STREAM RESTORATION BASIS OF DESIGN

For Calder Creek in Sebastopol, CA

Waterways Restoration Institute

WILDLING DESIGN STUDIO

Basis of Design for Calder Creek Restoration

I. Introduction

Calder Creek historically was the site of a widely celebrated water wheel feature, documented on old post cards which the Sonoma County Historical Society has in its records. Ives Park contained a wood slate dam that allowed the development and operation of a popular swimming hole in the central park. Today's park users have told us of parents who have memories of enjoying this swimming hole. Calder Creek was channelized (straightened) in the 1960s and lined in concrete made to look like stone. The channel was designed as a high velocity flood control channel, became viewed as a safety hazard, and was subsequently fenced off from the park.

That spurred some in the community to advocate "hiding" part of the creek. The 2013 Master Plan for Ives Park proposed covering a portion of the stream channel. BKF, an engineering firm, noted that the City would need to install new 53" x 84" culvert to contain the flood flows to make that work, which would be a substantial cost.

Nationally as well as locally since that time, a dramatic evolution has occurred in public awareness of the benefits of naturally functioning creeks for aesthetics, recreation and tourism potential. Likewise engineering practice has changed dramatically, instructed by the repeat experience that channelized streams are not safe because of high velocities and entrapping children in spaces they can't easily escape. Concrete lining and sacrete failures are now common performance legacies.

The project design for Calder Creek embraces a new design method that is now well described in modern day engineering manuals, guidance and reports published by federal agencies. The lesson overtime has been that trying to control streams in concrete channels has led to unexpected flood hazards and channel unraveling. The new methodology creates more predictable "stable "channels by paying attention to providing stable channel widths and depths and planform lengths. Our concept of "stable " is that the channels will not excessively deposit sediment or excessively erode. This means the high maintenance needs and costs of the older engineering model are avoided, such as continual channel repairs and sediment removal for channel capacity.

The design steps used in this Calder Creek naturalization first employ learning as much as possible from existing reaches of creek in reasonably stable (or equilibrium condition) to get an initial understanding of the channel shapes and planforms that should inform the restoration design. This involved locating upstream reference reaches of Calder Creek and surveying cross-sections and profiles. This information is combined with regional information collected on correlations with existing watershed drainage areas and stable channel shapes. Some of the best information that can inform design are historic records. The Sonoma County Historical Society tried its best to help find pre-flood control photos and maps but little information has so far been available. A newspaper record does record sighting of salmon in Calder Creek in the late 1800s (Sonoma County West Times and News, 1886). The city also provided an old photo and map of a portion of Ives park.

This information is then combined with what is referred to as the river science field of "hydraulic geometry." This science was able to correlate natural channel widths with the shapes of meanders. Another benefit of this new science has been the development of what are called "regional restoration curves" in which measured watershed areas (measured in square miles) can inform how wide and deep the stream channel should be.

The stream channel WRI designs for is referred to as the "active' or "bankfull channel". This is the channel which over a period of time carries the most sediment and is typically associated with the 1.5 to 2-year flood. By designing this channel correctly, we can avoid excessive erosion and deposition, lower maintenance, and also return the functions of a living stream and provide for habitat.

The hydrology contained in this report uses existing rational method calculations performed by BKF Engineering, with the calculations dating back to 2005. This report supplements this information with US Geological Survey multiple regression equations which have been developed for this region to estimate the different magnitude floods and how often they occur on average. Regional data collected from North Coast streams that equate the 2 and 5 year flood with bankfull discharges was also used.

Finally, vegetation is becoming a central tool in stabilizing the planform of a creek, creating shade and habitat for the native amphibians, reptiles, birds and fish. Shear stress tables published by the US Army Corps of Engineers that indicate the effectiveness of soil bioengineering systems to hold streambanks has been applied to this design. Soil bioengineering manuals and books began being published in the 1980s and the use of these bundled plant materials has become a mainstream method of erosion control and habitat creation.

I.1. Project Design Objectives

The overarching project goal is to naturalize Calder Creek through Ives Park, to develop a vision for daylighting Calder Creek through downtown Sebastopol, and to address backwatering and flooding at Petaluma Ave, as well as the constriction of flows within the Joe Rodota Trail.

Existing flooding in downtown Sebastopol is indicative of future flood risks under climate change, and a driver for increasing upstream flood storage when the Russian River backs up. This underscores the importance of the related project goal: to align with the State's water resources and climate change resiliency policies, by leveraging the passive benefits of natural stream functions and processes, including increased flood storage, groundwater recharge, evapotranspiration-derived urban cooling. By enhancing the groundwater table, vegetation moisture is retained, dampening likelihood of ignition and thereby reducing the likelihood of wildlfire. These outcomes of restoring streams help to prepare Sebastopol for an uncertain climate future.

As scientists with the Russian River Salmon and Steelhead Monitoring Program and Redwood Chapter of Trout Unlimited are now pit-tag monitoring the migration of hatchery Coho salmon through the Santa Rosa Laguna, the potential for return of salmonids to Calder Creek is now being considered.

Criteria that serve as project objectives include developing a design that:

- is lower maintenance;

- updates the 2013 Ives Park Master Plan concept to fully incorporate the stream into the proposed suite of park uses, creating a more aesthetic park experience that serves park users;
- reconnects Calder Creek to its floodplain, increases flood storage and promotes groundwater recharge;
- provides suitable fisheries habitat that would encourage fish migration if downstream conditions are also restored to provide access;
- addresses a public safety issue at the intersection of Jewell Ave and Willow St.

The restoration design for Calder Creek references existing estimates for stormwater runoff, local flood management standards, reference creeks, and geomorphic relationships. The information presents design criteria for channel geometry (shapes) and function, however it is also expected that the channel will adjust and evolve, especially as upstream and downstream conditions or other inputs change.

The recommended parameters are provided to establish a dynamically stable stream: a natural stream with earthen bed and banks, that erodes and deposits sediment in a balanced way to maintain its channel form. Because of the role that stream length and geometry plays in maintaining this stability, these parameters may require adjustment in restoration reaches where the ideal stream length, radius of curvature, or other criteria can not be attained. This is expected in the proposed downtown daylighting reaches.

This Basis of Design approaches the design of a better functioning creek channel at the Joe Rodota Trail. By proposing that the hydraulic constriction caused by the culvert connection between the downstream channel flowing to the Laguna be addressed by daylighting the creek under the trail and constructing a boardwalk over the creek. This approach allows for a channel to self- form in the daylighted reach and evolve to a flat gradient channel type which corrects for dammed up flows and backwater issues. The approach advocated for this reach is to create adequate space for the channel to build and form on its own.

I.2. Watershed Description

The Calder Creek watershed was analyzed by converting LiDAR to a DEM and 1' contour topography in QGIS. An operation for determining flowlines and watershed boundaries was then applied. The resulting map indicates that the Calder Creek watershed is a small, semi-developed watershed, totaling 1.04 square miles (667 acres) in size. It is characterized by rural-suburban lots in the upper reaches, and denser urbanization in the lower reach (below Jewell Avenue).

