through the 100-year design storm. The rock cascade reach has two 1.2'-deep x 7'-long pools and a larger 1.7'-deep x 12'-long pool for energy dissipation. The upstream end of each pool is formed with a rock weir that creates a 3"-9" plunge into the pool. A fabric reinforced earth fill (FREF) will cover the edges of the rock along these two reaches to minimize the extent of exposed rock and to allow vegetation to become established along the channel margins. The Cascade reach has a bankfull width and depth of 8' and 1', respectively (Figure 12). The Boulder Chute reach has a slightly deeper and wider rocked channel with a 9' bankfull width meant to prevent erosion from high flows through this very steep reach (Figure 13).

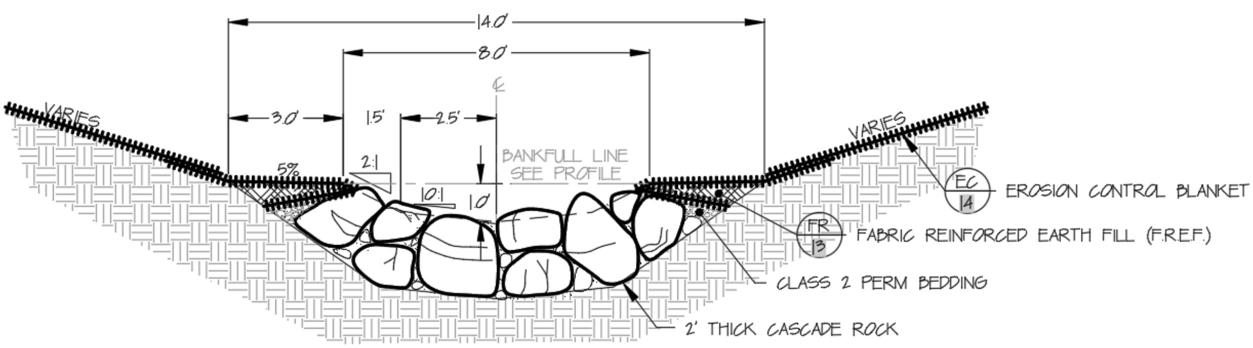


Figure 12. Typical Cascade channel cross section

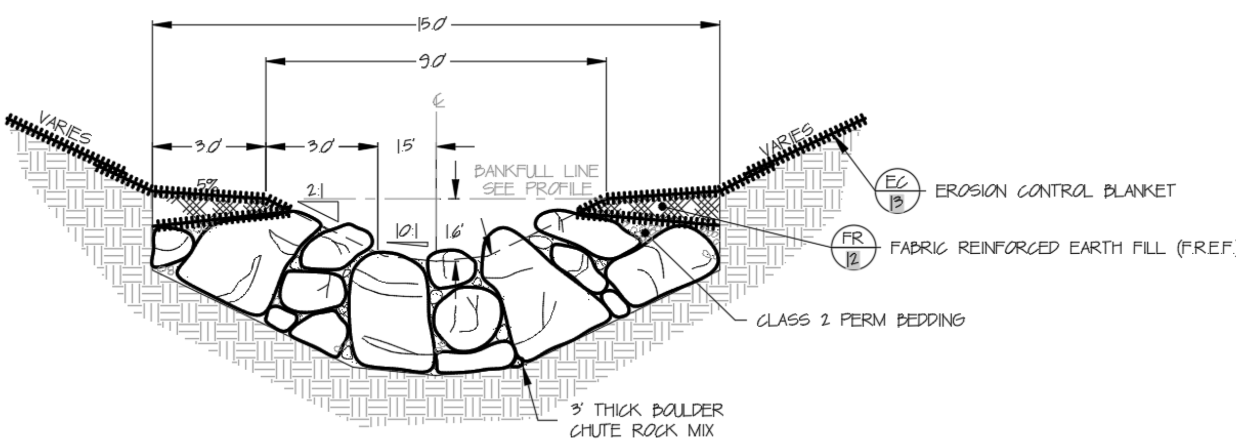


Figure 13. Typical Boulder Chute channel cross section

At the upstream end of the project, a ~30-foot section of new 24" reinforced concrete pipe will be installed from the existing drop inlet at the fire road. The outlet of this culvert was shifted to the west from the existing stormdrain alignment to avoid impacts to the existing water tank. 1:1 (horizontal:vertical) rock slope protection and an energy dissipation pool will be installed at the upstream conform to protect the channel bed and banks at the outlet of the culvert.

