Contrasting Fluvial Geomorphic Processes and Historic Change Through Time:

Supporting Watershed Management in Tributaries of the Napa River Watershed

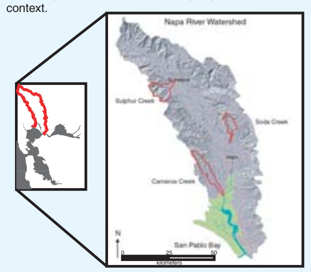
Sarah Pearce[1], Robin Grossinger[1], Matt O'Connor[2], and Lester McKee[1]   1 San Francisco Estuary Institute, Oakland, CA   2 O'Connor Environmental, Inc., Healdsburg, CA

San Francisco Estuary Institute
7770 Pardee Lane
Oakland, CA 94621
www.sfei.org

Introduction

In light of the sediment TMDL for the Napa River, declining anadromous fish populations, and concerns with flooding, it is important to understand how sediment is supplied from hillslopes, and channel bed and banks, and transported through the fluvial system. Detailed channel geomorphology and historical analysis of three sub-watersheds within the Napa Valley provide an understanding of current tributary channel forms and functions, as well as relative magnitude of sediment contribution from these basins to the Napa River.

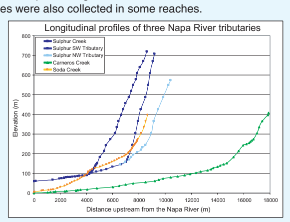
Three sub-watersheds were chosen for study: Soda Creek, Sulphur Creek, and Carneros Creek. Despite close geographic proximity (within 30 km of each other), the three sub-watersheds display substantially different channel forms, and physical responses to human impacts. We quantify and describe channel morphology, primary sediment sources, styles of sediment storage, and then present evidence of historic land use or channel change. These three examples illustrate the importance of placing fluvial systems into a larger geomorphic and historical context.



The Napa River Valley covers approximately 1100 km^2 (426 mi^2) on the northeastern side of San Pablo Bay, and is the third largest watershed in the nine-county Bay Area. Annual prepicitation ranges from 510-890 mm near the mouth of the Napa River, up to 1400-1525 mm at the headwaters near Mt. St.

Methodology

A field-based geomorphic watershed assessment was completed for Soda, Sulphur, and Carneros Creeks. A stratified random sampling plan was developed, with sample locations selected by comparing channel slope with land access. A set of 10 sample reaches (each 25 times the bankfull width in length) were selected in each creek to accurately portray the geomorphic characteristics. In each sample reach, data were collected, including: channel slope, cross-sections, surface sediment size distribution, volume and type of sediment deposits, volume and type of pools, volume and age of bank erosion, size and type of large woody debris, and riparian vegetation condition. Bulk subsurface sediment samples were also collected in some reaches.



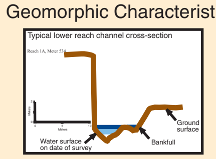
The historical ecology data collection focused upon using a multifaceted approach to build a strong historical dataset and to analyze key questions about historical land use, landscape and channel change in each watershed. Many types of historical data were used, including: aerial photographs, maps, land grant surveys and court documentation, historical documents and climatic records, long-time resident interviews, and field documentation of residual features on the current landscape. Evidence of native management practices and early Spanish/Mexican settler practices was also included in assessing landscape change.

Soda Creek

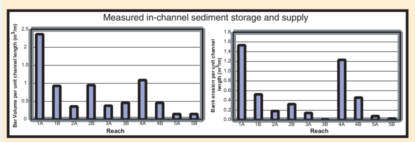
Watershed Context

Soda Creek is a 12.2 km^2 watershed underlain by Sonoma Volcanics, and with relatively low-intensity current and historic land uses. Current land use includes: suburban and rural residential, small areas of grazing and vineyards, open space scrub and chapparal. The creek provides fair salmonid habitat, affected most by the annual drying of surface flows, low numbers of LWD, and coarse bed sediment sizes. The stream remains close to its natural state, with the exception of the lowest reach, downstream of Silverado Trail (including sample reach 1A). This lowest reach is currently entrenched (illustrated by channel cross-sections), experiences backwater during flood stage on the Napa River, and is the location of local flooding hazards and