Drainage Area ID	Drainage Area (Acres)	Drainage Area (Sq Mi)	Description	Outlet
DA 1	424	0.66	Southern extent of watershed, mostly rural-suburban large lots. Partially sewered.	Southwest end of Ives Park
DA 2	73	0.11	Northwestern extent of watershed; a few rural-suburban lots, mostly smaller	Within Ives Park

			residential lots. Mostly sewered.	
DA 3	42	0.07	Flanks mainstem alignment of Calder Creek through small lot neighborhoods and Main Street development. Mostly sewered.	Main Street
DA 4	128	0.2	Small lot residential, commercial and industrial development. Mostly sewered.	Petaluma Ave
	727	1.04		

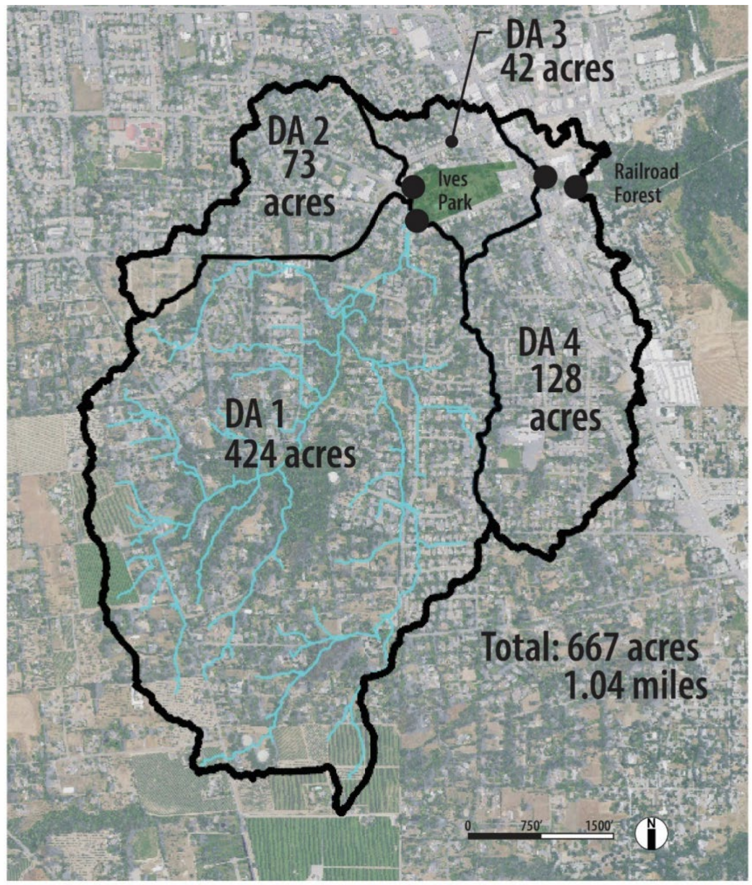


Figure 1 (right): GIS analysis of watershed drainage area and drainage pathways based on LiDAR data. Note that these drainage paths may not be surface flowing streams, but rather show the direction of waterflow by topography. Ives Park is the area highlighted

The City's 2005 Stormwater Utility Master Plan, which was visually summarized by GHD in the preliminary Hydraulic Model Domain Figure (2022), provides descriptions of the routing of watershed flows through these drainage areas. Much of the lower watershed has been sewered, and much upstream surface flow is also captured and delivered to the creek via culverts and ditches. At Ives Park, the main drainage, DA1, coming from the southwest, is carried by a 60" RCP stormdrain, and two additional pipes (36" RCP and 42" RCP) carry flows from the northwest (DA2). Downstream of Ives Park, the flows are routed through two stormdrains, a 66" RCP and a 48" RCP through a mix of public and private property from High Street to Main Street, with additional inflow coming from the north and south ends of Main Street (DA 3, with an 18" RCP and a 36" RCP). Between Main Street and Petaluma, the stormdrain pipes take divergent paths, with one carrying flows through a public parking lot, and the other beneath the Chamber of Commerce building and then through a parking lot. At Petaluma Ave DA4 is delivered to these pipes via a 42” RCP/CPFP. These flows outlet into a ditched wetland area of the Railroad Forest adjacent to the Joe Rodota Trail via a 66” RCP and a 6’ x 3’ concrete arch culvert.

II. Hydrology

A review of existing hydrologic data for the region, as well as for the Calder Creek watershed included:

- The 2005 City of Sebastopol Stormwater Utility Master Plan by BKF. This report estimates that discharge from the stormdrain that outlets into Ives Park, Pipe 487 60”Dia, delivers Q_{10} of 174 CFS. The Rational Method was used for computing this with an assumption of 35” annual rainfall. Estimated Q_{10} at Petaluma Ave from all stormdrains is 322.99 CFS;
- Regional Curves of Hydraulic Geometry for Wadeable Streams in Marin and Sonoma Counties, San Francisco Bay Area. Draft Summary Report. (Collins-Leventhal, 2012);
- The Regional Leopold data contained in A View of the River (1994)which uses data from 42 gage stations in coastal northern California that estimate the Q5 and Q2 in relation to bankfull discharges;
- To calculate hydrology and obtain average annual rainfall assumptions, we were directed by the City of Sebastopol Public Works Director to the Sonoma County Water Agency Flood Control Design Manual. This manual refers planners to Methods for Determining Magnitude and Frequency of Floods in California, Based on Data through Water Year 2006, by USGS Scientific Investigation Report 2012-5113 to calculate recurrence interval discharges. This report’s updated isohyetal map from the USGS document places Sebastopol within the 43” annual average rainfall zone. Note that the WRI hydrology calculated for Calder Creek project design uses this updated 43 inches average annual rainfall as opposed to the previous rational method estimates using an assumption of 35 average annual precipitation .

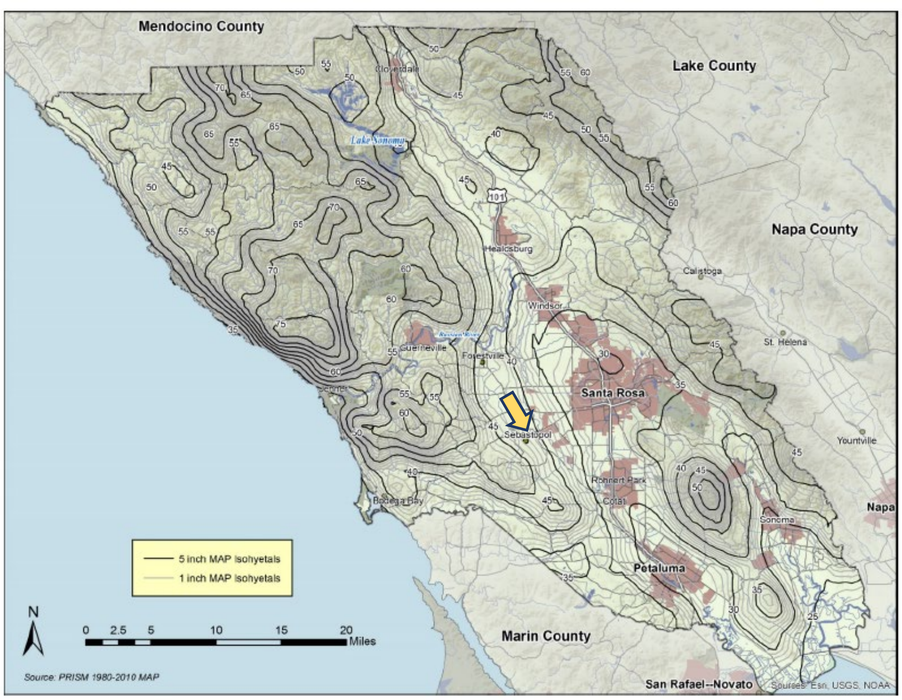


Figure 2: Isohyetal map with arrow indicating Sebastopol. Source: Sonoma Valley Water Agency.

