Creating an Anticipatory Management Plan for Carneros Creek, Napa CA

by

Julie Rubens Beagle

A thesis submitted in partial satisfaction of the

requirements for the degree of

Master of Landscape Architecture

in

Landscape Architecture and Environmental Planning

in the

Graduate Division

of the

University of California, Berkeley

Committee in charge:

Professor G. Mathias Kondolf, Chair
Professor Joe McBride
Professor Randolph T. Hester

Spring 2010

The thesis of Julie Rubens Beagle titled
Creating an Anticipatory Management Plan for Carneros Creek, Napa, CA
is approved:

Chair ______________________________ Date ______________
Professor G. Mathias Kondolf

______________________________ Date ______________
Professor Joe McBride

______________________________ Date ______________
Professor Randolph T. Hester

University of California, Berkeley
Spring 2010

Table of Contents

List of Figures

Acknowledgements

I would like to thank my committee, Matt Kondolf, Joe McBride and Randy Hester for their help and tireless days in the field. Other faculty advisors were of great help to me including Stephanie Carlson and Rich Adams (OSU).

I am grateful to my many field assistants: Sarah Richmond, Nelia White, Darcie Luce, Gabe Treves, Clare O'Reilly, and Rafi Silberblatt and to Maya Hayden, for her expertise in dendrochronology. Thanks also to Laurel Marcus for envisioning and facilitating the project.

I owe thanks to the landowners and farmers of Carneros Creek for being open-minded about alternative possibilities for stream management and for welcoming me onto their farms and into their creek.

Thanks to my parents for two decades of editing and to Eric without whom I would still be sitting on a gravel bar counting pebbles.

*All photographs were taken by the author, unless otherwise noted

Chapter 1 | Introduction

This thesis addresses the issue of how to manage streams over the long term and with landowner participation. Since most of northern California is privately owned and managed and because many watersheds support high value agriculture, often planted up to the bank edges of streams to make the most of arable land, engaging private landowners in management strategies is becoming increasingly important. The Carneros Creek watershed, like many in Northern California, supports high value agriculture, in this case extensive and well-established vineyards, a rural residential community and a struggling population of steelhead trout (*Oncorhynchus mykiss*). And like many other creeks, Carneros Creek's hydrologic history demonstrates a common pattern: increasingly incised channels which undercut the stream banks, causing periodic collapse. In reaction, landowners dump rip-rap, car bodies, and other debris—until recently the accepted ways of preventing further bank failure and retreat.

Figure 1.1. Examples of bank hardening on Carneros Creek

This hardscaping, aside from creating poor aquatic habitat, increases velocities and shear stresses even further against downstream banks, encouraging more bank failures, and continuing the cycle.