The downstream end of the proposed design was pushed far enough away from the administration building to meet the required horizontal confinement off the building's foundation. Consideration was also taken to allow this downstream termination of Phase 1A to be the beginning of a new meander that would lead into the upstream end of Phase 1B if funding becomes available.

3.2 Site Access, Outdoor Spaces, Landscape & Stormwater Features

Access to the main school buildings will be maintained with accessible routes connecting all of the existing pathways that the project crosses. A meandering path will maintain access from the main campus to the trail system, with a set of shortcut stairs that lead directly to the base of the existing parking lot steps. A new accessible creek trail will parallel the creek along the right bank (looking downstream) and provide access to an outdoor classroom and amphitheater with seating capacity for approximately 60 students. This creek trail ultimately leads to the floodplain/wildflower meadow in the upper riffle pool reach with easy access to the water's edge (Figure 14).

Figure 14. Accessible routes through the Project.

A new 6' x 33' pedestrian bridge will be installed over the creek to connect the school garden and adjacent classroom to the main campus. On the west end of this bridge, there will be a creek overlook area with a retaining wall/stormwater planter bed and seat-wall down to the floodplain below. This stormwater planter bed will provide detention and filtration for runoff from the new creek overlook area. Access steps will lead from this overlook area down to a gravel bar, streamside activity area just upstream of the bridge.

A fence will be installed near the top-of-bank from the pedestrian bridge to the downstream conform to limit access to this steep portion of creek and to keep any schoolyard balls from entering the creek. A safety grate will be installed at the culvert inlet at the downstream end of the project to further keep any animals, or floating debris from entering the stormdrain system.

Two new stormwater treatment basins will be installed on either side of the creek to provide treatment for surrounding runoff. On the east side of the creek a biofiltration basin/swale will be installed to collect existing runoff from the staff parking lot. This basin will provide natural filtration and treatment for hydrocarbons and other contaminants coming off the parking lot, as well as allow for groundwater recharge through infiltration and peak flow reduction through retention. The total retention volume of this basin is approximately 1,100 gallons. The basin will be planted with wetland vegetation and will be surrounded by a butterfly garden and a secondary trail connection to the amphitheater. On the west side of the creek, a raingarden/retention basin will capture hillslope runoff that is currently intercepted in a concrete lined V-ditch. This basin will hold approximately 2,500 gallons before overflowing through a rock-lined swale into the creek. All stormwater treatment on site will be designed to drain within 72 hours to prevent cultivation of mosquitos.

In addition to the raingarden/retention basin on the west side of the creek, roof drainage from the classroom building will be collected in a rainwater catchment tank located in the school garden area. This water can then be used to water the school garden throughout the year. Overflow from this tank will flow into the adjacent raingarden/retention basin as a secondary capture system.

4 ENGINEERING DESIGN

Hydrologic and hydraulic analyses were conducted to assist with the design of the proposed channel and stormwater treatment basins and to ensure that the proposed project does not create flooding conditions at the site. This section documents the engineering analyses used to guide the proposed design.

4.1 Stream Channel Hydrology

Peak runoff hydrology was determined using the small watershed hydrology program WinTR-55, which is a single-event, rainfall-runoff hydrologic model developed by the Natural Resources Conservation Service (NRCS) as a simplified procedure for calculating storm runoff volume, peak rate of discharge, and storage volumes for storm water management structures. The program generates hydrographs from both urban and agricultural areas based on watershed area, hydrologic soil group, and SCS curve number for each drainage element (NRCS, 2014). Precipitation depth data were taken from NOAA's National Weather Service precipitation frequency estimates for Sausalito (Latitude: 37.8630; Longitude: -122.5030) (NOAA Atlas 14 Point Precipitation Frequency Estimates, 2015) (Table 1).