Geomorphic Characteristics



Soda Creek	
Watershed Area (km^2)	12.2
Watershed Area (mi^2)	4.7
Total Channel length (km)	8.1
Predominant Bedrock Geology	Sonoma Volcanics
Range of Sampled Channel Slopes	0.6% to 14.0%
Surface Sediment Grainsize Characteristics:	
Range of D50 (mm)	5.7 to 95
Range of D16 (mm)	<2 to 12.0
Range of D84 (mm)	84 to 330
Range of % <2mm	5 to 23
Subsurface Sediment Grainsize Characteristics:	
Range of D50	38 to 70
Range of %<6.35 mm	14 to 27
Range of %<1 mm	3 to 7
Average LWD Density (m^3/km)	0.86
Average Pool Spacing (in bankfull widths)	3.2



- Overall, Soda Creek supplies a small volume of sediment to the Napa River. The majority of sediment is stored in the lowest reach (1A) in a few large bars, and is partially sourced from localized bank erosion.
- Reach 4A, with the second highest measured bank erosion, has bedrock exposed along a majority of the channel bed, focusing any stream erosion upon the banks, rather than the more resistant channel bed.

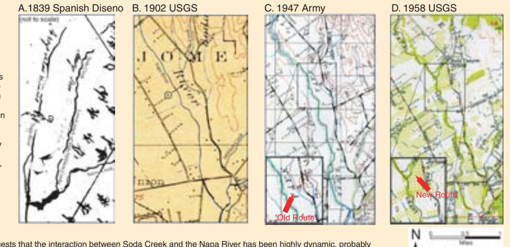
Channel Modification History (selected example)

This historical map series highlights the changes that have occurred at the junction of Soda Creek with the Napa River.

Prior to European management, lower Soda Creek flowed south, joining Milliken and Sarco Creeks before joining the Napa River (A-C). At some point in the mid 20th century, this route was removed as Soda Creek was ditched to run directly into the Napa River (D).

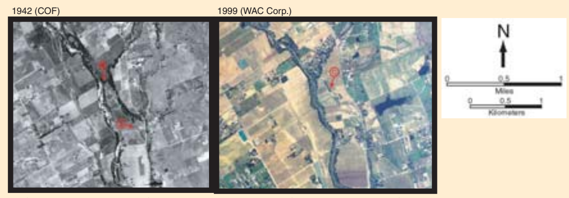
The more direct connection likely occurred before 1942 (riparian evidence shown on aerial photo), despite contradictory evidence from the 1947 Army map.

A.1839 Spanish Diseno   B. 1902 USGS   C. 1947 Army   D. 1958 USGS



- The historical record suggests that the interaction between Soda Creek and the Napa River has been highly dynamic, probably both as a result of natural process and human activity. In general, the trend in the past 60 years in this system has been one of channel simplification. Evidence suggests that Soda Creek has been disconnected from its historical drainage system by the removal of an approximately 600 m (2000 ft) section of stream channel.

1942 (COF)   1999 (WAC Corp.)



The first aerial photography available for Napa was produced in the early 1940's and shows further evidence of a direct connection between Soda Creek and the Napa River. It is a fairly straight connection, with riparian overstory substantially narrower than the route to the southeast. (a) new route, (b) old route.

Aerial photography from 1999 illustrates that the former route of Soda Creek is barely visible, except for an elongate agricultural reservoir made from the former channel (c).

- This change in channel location has ramifications for the entire subwatershed, including loss of low-gradient stream channel salmonid habitat, potential downcutting by Soda Creek at this location as it adjusts to the new local baselevel, increased flood hazards, and a greater connectivity for sediment delivery to the mainstem Napa River.

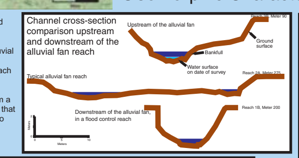
Sulphur Creek

Watershed Context

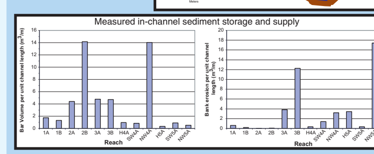
Sulphur Creek is a 24.2 km^2 watershed underlain by the highly-erodible Franciscan Formation, with moderate intensity current and historic land uses. Historically, the upper watershed was managed for hunting and grazing, while the alluvial fan suppored a gravel mining operation, and the lowest reaches were confined by the town of St. Helena. Currently, gravel mining has ceased, however, the channel is still affected by St. Helena and grazing, in addition to effects from hillslope conversion to vineyard. Landslides and other hillslope mass movements are the primary source of sediment provided to the creek. Areas of good to excellent salmonid habitat are provided by the creek, affected most by the seasonal drying of the alluvial fan reach.