II.1. Discharge estimates for DA 1, at Ives Park

The regional flood frequency equations for rural ungaged streams in California (USGS 2012) were used to calculate 5- to 100-year discharge for Calder Creek above Jewell Avenue (watershed area of 424 acres). Assumptions used include:

- Drainage area 0.7 sq mi (rounded up from 0.66 sq mi)
- 43" average annual rainfall
- 20 % culverted watershed
- 30% developed watershed

The USGS references Rantz (1971) for urbanization factors in their regional flood frequency equations. At the outfall of DA1(Pipe 487) in Ives Park, this yielded an estimated 2-year recurrence interval (RI) flow of 79 CFS, a five year RI of 135 cfs, a 10-year RI of 185 cfs, a 25 year RI of 252 CFS, a 50 year RI of 305 CFS, and a 100 year RI of 360 CFS.

The Regional Curves of Hydraulic Geometry for Wadeable Streams in Marin and Sonoma Counties(Collins and Leventhal, 2013) estimated active channel discharge as 30 CFS for $Q_{1.3}$ recurrence interval.

The Leopold ratio for North Coast stations of Q_2 to bankfull calculates bankfull discharge of about 50 cfs (Leopold, 1994).

The following table summarizes calculated discharge alongside discharge estimates from these previously referenced sources.

Table 1: Discharge Estimates for Ives Park from Different Sources

Recurrence Interval	**Calculated Discharge (CFS)** USGS Method	**Discharge** (CFS) per Royston Hanamoto and Abey 2013 (Ives Park MP Appendix)	**Bankfull Discharge Estimate** (CFS) (Leventhal/Collins, 2013)	**Leopold North Coast Stations*** (CFS) (Leopold, 1994)
1.3 hr*	-	-	30	-
2 yr	79	-	-	1.9 x 30cfs (bf) = 57
5 yr	135	-	-	4.5x 30 cfs (bf) = 135
10 yr	185	174	-	-
25 yr	252	-	-	-
50 yr	305	-	-	-
100 yr	360	-	-	-

*Leopold used data from 42 stations in the coast range of California to develop ratios between bankfull and other discharges. These ratios include Q_2= 1.9x bankfull; Q_5 = 4.5x bankfull (Leopold, 1994.

II.2. Discharge estimates for DA's 1-4, at Petaluma Blvd

At Petaluma Blvd, discharge was calculated using the USGS 2012 regional flood frequency equations. The assumed drainage area used was 1 square mile, average annual precipitation remained 43", and urbanization factors were 30% culverted, and 60% developed. Data from the 2013 Ives Park Master Plan, Collins-Leventhal report, and Leopold North Coast Stations for this drainage area:

Table 2: Discharge Estimates for Petaluma Ave (Downtown Reaches) from Different Sources

At Petaluma Blvd				
Recurrence Interval	**Calculated Discharge** (CFS) USGS Method	**Combined estimated** (CFS) Discharge from P-578,P-508, P-576,P-516 (BKF et al)	**Bankfull Discharge Estimate** (CFS) (Leventhal/Collins)	**Leopold North Coast Stations*** (CFS) (Leopold, 1994)
1.3 hr*	-	-	50	-
2 yr	146	-	-	1.9 x50cfs (bf) = 95
5 yr	259	-	-	4.5 x 50cfs (bf) =225
10 yr	304	323	-	-
25 yr	386	-	-	-
50 yr	466	-	-	-
100 yr	530	-	-	-

*Leopold used data from 42 stations in the coast range of California to develop ratios between bankfull and other discharges. These ratios include Q_2= 1.9x bankfull; Q_5 = 4.5x bankfull (Leopold, 1994.

The USGS doesn't provide data for calculating a $Q_{1.3}$ discharge. The two year recurrence interval discharge is frequently used as a high end estimate for bankfull discharge. It is expected that bankfull discharge will be similar for both DA1 (approximately 0.7 sq mi) and DAs 1-4 (approximately 1 square mile).

Leopold's research of 1994 showed that Q50 flood elevation can be estimated to be about 2x bankfull depth.

II.3. Hydrology Conclusions

We computed bankfull discharge to be able to size a dynamically stable bankfull channel. At Ives Park, the channel forming discharge estimates include Collins-Leventhal at 30 CFS, Leopold at 50 CFS. The $Q_2$from the USGS is 80 CFS. These values are all remarkably similar adding confidence to use a design assumption of30-50 cfs for the bankfull or active channel. Given the small change in drainage area from Jewell Ave to Petaluma Blvd area we are assuming that the 30-50 CFS range is a good assumption for bankfull discharge design throughout.

We computed discharge for low frequency high magnitude storms for two reasons:

- to understand capacity or lack of capacity of these culverts for bigger storms

- to design enough floodplain in the event that the stormwater system changes.
- to accommodate future flooding predicted by climate change models.

Given the general concurrence between calculated discharges for Q10 storms, we feel confident in using these numbers for planning floodprone areas of the stream corridor.

The culverts are sized with efficient hydraulics that should be able to convey the 25-year flood. However, flooding at Petaluma Ave has raised questions about the capacity of these pipes. They have been observed to be blocked with sediment, likely caused by backwatering from the Laguna. Upstream sediment supply is likely also exacerbating the problem, which has been noted by the City Engineer. If these issues were addressed, the capacity of the pipes would likely be adequate.

A watershed approach stabilizing Calder Creek by working with upstream landowners can over time reduce sediment from these sources. This should be viewed as a long term more labor-intensive effort. Backwatering of the Laguna however seems to be the primary driver of hydraulics. Therefore our design looks at the option of opening up the channel downstream of Petaluma Ave to remove hydraulic constrictions and allow flow to spread, with the additional benefit of lowering of water surface elevations in Calder Creek above Petaluma Ave.

III. Stream Restoration Design

Designing a restoration channel shape for an urban stream is a particular discipline within stream restoration. It requires detective work to pull as much information from different sources together to arrive at a reasonable width, depth, and cross-sectional area for the channel.

Our design objective is to mimic natural channel dynamics so that we have some erosion and deposition forming of pools and riffles, so that the creek is alive. Designing in this manner avoids excessive erosion and deposition thereby typically preventing any channel maintenance needs.