Table 1. 24-Hour Precipitation depth-frequency estimates for the project site.

Period	Depth (in)
1-yr	2.55
2-yr	3.25
5-yr	4.2
10-yr	5
25-yr	6.13
50-yr	7.03
100-yr	7.98

Marin County is mapped as being in the lower extent of the Type 1A rainfall distribution (Figure 15). The Type 1A rainfall distribution is the least intense of the four synthetic 24-hour rainfall distributions.

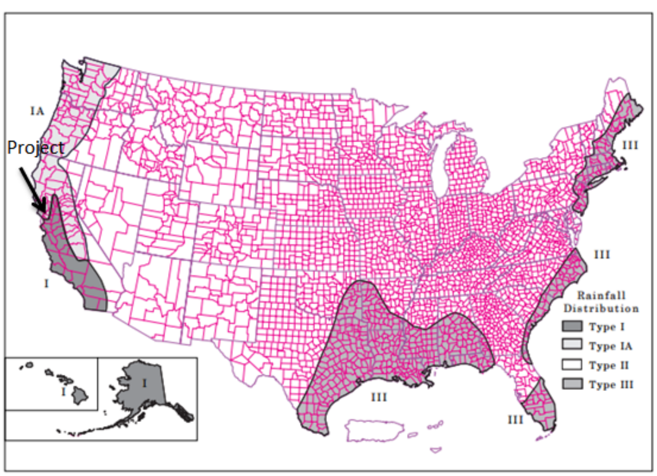


Figure 15. Synthetic rainfall distribution map for the United States (NRCS, 2014).

Using LiDAR-generated contours, the watershed area for the culvert was determined to be 105 acres (Figure 16).