Geomorphic Characteristics

- The Sulphur Creek watershed produces large volumes of sediment, with a majority currently in storage in the alluvial fan (reaches 2A and 2B, see cross-sections). However, reach NW4A is also an important storage location because it is immediately downstream from a large landslide (Devil's Slide) that has been documented back to 1869.



Sulphur Creek	
Watershed Area (km^2)	24.2
Watershed Area (mi^2)	9.3
Total Channel length (km)	20.5
Predominant Bedrock Geology	Franciscan Formation
Range of Sampled Channel Slopes	0.2% to 18.1%
Surface Sediment Grainsize Characteristics:	
Range of D50 (mm)	8 to 48
Range of D16 (mm)	<2 to 15
Range of D84 (mm)	27 to 400
Range of % <2mm	1 to 32
Subsurface Sediment Grainsize Characteristics:	
Range of D50	8 to 16
Range of %<6.35 mm	21 to 41
Range of %<1 mm	6 to 16
Average LWD Density (m^3/km)	26.63
Average Pool Spacing (in bankfull widths)	5.3



- Bank erosion is related to landslides that impinge directly upon the channel. An entire bank in reaches 3B and NW5A is sliding into the channel, causing the high bank erosion measures. Other reaches have fairly low amounts of bank erosion either due to channel aggradation, revetment, or exposed bedrock in the channel banks.
- Sulphur Creek is a wide, braided channel, lacking large, established riparian vegetation as it flows across the alluvial fan. This highly dynamic reach stores sediment both in long-term storage (terraces and floodplains), and short-term storage (point and medial bars).
- Observations suggest that this channel morphology is, and was a unique feature in the Napa Valley. Not coincidentally, Sulphur Creek has been the site of the largest long-term gravel mining operation in the Napa Valley, appearing repeatedly in the historical record as an important source of gravel for major construction efforts. High sediment loads and channel aggradation naturally replenished gravel each wet season during mining operations.

1902

Previous channel form is illustrated by this 1902 USGS Napa Quadrangle map (surveyed in 1896/99). The route of Sulphur Creek below the canyon mouth is shown as a stippled pattern (red arrow), which conventionally represents sand. This is in noteworthy contrast to the traditional "blueline" used to depict creeks in the rest of the map, which covers a majority of the North Bay.

Channel Modification History (selected example)

- Historical maps and the 1940s-era aerial photography indicate that, for the most part, Sulphur Creek has followed the same route across the alluvial plain through historical times (based upon little evidence of ditching or channelization). However, there is one significant exception, where the channel route has been substantially altered -- the 2000 ft reach immediately upstream of Main Street. Here, the braided channel configuration has been replaced with a straight, narrow, single-thread channel to bypass a large meander of the braided channel system.
- This anthropogenic change less than 60 years ago has probably caused significant effects upstream and downstream, in addition to the direct effects upon this reach. The creation of the bypass channel has reduced the channel length of this section from approximately 1850 feet to 1300 feet. As a result, the stream gradient has increased and the function of this reach has probably changed from sediment storage to sediment transport. Increased stream velocities may also be responsible for downstream incision.

Photo of alluvial fan reach (looking upstream)

1942   1993

A comparison of aerial photographs from 1942 and 1993 shows channel changes; the main channel of the braided 1942 stream (left) is shown as a dashed light blue line in 1993 (right). The new, straight channel, shown with a solid blue line, was created by cutting northeast through agricultural fields (circled in red) to connect into an existing small ditch. The ditch, clearly shown in the 1942 photography despite having only a few trees at this time, was initially dug to divert a small tributary. With the redirection of Sulphur, the ditch has been substantially widened to entrain the much larger Sulphur Creek. Since the change, the new channel has developed a narrow, tall riparian canopy that contrasts with the dispersed, low riparian habitat which characterized the earlier channel. Three large valley oaks (green dots) that previously occupied the alluvial plain to the left of the creek have maintained their position, and are now on the right side of the creek. The area outlined in green is an existing remnant of vegetation likely evolved from the former braided channel habitat.