III.1. Hydraulic Geometry: Channel Shape

Regional hydraulic geometry is explored using regional curves, and further informed by reference stream explorations. Each sub-section covers both restoration for Calder Creek in Ives Park and downstream Downtown reaches where the channel shape and slope are expected to change.

Regional Hydraulic Geometry and Regional Curves

One of the first things we do is look at regional hydraulic geometry. Active or bankfull channel discharges form the bankfull channel dimensions. We are fortunate that Roger Leventhal, a flood control engineer at Marin County FCD, with geomorphologist Laurel Collins, completed a study creating regional curves of hydraulic geometry of equilibrium channels in 2013. Regional curves of hydraulic geometry collect information from a large number of stream sites, correlating the drainage areas with channel widths, depths, discharges, and cross-sectional areas of equilibrium (stable) streams. This means they don't excessively erode or deposit, which is one of our design objectives. The Collins-Leventhal report, using multiple data stations through Sonoma and Marin County, determined that most urbanized streams were formed by the 1.3 recurrence interval discharge. Their report references 45 sites of "hydraulic geometry dimensions of cross-sectional area, width, and depth at what was identified from field surveys as the possible channel stage associated with the discharge the tends to maintain stable channel geometry."

Jewell Avenue/Ives Park Drainage Area

For a watershed of about 0.7 square miles, which represents Jewell Avenue, the regional averages show a cross sectional area of 10 square feet, or 1 foot wide by 10 feet deep.

Downtown Area

For 1 square mile, which represents Petaluma Blvd, the cross-sectional area is about 15 square feet. We use the regional information to guide our field reference explorations.

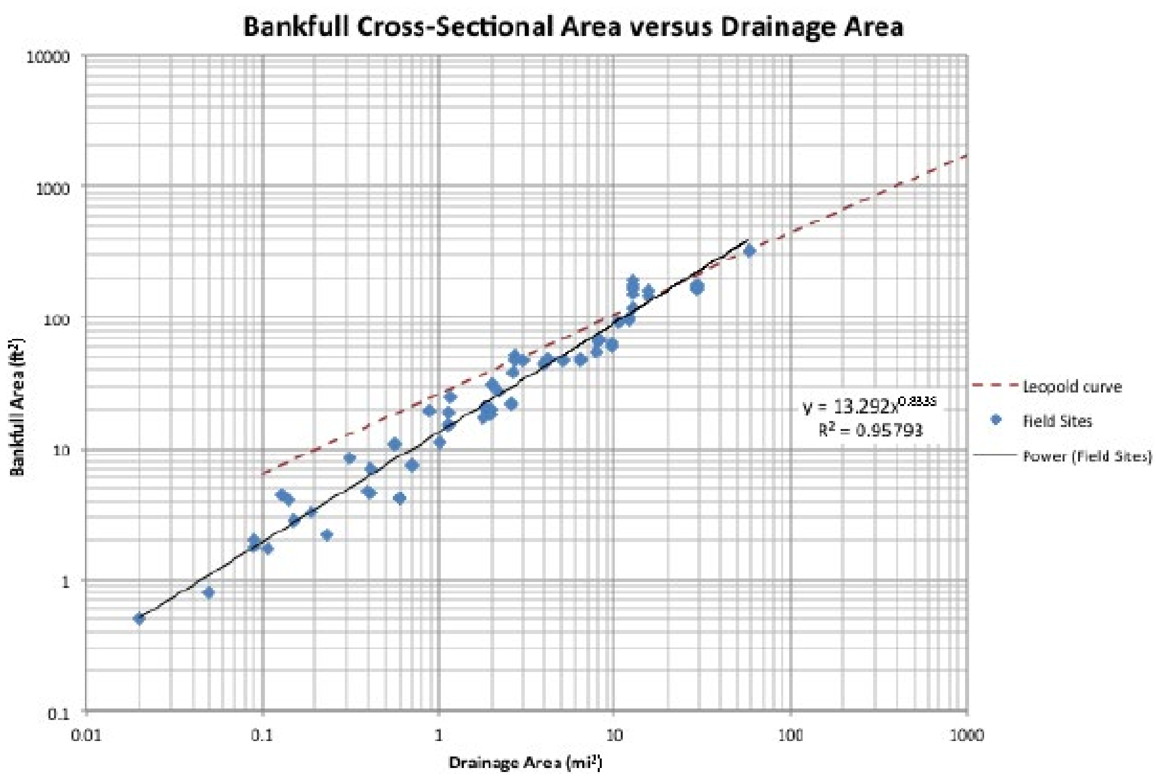


Figure 3 Regional Curve for Cross Sectional Area vs Watershed Drainage Area. Collins and Leventhal, 2013.

Reference Sites

Reference sites provide real-world context for regional curve and modeled data. In stream restoration design, this is referred to an analog for informing design. Ideal reference sites are undisturbed equilibrium reaches of either the same stream nearby, or from neighboring watersheds with similar levels of rainfall, development, and profile slope.

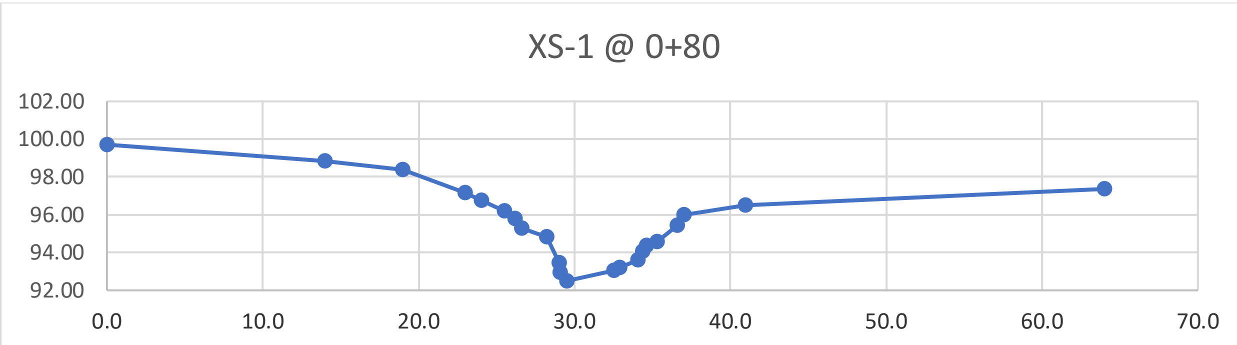
Jewell Ave Upstream Reference Sites

We visited six properties upstream, to look at reaches in equilibrium. Out of the six properties that we visited, three could provide reference conditions. In the interest of maintaining the privacy of these property owners, they are referred to as Residence 1, 2 and 3.

Residence 1: Channel dimensions were similar to those found at Residence 2.

Residence 2: Three cross sections were surveyed. The cross sections indicated that the upper two were impacted by culverts and debris in the channel, so the most downstream cross section was ultimately used as a reference. Bankfull channel form presents a channel width of about 6' and a depth of about 2'.

Table 3: Reference Channel observed at Residence 2



Residence 3: The channel at Residence 3 tended to be 8-10' channel widths.