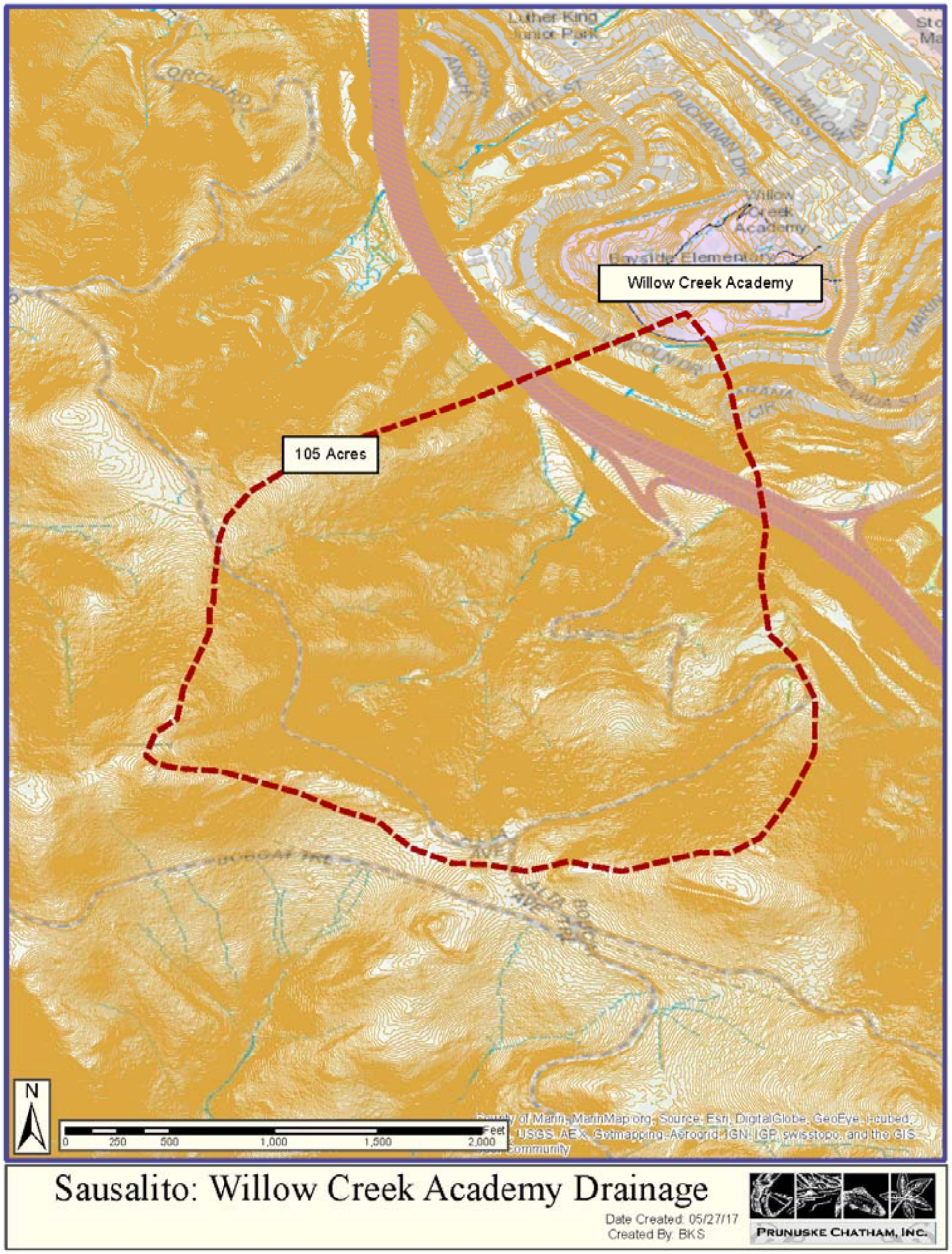


Figure 16. Watershed map for the Project

Hillslope areas were assumed to be woods in good condition with an SCS curve number of 70. Underlying soil for the project site is classified as hydrologic soil group C (NRCS, 2013). A half-acre portion was listed as developed urban and classified as hydrologic soil group D (NRCS, 2013). Hydrology results were generated for the culvert for return periods ranging from the annual peak storm (1-year R.I.) to the 100-year design storm (Table 2).

Table 2. Peak flow hydrology results from TR-55 analysis.

Period	Flow (cfs)
1-yr	10
2-yr	21
5-yr	40
10-yr	57
25-yr	83
50-yr	105
100-yr	128

USGS Regional Regression Equations were then used for comparison against the results generated by TR-55. Regional regression equations were developed for six regions in California by the USGS to predict the 2, 5, 10, 25 and 100-yr return period flows (Wannanan A. O. & Crippen J.R., 1977). The equations relate flood magnitudes of selected frequency to basin characteristics such as drainage area, precipitation, and altitude. They were developed for streams that have natural flow, or flow not substantially affected by storage. Sausalito is located in the North Coast Region. A mean annual precipitation depth of 36 inches was obtained from the Parameter-elevation Regressions on Independent Slopes Model (PRISM, 2007) and a mean basin elevation of less than 1,000 feet was obtained from USGS topographic maps. Results from the analysis show significantly lower peak flow values from the regression equations (Table 3). Because of the potentially significant risk to property and safety if flooding were to occur at the site, the more conservative values obtained from the TR-55 model were used to design the stream channel.