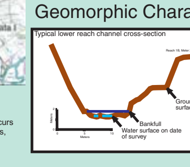
Carneros Creek

Watershed Context

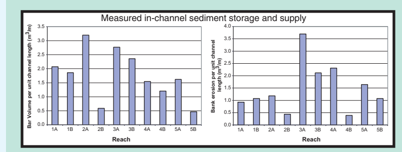
Carneros Creek is a 23.0 km^2 watershed underlain by Cretaceous/Jurassic mudstones and siltstones, and Miocene sandstone, siltstone and sandy shales. Although some small landslides are observed in the watershed, bed and bank erosion is the primary source of sediment to the channel. Historic land use includes native burning and management, grazing, agriculture and orchards. Current land use includes grazing, vineyards, and rural residential areas. The creek provides moderate to good salmonid habitat, primarily limited by lack of perennial surface flows. The lowest reaches are highly entrenched, and have many areas in which the remaining riparian corridor is jeopardized by undercut banks. However, we did not observe any evidence to suggest that the entrenchment was a recent phenomena, or was directly related to land use.

Geomorphic Characteristics

- Carneros Creek supplies a moderate amount of sediment to the Napa River. Sediment storage occurs as in-channel bars in the middle and lower reaches, especially in the slightly wider reach 2A.



Carneros Creek	
Watershed Area (km^2)	23.0
Watershed Area (mi^2)	8.9
Total Channel length (km)	17.9
Predominant Bedrock Geology	Mudstones, siltsones, and sandstones
Range of Sampled Channel Slopes	0.5% to 9.5%
Surface Sediment Grainsize Characteristics:	
Range of D50 (mm)	2 to 63
Range of D16 (mm)	<2 to 5
Range of D84 (mm)	14 to 285
Range of % <2mm	5 to 49
Subsurface Sediment Grainsize Characteristics:	
Range of D50	13 to 33
Range of %<6.35 mm	26 to 31
Range of %<1 mm	9 to 16
Average LWD Density (m^3/km)	87.04
Average Pool Spacing (in bankfull widths)	4.0



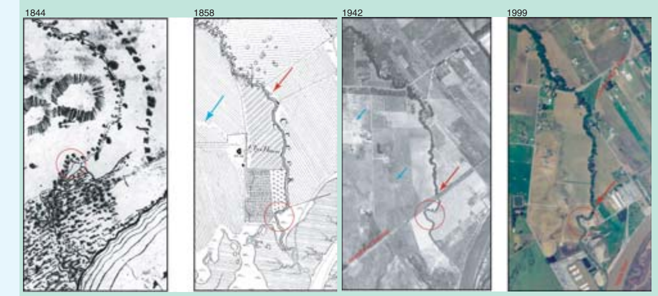
- Bank erosion, land use, and occasional landslides are the primary sources of sediment to the creek. The middle reaches have the highest measures of bank erosion, due to a few dynamic meanders that are able to erode the entire height of the channel bank.

Channel Modification History (selected example)

- Comparison of the present-day channel route with the earliest historical documents indicates that Carneros Creek has experienced very little redirection, straightening, or meander loss since the mid 19th century. U.S. Cadastral Engineer Joy notes the lack of change between 1858 and 1921 during his resurvey of lower parts of the stream, reporting that "there are no indications of change in the position of the creek during the years that have elapsed since the survey, also the retracements conform very closely to the meanderings of the creek at this time." It appears that some small meanders may have been removed, but this could also be due to natural causes. Significant straightening has occurred only in the short tidal reach.
- Recent SFEI studies suggest that prior to European settlement many of the tributaries of the Napa River did not maintain continuous channels across the valley floor. These streams did not directly connect to the mainstem until the creation of ditches in the late 19th or 20th century. In the case of Carneros Creek, however, evidence suggests that the creek was able to maintain a clearly defined channel across its alluvial plain during historical times.
- Distinctive hatch marks on the USCS (1858) depiction of Carneros Creek, indicating steepness alongside the creek, suggests that the creek was already incised to some degree near the time of European contact. Since that time, incision does not appear to have been massive but may be substantial in places.
- A preliminary examination of the lowest channel reaches found many large trees with exposed roots well above channel bed and substantial localized bank erosion. Widening of the channel appears to be taking place, which could explain the observed expansion in width of riparian canopy in some places along the creek.

Photo of entrenched reach, and severely undercut tree.