Railroad Forest Reference Site

We observe that the slope associated with the channel configuration in Railroad Forest actually begins between High Street and Petaluma Ave. For this reason, we recommend using the observed channel in Railroad Forest as the reference for that reach, which we are calling the Downtown reach.

The natural channel within Railroad Forest was visited and observed. Measurements at reference sites here indicate a channel that is 6 feet wide and up to 4 feet deep, or a cross-sectional area of 24 sq ft. The cross sectional area in square feet is slightly larger than the upstream creek and the dimensions between width and depth are distributed differently.

Restoration Channel Shape Discussion and Summary

The reference channel cross sectional areas were close to estimates provided by the Regional Curves, but the width and depth dimensions were distributed differently. Reference streams on Calder Creek had deeper and narrower channels than the regional average.

It is expected that after the channels are graded at the recommended dimensions they will act on their own to attain their final dimensions. Our design objective is to estimate as closely as possible what the final shapes will evolve towards. The level of adjustments made by Calder Creek will not impact the basic site design parameters.

Channel shape parameters for Ives Park

Generally, the natural stream type observed upstream of Ives Park was a typical pool and riffle stream. This is also consistent with the stream gradient observed. We consider a more optimum channel width for design is 8 feet wide and 1.5 feet deep as a starting point for channel design at Ives Park.

Channel shape parameters for Downtown Reaches

The stream channel downstream of Petaluma Avenue represents a different stream type than the more typical pool riffle channel upstream of Ives Park. This channel is heavily influenced by the flat gradient and backwater dynamics of the Laguna. As a result, the width to depth ratio is going to adjust to a narrower and deeper channel. For the purposes of design in the downtown area we are selecting a channel 8 feet wide by 3 feet deep which represents a transition channel type between upstream and below Petaluma Avenue.

III.2. Sinuosity

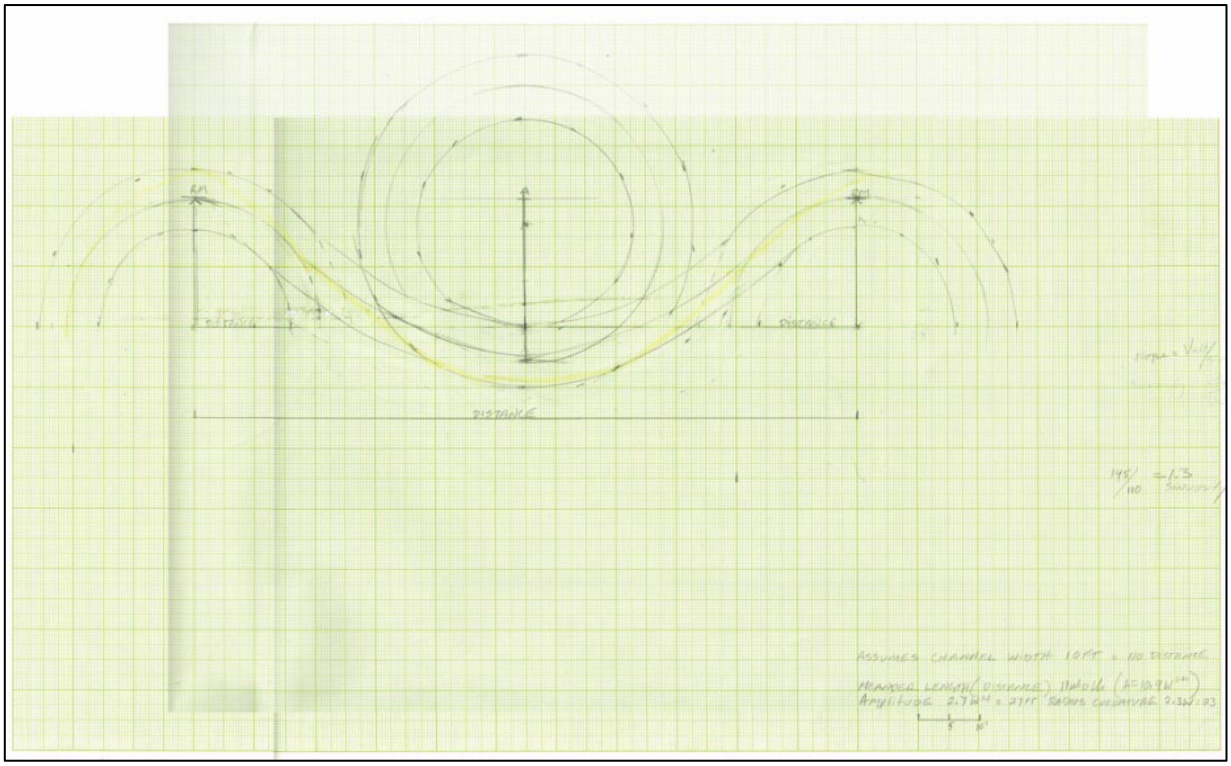
There are two main methods used to estimate the design sinuosity of the channel through Ives Park. Sinuosity refers to the meandering length of stream over a given valley distance.

The first method was to observe upstream reaches on Calder Creek that have achieved near stable conditions. The second method uses stream science dated to the 1950s-1960s which calculated correlations between the lengths of streams and the shapes of channels with channel widths (Leopold, Wolman, and Miller, 1964). Historic information provided by the city informs the previous shape of the stream meander in Ives Park which correlates well with the other two sources of information.

The reference site surveys provided data for estimating the stream lengths and shapes. The survey at Residence 2 was used to create a ratio of the meandering stream length to its straight-line distance. The bridge to the downstream fence was 121 feet. The actual channel length from the bridge to that same point was 168 feet. The sinuosity was 1.38. The sinuosity we derived from the correlation method of estimation was 1.3. At this property, we also measured valley length from vehicle entry road to south end of property. Valley slope is similar at 0.017 (Residence 2) to the park's 0.013.

Observing properties upstream, the stream has frequently outflanked bank stabilization works put in by property owners. This indicates that one of primary means of channel adjustment to watershed hydrology and conditions to establish an equilibrium slope is channel lengthening. The upstream stream reaches indicate that efforts to straighten Calder Creek have been met with failure with the channel eroding around hard points built on outside bends.

The correlation method of estimating sinuosity assumed that the channel length for a mid-watershed pool- riffle channel would be approximately 11 times the width. A ratio of 2.7 times the channel width was used to determine the meander amplitude. Assuming a channel width between 8 and10 feet, the amplitude would be between 21.6 and 27 feet. The radius of curvature is estimated at 2.3 times the channel width, or 18.4 to 23 feet. These dimensions were used to draw a design meander.



It is not intended that the graphic of an idealized meander should be the literal design channel appearance. This drawing is applied to inform sinuosity.