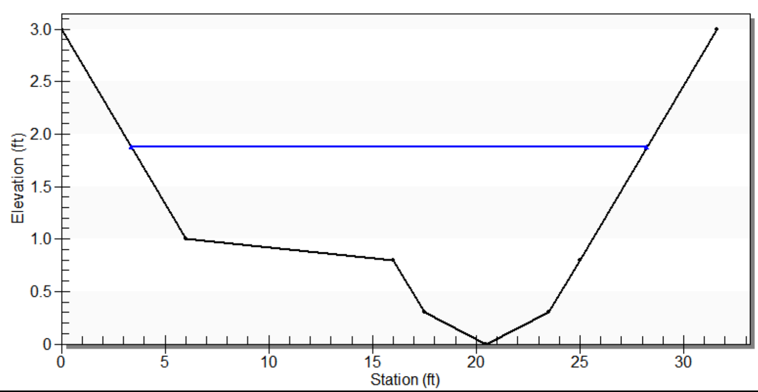
Table 3. Peak flow hydrology results from USGS Regional Regression Equations.

Period	Flow (cfs)
1-yr	-
2-yr	17
5-yr	26
10-yr	35
25-yr	46
50-yr	55
100-yr	62

4.2 Stream Channel Hydraulics

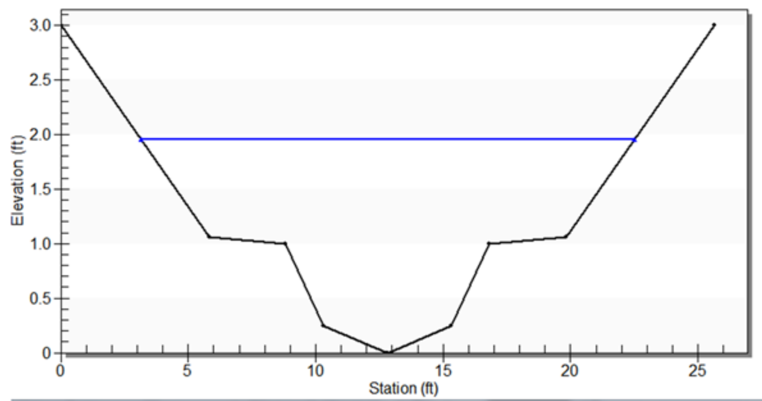
Open channel flow hydraulics were determined for each reach using the 1-dimensional, single-section hydraulic analyzer, Hydraulic Toolbox (FHWA, 2014). This program uses Manning's equation to estimate depth, velocity, and other hydraulic variables at a single cross section. The 100-yr design flow of 128 cubic feet per second (cfs) was used for all sections. Results show water depths of less than 2 feet through all reaches during the 100-yr design storm event (Figure 17).

Riffle Pool Reach



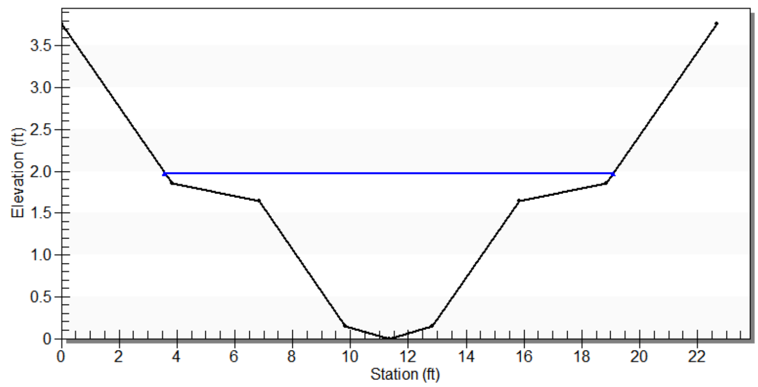
Flow	128	cfs
Depth	1.876	ft
Area of Flow	26.993	sq ft
Wetted Perimeter	25.37	ft
Hydraulic Radius	1.064	ft
Average Velocity	4.742	fps
Top Width (T)	24.859	ft
Froude Number	0.802	
Max Shear Stress	1.756	lb/ft^2
Avg Shear Stress	0.996	lb/ft^2
Manning's Roughness	0.04	

Cascade Reach (next page)



Flow	128	cfs
Depth	1.954	ft
Area of Flow	21.07	sq ft
Wetted Perimeter	20.033	ft
Hydraulic Radius	1.052	ft
Average Velocity	6.075	fps
Top Width (T)	19.363	ft
Froude Number	1.026	
Max Shear Stress	12.192	lb/ft^2
Avg Shear Stress	6.563	lb/ft^2
Manning's Roughness	0.08	