1844   1858   1942   1999

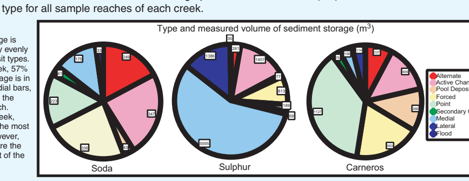


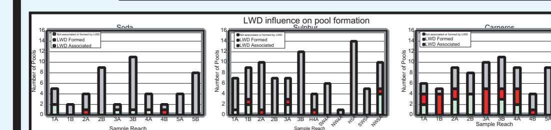
Time-series views of the lower reach of Carneros Creek: 1844 Huichica land grant, 1858 US Coast Survey, 1942 and 1999 aerial photography. The 1844 map shows a continous corridor of trees along the entire creek, but due to the scale, may not be very spatially precise. In contrast, the 1858 map, produced at 1:10,000 scale, shows the lowest section of creek as unwooded, beginning at the point marked with the red arrow. Note similarity in the depiction of channel meanders (circled in red), hatch marks indicating bank steepmess, and the route of a former channel, marked by a break in farming, indicated by the blue arrows. By 1942, the riparian tree canopy has extended downstream to the crossing of the recently abandoned railroad (red arrow). By 1999, the riparian canopy has slightly expanded further.

Comparitive Channel Geomorphology

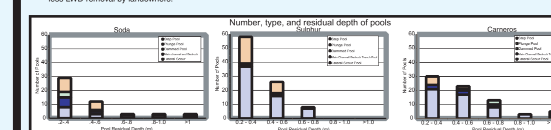
- Measured channel geomorphic characteristics help illustrate current dominant processes that are affecting the channel form and function. The first set of graphs shows total volume (m^3) of sediment stored in each deposit type for all sample reaches of each creek.

In Soda Creek, sediment storage is distributed fairly evenly amongst deposit types. In Sulphur Creek, 57% of the total storage is in the form of medial bars, most located in the alluvial fan reach. In Carneros Creek, point bars are the most significant. However, pool deposits are the most significant of the three creeks.

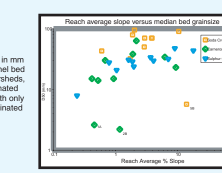




- This set of graphs illustrates the number of pools measured in each sample reach, and the effect of LWD on pool formation. LWD plays a minor role in pool formation in Soda Creek, due to low numbers of LWD pieces in-channel, and primarily hardwoods composing the riparian vegetation. Sulphur Creek has a much higher number of pools, but still a very small influence by LWD on pool formation, despite a more heavily forested watershed containing redwoods and conifers. Carneros Creek has the largest influence by LWD; nearly 50% of all pools measured were either directly formed by, or were associated with LWD pieces. This is likely due to the nearly continuous riparian corridor, and less LWD removal by landowners.



- This set of graphs depicts the number, type, and residual depth class of all pools measured in each creek. Although Soda Creek has a low total number of pools measured, the pools present represent all pool types and depth classes. Sulphur Creek has a large total number of pools, but none greater than 0.8 m in depth, with most being lateral scour pools and step-pools near the headwaters. Carneros Creek has a good distribution of pools of nearly all types, in all depth classes, with the largest, and potentially most important for salmonid oversummering being lateral scour and main channel pools.
- This graph shows reach average percent slope versus median grainsize (D50) in mm for sample reaches in each creek. Typically as channel slope decreases, channel bed grainsize will also decrease. This pattern is generally evident in the three watersheds, with the exception of three sample reaches. Carneros Creek reach 1A is dominated by a long, low-gradient pool, whereas reach 2B is a scoured bedrock trench with only a small veneer of sediment. Soda Creek 5B is a small headwater channel dominated by hillslope supply of sediment directly into the channel.



Conclusions

- As illustrated by Soda, Sulphur, and Carneros Creeks, although close in proximity, tributaries of the Napa River can be dominated by substantially different physical processes, which are expressed as unique channel morphologies. Channel geomorphology data is a useful tool in illustrating these differences.
- Together, many sources of historical data can build the history of a watershed, including landscape-scale ecology, land use and localized channel modifications. This landscape change analysis was able to answer specific questions about unusual locations in each watershed, and identify important factors affecting stream restoration potential.
- Interpretations of modern channel morphology and process can be affected by historic anthropogenic channel modifications. The increased connectivity of the lowest reach of Soda Creek, and the ditching of Sulphur Creek are prime examples.
- Combining current observations of physical processes and channel morphology along with an understanding of land use and anthropogenic changes to the fluvial system help in determining the historic and current sediment contribution of each tributary to the Napa River. Sediment supply to the mainstem Napa River is relatively low in Soda Creek, high in Sulphur Creek, and moderate in Carneros Creek. However, the high sediment supply in Sulphur Creek is buffered by the high sediment storage capacity of the alluvial fan.