Sinuosity and Stream Length for Stream Reaches

For purposes of design, we selected a design sinuosity of 1.3. Applying this factor resulted in target restored stream lengths for each reach:

- Within Ives Park: 749 x 1.3 = 973 ft
- Between High Street and Main Street: 392 x 1.3 = 510 ft
- Between Main Street and Petaluma: 276 x 1.3 = 359 ft

Applying the hydraulic geometry relationships between channel width, radius of curvature and amplitude (Leopold, Miller and Wolman 1964), we estimated the channel width and meander length ranges between 9 to 11 x the channel width. Considering the stream's mid-watershed location, pool-riffle reach, and Bay Area experience, this range was narrowed down to a factor of 11.

Meander Belt and Floodplain Design

Combining the design channel width of approximately 8 - 10 feet and the meander amplitude of 21.6 to 27 feet provides design floodplain width of 30 to 37 feet for purposes of achieving channel planform stability. The floodplain cross slope was assumed to be 2%.

Table 4: Minimum estimated channel and floodplain at Ives Park

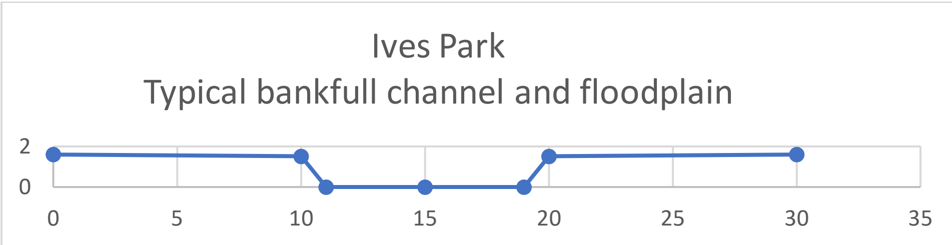
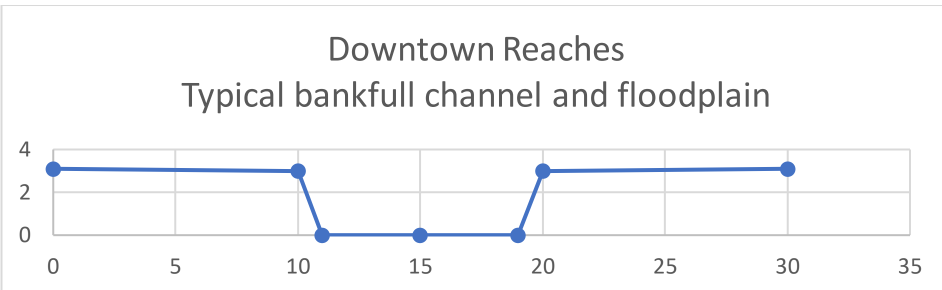


Table 5: Minimum estimated channel and floodplain for downtown reaches



Minimum Corridor at Ives Park

The banks from the floodplain to top of the stream corridor have been designed ranging from a 2H:1V slope to shallower slopes for access. Note that 1.5H:1V is likely acceptable given the soils at reference sites. In several places, constraints with meeting grades results in short (<30”) vertical walls at the top of banks. In general, the difference in grade between the channel thalweg and top of the stream channel corridor was approximately 4 to 5 feet. The steepest change in grade from the top of banks to the channel thalweg was 8.28 feet. The resulting minimum corridor width ranges from 52 to 68 feet with 2H:1V sides slopes. The proposed project actually varies from 23 to 130 feet, responding to constraints, and accounting for more variety, access, and other project goals (such as recharge) within the stream corridor.

Minimum Corridor at Downtown Reaches

Based on stormdrain invert elevations and available survey data for surface elevations through downtown, we estimate an average of 7’ difference between a restored channel bottom and existing grade through downtown. This leads to a minimum corridor width of 58 feet.

Discussion

Our initial estimation is that these rights- of -way contain the one in 50-year flood discharge. However, ultimately the hydraulic model should take into account backwater conditions from the Laguna and particularly the culvert located at the downstream end of Ives Park.

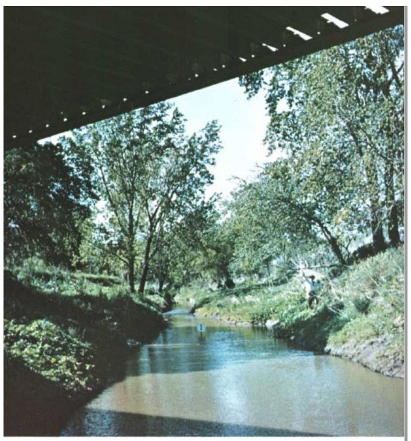
III.3. Channel Slope

The sinuosity of the Ives Park channel returns a thalweg slope of 0.0128.

The existing slope between High and Main Street appears to be 0.005. It is not clear if available survey was to actual inverts or to top of sediment deposits, given the acknowledged issue of sedimentation in the stormdrains. Between MainStreet and Railroad Forest the slope is estimated at 0.004, which we do not see reason to change for preliminary planning. Subsequent work including more detailed survey and reference site analysis in the Laguna may indicate that a shallower slope is appropriate.

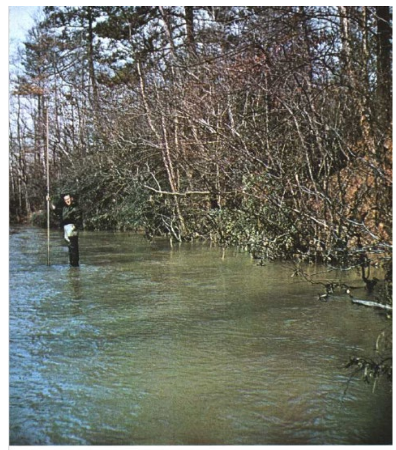
III.4. Channel Roughness

The “n value” is a factor describing the effect of frictional forces on the flow of water in a stream. Sediment in the channel, including pebbles, cobble, and boulders on the bed and banks, as well as vegetation or other material lining the banks of streams all contribute to the n value. We reference the USGS publication, “Roughness Characteristics of Natural Channels” (Barnes, 1967) along with experience, to derive recommended n values. Barnes obtained gage data with known discharges at multiple streams and calculated n values. Some examples are provided below for context.



No. 824 downstream from above section 1,
Salt Creek at Roca, Nebr.

Figure 5: Computed n value of 0.030 for recorded discharge 1,860 cfs and mean depth of 7.4 ft

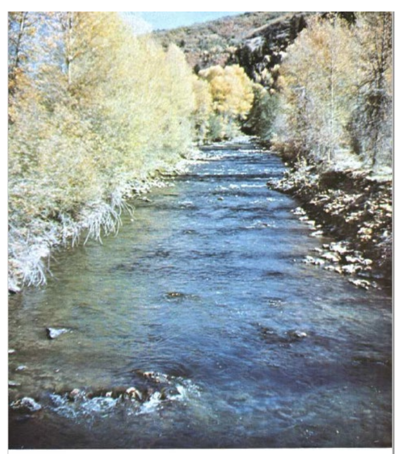


No. 1179 upstream from section 2,
South Beaverdam Creek near Dewy Rose, Ga.

Figure 6: Computed n value of 0.052 for recorded discharge 820 cfs and mean depth of 5.1; computed n value of 0.047 for recorded discharge of 221 cfs and mean depth of 2.8 ft

No. 1183 downstream along right bank from section 6,
Haw River near Benaja, N.C.