Boulder Chute Reach



Flow	128	cfs
Depth	1.977	ft
Area of Flow	13.562	sq ft
Wetted Perimeter	16.305	ft
Hydraulic Radius	0.832	ft
Average Velocity	9.438	fps
Top Width (T)	15.508	ft
Froude Number	1.779	
Max Shear Stress	40.711	lb/ft^2
Avg Shear Stress	17.129	lb/ft^2
Manning's Roughness	0.08	

Figure 17. Open channel hydraulic results for the different channel reaches.

A compilation of the hydraulic results indicates that the project has a minimum of 12" of freeboard from the 100-year water surface elevation to the top-of-bank and that the pedestrian bridge also has a minimum of 12" of freeboard (Figure 18).

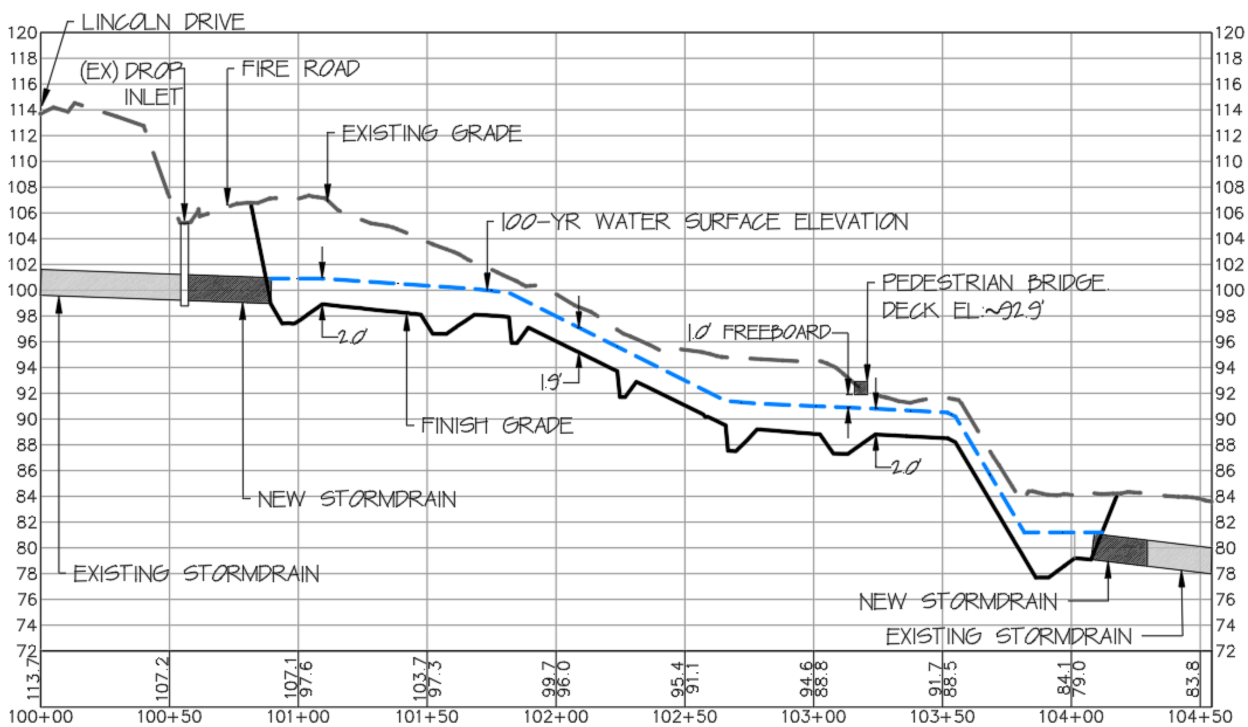
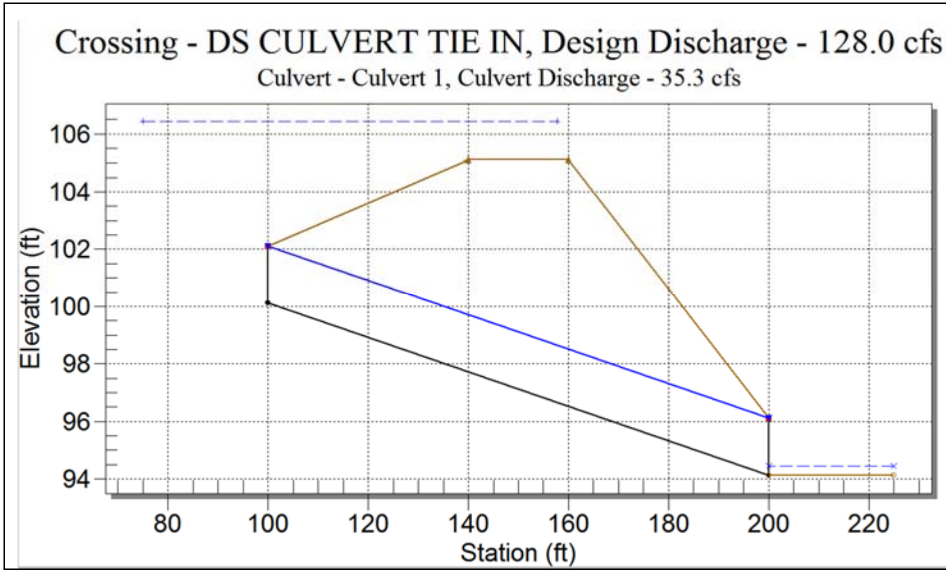


Figure 18. Predicted water surface through the project site during the 100-yr storm event.

4.3 Culvert Hydraulic Analysis

The Federal Highway Administration culvert analysis program, HY-8, was used to predict the water depth at the inlet of the stormdrain at the downstream project conform (FHWA, HY-8 Culvert Hydraulic Analysis Ver 7.5). Results from this analysis indicate that the existing stormdrain that the daylighting project would tie into is undersized to convey the 100-yr storm event (128 cfs). The culvert has capacity for approximately 15 cfs before first becoming surcharged and overflow of the stream bank adjacent to the culvert would occur at approximately 30 cfs (Figure 19).



Total Flow (cfs)	Culvert Flow (cfs)	Inlet Depth (ft)	Headwater Elevation (ft)
20	20	2.88	102.88
30.8	30.53	5.02	105.02
41.6	31.62	5.3	105.3
52.4	32.31	5.48	105.48
63.2	32.88	5.63	105.63
74	33.38	5.76	105.76
84.8	33.84	5.89	105.89
95.6	34.27	6.01	106.01
106.4	34.64	6.12	106.12
117.2	35	6.22	106.22
128	35.34	6.33	106.33

Figure 19. Culvert hydraulic results for the downstream conform during the 100-yr design storm event.

Though these hydraulic results appear unfavorable for the daylighting design, the reality is that there is an existing daylighted portion of channel upstream of Phase 1A between Lincoln Drive and Hwy 101 that also conforms back into a 2’ diameter culvert; and to PCI’s knowledge, this culvert has not flooded due to a lack of capacity. This is indication that either the hydrology estimation used is overly conservative (too high) as the Regional Curves indicate, or that the 2’ diameter culvert crossing under Hwy 101 provides enough detention to attenuate the peak flows and prevent flooding. As discussed earlier, the channel design for Phase 1A assumes a fully daylighted creek upstream with no detention.

PCI recommends conducting a future detention analysis to study the relationship between the inflow and outflow hydrographs for the Hwy 101 crossing in the next phase of design. If the results from that analysis indicate that the crossing does not provide enough peak flow attenuation, other engineering controls can be installed to prevent flooding. These include modifications to the downstream stormdrain system, raising the embankment at the Phase 1A downstream conform, or reducing the size of the pipe inlet at the Hwy 101 crossing to create more detention and further restrict flows into the project site and downstream stormdrain.