Figure 7: Computed n value of 0.059 for recorded discharge of 1,000 cfs and mean depth of 4.9 ft



No. 770 upstream from section 3, Provo River near
Hailstone, Utah.

Figure 8: Computed n value of 0.045 for recorded discharge of 1,200 cfs and a mean depth of 3.5; and computed n value of 0.073 for recorded discharge of 64.8 cfs and a mean depth of 1.1 ft

It should be noted that as floodwaters rise, assuming that the forested area of the channel has not changed, the roughness decreases. This should be reflected in flood modeling. We therefore recommend one n value for the Q_2 through Q_{25} floods, and to assume a different n value in modeling for larger magnitude floods.

Roughness for Jewell Ave/Ives Park

To account for the likely density of willow and alders, with groundcover vegetation on the floodplains, an n value of 0.065 is selected for lower magnitude floods Q_2 to Q_{25} between Jewell Avenue and High Street. For larger discharges, with the same level of vegetation, the n value should go down to 0.05.

Roughness for Downtown Reaches

Given the stream between High Street and Petaluma will have a steeper bankfull channel and a composite of vegetation and concrete flood walls, an n value of 0.060 is selected for use for Q2 to Q25. At higher flow, an n value of 0.055 is recommended.

III.5. Streambank Stabilization

Streambank stabilization applies tables containing calculations of expected channel velocities and shear stress to inform channel design. Shear stress calculations are considered the most relevant measures for bank stabilization design to avoid erosion problems. The U.S. Army Corps of Engineers Stability Thresholds for Stream Restoration Materials provides stream restoration designers with a table of "permissible shear and velocity for selected lining materials" which presents quantitative guidance on the selection of biodegradable fabrics and soil bioengineering systems capable of holding banks. (Fischenich, 2001). The Natural Resources Conservation Services provides similar guidance in its National Engineering Handbook (2007).

Bankfull Velocity and Shear Stress

For Ives Park and between High Street and Main Street

The initial velocities for bankfull discharges estimated with the Mannings Equation is 3.4 fps. The estimated shear stress in pounds per square foot is 1.19 lbs/sq ft, where:

Manning's equation for estimated velocities:

V= velocity, R = hydraulic radius, S = channel longitudinal slope or profile, n = channel roughness

$$V = 1.49\,(R)^{2/3}\,(S)^{1/2}/n$$

$$V = 1.49(1.5)^{2/3}\,(0.128)^{1/2}/0.65$$

$$V = 3.4 \text{ fps}$$

Shear stress equation (Leopold, Wolman and Miller, 1964):

$\tau = \gamma Rs$ (lbs./sq.ft.), where

Γ – specific density of water (62.42 lbs/cu ft)

R – Hydraulic radius (Mean Depth)

S - slope

(62.42 lbs/cu ft) (1.5) (0.128) = 1.19 lbs/sq ft

WRI calculated a high or more conservative value for shear stress acting on the channel using Corps guidance for channels with wide meander bends. The shear stress value acting on the channel therefore is multiplied by 1.15 to represent meander bend areas of the channel:

1.19 lbs/sq ft x 1.15 = 1.37 lbs/sq ft for meander bends.

Between High Street and Petaluma Avenue

The initial velocities for bankfull discharges estimated with the Mannings Equation is 3.9 fps The estimated shear stress in pounds per square foot is 1.2lbs/sq ft, where:

Manning's equation for estimated velocities:

V= velocity, R = hydraulic radius, S = channel longitudinal slope or profile, n = channel roughness

$V = 1.49 (R)^{2/3} (S)^{1/2}/n$

$V= 1.49(3)^{2/3} (0.004)^{1/2} /0.6$

V = 3.2 fps

Shear stress equation (Leopold, Wolman and Miller, 1964):

$\tau = \gamma Rs$ (lbs./sq.ft.), where

γ – specific density of water (62.42 lbs/cu ft)

R – Hydraulic radius (Mean Depth)

S - slope

(62.42 lbs/cu ft) (3) (0.004) = 0.75lbs/sq ft

The conservative/meander bend shear stress value acting on the channel represented by multiplying by 1.15 is:

0.75lbs/sq ft x 1.15 = 0.86lbs/sq ft for meander bends.

Higher Magnitude Flood Shear Stresses

Although most erosion and deposition occurs during bankfull flows, we thought it was important to generally consider shear stresses for greater depths. With expected higher discharges depth could reasonably achieve three or four feet, the related shear stresses could increase to somewhere between 2.76 and 3.68 psf through Ives Park, and 1.72 to 2.01 psf through downtown. These values are within the realm of soil bioengineering for bank protection.

Backwatering can have differing effects on shear stress, which is not discussed here.

Discussion

Following the design guidance in the USACE Stability Thresholds for Stream Restoration, we need to note that given the high suspended sediment loads in Calder Creek, that the stabilization thresholds for soil bioengineering systems presented in their table increases by 1.5 to 3 times. This is due to the way in which "sediments in suspension have the effect of dampening turbulence within the flow. Using erosion control fabric such as coir (made from coconut fibers) can perform erosion protection at 3-5 pounds per square foot shear stresses and increases to 4.5 pounds per sq ft with the sediment loading factor. This fabric alone most likely addresses much of the potential erosion control along the restored channel given the equilibrium active channel design. The Army Corps table indicates that a vegetated coir mat increases the shear stress performance to 4-8 pounds per square foot before adding in a sediment factor. WRI recommends combining vegetation with coir to protect streambanks. WRI experience indicates that securing the fabric with 6-to-9-inch staples provides at least the level of protection shown in government tables. The NRCS table indicates a combination of coir used with vegetated reinforced soil slopes (VRSS) provides an immediate bank protection for 3 to 5 lbs/sq ft with a protection level of 10+ lbs/sq ft once growth is established.

The WRI recommends the use of coir fabric along the active channel and jute netting for the side slopes of the floodplain. This adds an attractive component to the just graded channel and functions for weed control. The soil bioengineering systems can be applied to the meander bends and live willow or dogwood stakes should be adequate for cross-over sections of the channel.

Table 6:Excerpt from USACE (Fischenich, 2001) table: Permissible Shear and Velocity for Selected Living Materials

Boundary Category	Boundary Type	Permissible Shear Stress (lb/sq ft)	Permissible Velocity (ft/sec)	Citation(s)
Soil Bioengineering	Wattles	0.2 – 1.0	3	C, I, J, N
	Reed fascine	0.6-1.25	5	E
	Coir roll	3 - 5	8	E, M, N
	Vegetated coir mat	4 - 8	9.5	E, M, N
	Live brush mattress (initial)	0.4 – 4.1	4	B, E, I
	Live brush mattress (grown)	3.90-8.2	12	B, C, E, I, N
	Brush layering (initial/grown)	0.4 – 6.25	12	E, I, N
	Live fascine	1.25-3.10	6 – 8	C, E, I, J
	Live willow stakes	2.10-3.10	3 – 10	E, N, O

[1] Ranges of values generally reflect multiple sources of data or different testing conditions.