4.4 Channel rock sizing

Because the project is located in a well-developed urban area, the channel bed and banks were designed to remain stable. The channel bed was designed using Engineered Streambed Material (ESM) based on methods outlined in the California Stream Habitat Restoration Manual (CDFW, 2009). ESM is a well-graded mixture (diversified particle sizes) of material with large framework rock designed to remain stable up to the 100-yr storm with interstices full of smaller material to ensure surface water remains through the reach. The bed thickness through each reach was selected to be a minimum of the D84 (84[th] percentile size class) of the ESM (Table 4). See Attachment A for ESM calculations.

Table 4. Engineered Streambed Material design for all project reaches.

	Riffle Pool (ft)	Cascade (ft)	Boulder Chute (ft)
D8-ESM =	0.0062	0.0069	0.0071
D16-ESM =	0.024	0.041	0.053
D50-ESM =	0.23	0.75	1.5
D84-ESM =	0.58	1.9	3.0*
D100-ESM =	1.45	3.0*	4.0*

*-Note: values with asterisks have been adjusted to be appropriate for channel dimensions

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Attachment A – Engineered Streambed Material Design

Willow Creek Daylighting Phase 1A
Engineered Streambed Material Design

Calcs By: LW
Date: 7/12/18

Parameters	Riffle Pool	Cascade	Boulder Chute	Input	Calculated
Design Flow (100-yr):	128	128	128	cfs	Note: This is only the portion of flow in the active channel.
Active Channel Width:	9	9	9	ft	Overbank flow should be subtracted from the total flow. See p. XII-68 of Restoration Manual.
hydraulic slope (S):	0.012	0.1	0.33	ft/ft	overall slope of roughened riffle, not individual riffle slopes

Unit Discharge in Chute

q = Qdesign/Wactive	14.2	14.2	14.2	ft3/sec/ft

ESM Gradation

$$D_{30-riprap} = \frac{1.95S^{0.555}1.25q^{2/3}}{g^{1/3}}$$

ACOE (2004) - initial estimate for a riprap channel at the stable bed design flow

$D_{30\text{-riprap}}$=	0.39	1.25	2.43	ft

$D_{84-ESM} = 1.5D_{30-Riprap}$ $\quad D_{50-ESM} = 0.4D_{84-ESM}$ $\quad D_{100-ESM} = 2.5D_{84-ESM}$ CDFG (2009)

$D_{84\text{-ESM}}$ =	0.58	1.88	3.65	ft
$D_{50\text{-ESM}}$ =	0.23	0.75	1.46	ft
$D_{100\text{-ESM}}$ =	1.45	4.70	9.12	ft

Interstitial Voids

$D_{8-ESM} = 0.16^{1/n}D_{50-ESM}$ $\quad D_{16-ESM} = 0.32^{1/n}D_{50-ESM}$ modified form of the Fuller-Thompson equation.

n =	0.51	0.39	0.34	not Manning's roughness. Adjust n until D8 is roughly 2mm (0.0066 ft) (coarse sand).	
$D_{8\text{-ESM}}$ =	0.0062	0.0069	0.0071	ft	This is to ensure that between 5-10% of the ESM consists of sands and silts.
$D16_{\text{-ESM}}$ =	0.024	0.0406	0.0533	ft	

	Riffle Pool (ft)	Cascade (ft)	Boulder Chute (ft)
D8-ESM =	0.0062	0.0069	0.0071
D16-ESM =	0.024	0.041	0.053
D50-ESM =	0.23	0.75	1.5
D84-ESM =	0.58	1.9	3.0*
D100-ESM =	1.45	3.0*	4.0*

*-Note: values with asterisks have been adjusted to be appropriate for channel dimensions

Bed Thickness (ft)	
Riffle Pool Mix	1
Cascade	2
Boulder Chute	3