A. Chang, H.H. (1988).
B. Florineth. (1982)
C. Gerstgraser, C. (1998).
D. Goff, K. (1999).
E. Gray, D.H., and Sotir, R.B. (1996).
F. Julien, P.Y. (1995).
G. Kouwen, N.; Li, R. M.; and Simons, D.B., (1980).
H. Norman, J. N. (1975).
I. Schiechtl, H. M. and R. Stern. (1996).
J. Schoklitsch, A. (1937).
K. Sprague, C.J. (1999).
L. Temple, D.M. (1980).
M. TXDOT (1999)
N. Data from Author (2001)
O. USACE (1997).

IV. Design Summary

The table below summarizes the design criteria discussed above by the two main design reaches considered, between Jewell Avenue - (Ives Park, and from High Street to Petaluma Avenue and into the Railroad Forest.

Design Criteria	Reach	
	Jewell Ave-Ives Park	**High Street-Petaluma/Railroad Forest**
Bankfull Cross Sectional Area	12-15 sf	24 sf
Bankfull Mean Width/ Mean Depth	8 - 10' x 1.5'	s8' x 3'
Sinuosity	1.3	1.3
Meander Length	88-110'	88'
Meander Amplitude	21.6-27'	21.6'
Meander Radius of Curvature	18.4 - 23'	18.4'
Floodplain and Bankfull Channel Combined Minimum Width	30-37'	30'
Minimum Estimated Stream Corridor Width	52-68'	58'
Thalweg (Profile) Slope	0.0128	0.004
Channel Roughness (n value)	0.065/ 0.05	0.06/ 0.055
Bankfull velocity	3.4 fps	3.2 fps
Bankfull shear stress	1.19 psf	0.75 psf
Bankfull outside meander shear stress	1.38 psf	0.86 psf

V. Community Review

Restoration design unfolded through a process of online meetings hosted by the Planning Commission, including:

- August 24, 2021: WRI presented examples of successful stream restoration in other small communities.
- October 26,2021: WRI presented examples of failed stream protection strategies, in order to build understanding for the role restoration plays in creating lower maintenance, more aesthetically desirable environments.

- November 16,2021: WRI met with the Planning Commissioners Evert Fernandez and Kathy Oetinger, who compose the Ives Park Subcommittee, to charrette park design options with proposed stream restoration alignments. The group reviewed potential alignments and then focused on a park layout that worked with an increased stream length along the baseball field.
- December 14, 2021: WRI presented three stream restoration alternatives following the input from participants of the November charrette session. The alternatives included: “Constrained Creek” that fit the alignment into a shortened stream length following its existing path; the “Updated Charrette” alignment based the concept that was the focus of the Nov 16 charrette, and at the Ives Park Subcommittee’s request, a “Stable Planform Creek” that explores the potential for restoration without the ballfield. At this meeting Planning Commissioners voted to recommend two alternatives to the City Council for adoption. This included an alternative that removed a baseball field to provide for greater stream length and new park experiences, and an alternative that worked the stream alignment around the existing baseball field.
- February 1, 2022: City Council reviewed preferred alternatives and selected Alternative 2, restoration with baseball field.

WRI also conferred with the City’s consulting arborist, Becky Duckles, and Wendy Trowbridge, the Director of Restoration and Conservation Science Programs with the Laguna de Santa Rosa Foundation. Ms Duckles provided information to help with planning around existing trees, and offered some insights into the health of specific trees. Ms Trowbridge provided a range of perspectives including regional soil characteristics, recharge potential, local priorities for the Laguna and habitat restoration, and climate change concerns.

There were also in-person visits with various property owners for both reference site surveys and to provide advice for managing their stream.

VI. Notes on Preliminary Conceptual Grading

Development of the preferred design concept included preliminary conceptual grading, based upon survey from the 2013 Master Plan that had been adjusted by GHD Inc, with additional survey points taken by GHD Inc. Grading design also considered planned ADA improvements to existing paths, and included a coordination meeting with the City. Preliminary grading focused on the following design objectives:

- A consistent grade for stream thalweg along its entire length in Ives Park. WRI expects the thalweg to develop pools and riffles over time, which would result in variation of the channel thalweg.
- A consistent initial bankfull channel cross-section through Ives Park.
- Variable width floodplains and terraces to increase flood storage and groundwater recharge, provide for gentler grades for park user access, and increase riparian corridor habitat. A minimum floodplain width of 5 feet on each side of the bankfull channel is assumed. The floodplain cross-slope is assumed to be 2% or less.
- Path grades of less than 5% in order to maximize ADA accessibility, reduce handrail infrastructure, and promote greater ease of park use.

- Low vertical retaining walls are used where site constraints would create a steeper than 2:1 slope on channel banks. The distance from top of bank to paths is less than 30” when these walls are used, in order to minimize the need for guardrails. Design refinements in future phases may include consideration of stepped or terraced banks for increased access in these areas.

VII. References

Barnes, Harry H. Jr. 1967. Reprinted 1987. Roughness Characteristics of Natural Channels. USGS Water Supply Paper 1849. Denver, CO.

City of Sebastopol. 2005. Storm Drain System Utility Master Plan.

Collins, Laurel, and Leventhal, Roger. 2013. Regional Curves of Hydraulic Geometry for Wadeable Streams in Marin and Sonoma Counties, San Francisco Bay Area. Draft Summary Report.

Fischenich, C. 2001. "Stability Thresholds for Stream Restoration Materials," EMRRP Technical Notes Collection (ERDC TNEMRRP-SR-29), U.S. Army Engineer Research and Development Center, Vicksburg, MS.

GHD. 2022. Hydraulic Model Domain Preliminary Figure.

Gotvald, A. J., Barth, N. A., Veilleux, A. G., and Parrett, Charles. 2012. Methods for determining magnitude and frequency of floods in California, based on data through water year 2006: U.S. Geological Survey Scientific Investigations Report 2012-5113.

Leopold, Luna. 1994. A View of the River. Harvard University Press.

Natural Resources Conservation Service. 2007. Streambank Soil Bioengineering Technical Supplement 141. Part 654 National Engineering Handbook.

Rantz, S. E. 1971 Suggested criteria for hydrologic design of storm-drainage facilities in the San Francisco Bay region, California: U. S. Geological Survey Open-File Report 71-341.

Royston Hanamoto Alley &Abey. 2013. Ives Park Master Plan Report. City of Sebastopol

BKF Engineers. 2013. Hydrology Report, Ives Park,Sebastopol CAAppendix HIves Park Master Plan

Leopold Luna B.,M. Gordon Wolman,John P. Miller, 1964. Fluvial Processes in Geomorphology. W.H. Freeman Inc.

Sonoma County West Times and News. 1897 Feb 10.Provided by Mary Dodgion West Sonoma County Historical Society County Museum, Sebastopol.

City of Sebastopol. 2005. Storm Drain Utility Master Plan

Sonoma County Water Agency Flood Management Design Manual. 2020. Santa Rosa

Sonoma County Flood Conveyance Reference ManualD-2.1. 2020.