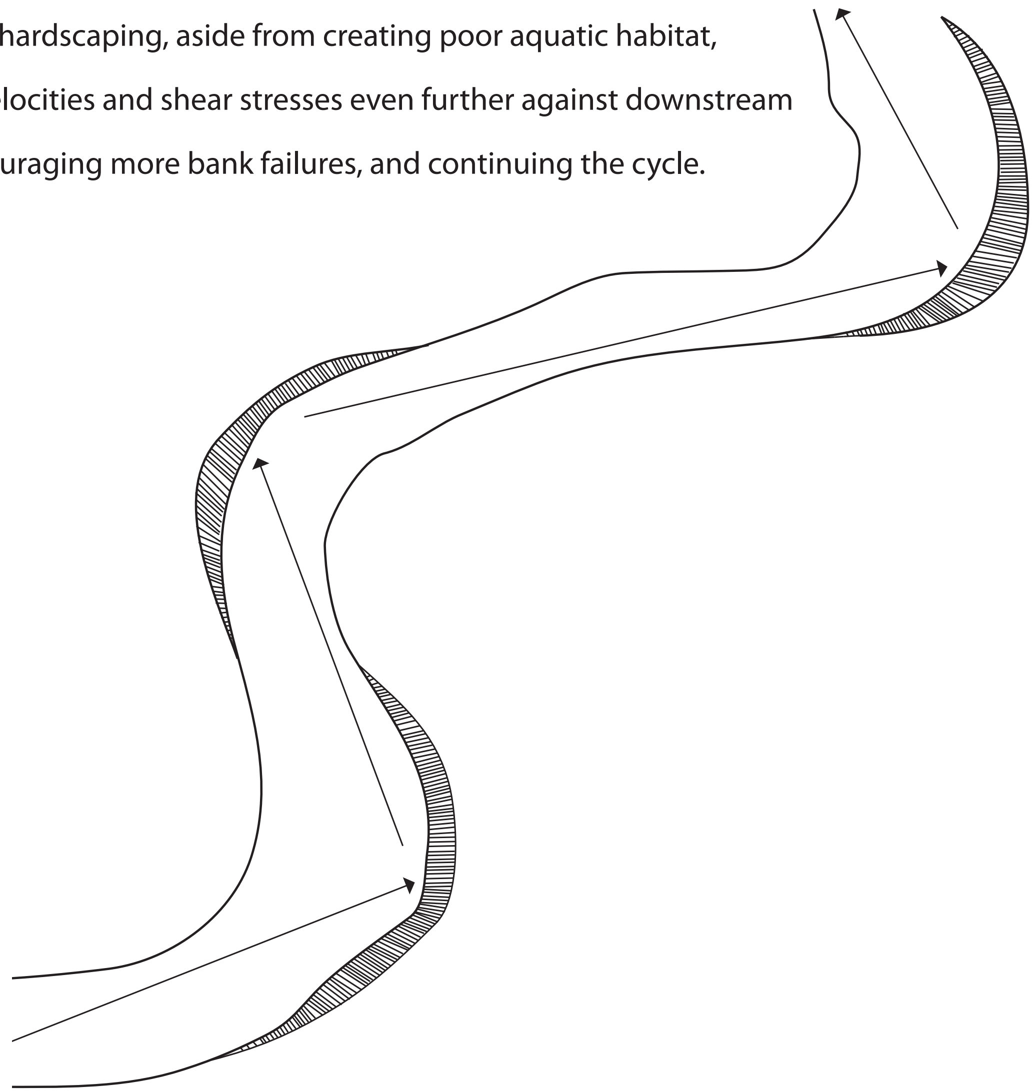


Figure 1.2. Diagram of effect of bank hardening on downstream outer bends

Continued bank failure can have both positive and negative effects on the stream. Accelerated erosion can lead to increases in sedimentation in cobbles and gravels in the channel bed, which degrades fish habitat by inhibiting egg development and fry emergence from spawning gravel. Bank failure is a continuing concern for the landowners along the creek, who routinely find sheds, trees, fences and sometimes vines which have fallen into the creek after large rain events.

However, bank erosion can also create channel bedforms, and cause recruitment of large woody debris into the channel. In incised, degraded creek systems, erosion can often increase channel complexity, which is necessary for spawning and rearing of salmonids.

Failures occur every year, so they are 'expected events.' Furthermore, erosion often creates the best habitat for fish in these incised channels. If landowners and managers can anticipate these changes and prepare for them, instead of reacting to them with rip rap and hardened banks, the stream can adjust and restore itself leading to improved fish habitat.

A new method of watershed and stream planning is necessary, and is based on what I have termed 'anticipatory management.' The goal of anticipatory management is to create a plan for and with the riparian landowners that allows the channel room to adjust and restore itself, accepts erosion as an expected event, anticipates bank failures and moves agriculture, roads and perhaps houses, back away from the creek proactively, instead of continuing piecemeal management. In other words, anticipatory management gives the creek 'room to fail' by creating a template for analysis that values process-restoration, a comprehensive understanding of the watershed, and self-enforced management on property by property basis.

Carneros Creek (17 km^2) provides the case study for developing an anticipatory management plan. It is one of the largest tributaries of the Napa River, and one of the few remaining unblocked steelhead trout migration corridors in the Bay region. Carneros Creek is sinuous, dynamic, and incised from 2 to 6 m below the valley bottom, so negative effects of reactive management are intensified.

Figure 1.3. Incised banks and sinuous stream

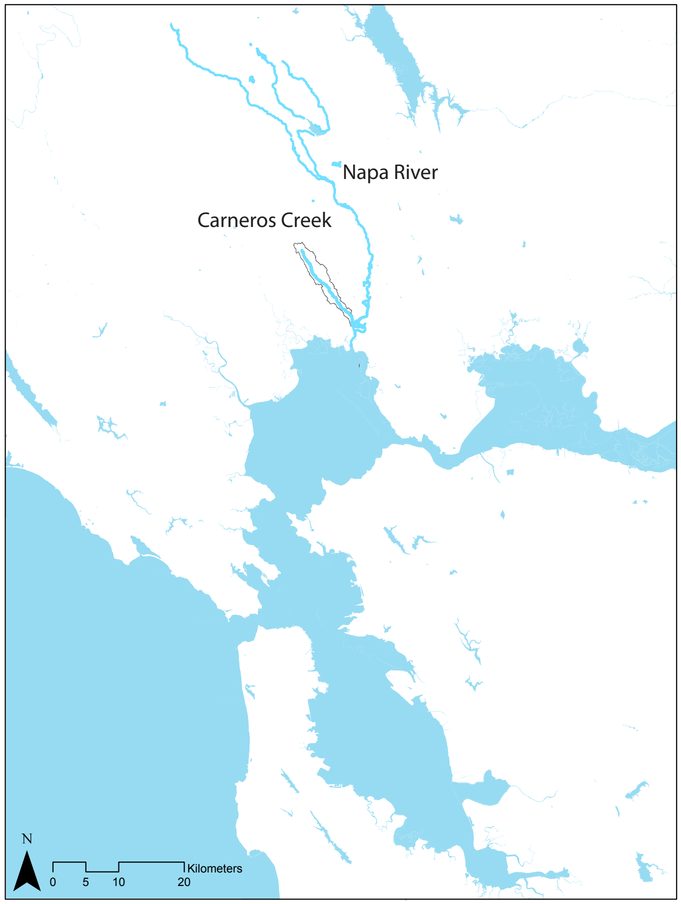


Figure 1.4. San Francisco Bay context

The aim of this project is to avoid further habitat degradation by predicting where bank erosion and retreat is most likely to occur over the next 20 years, set vines and roads back in anticipation of failures, and provide a set of management tools as failures occur in order to avoid reactive and degrading management practices. A secondary goal is to create a template for watershed-wide management, and provide an alternative to hard-engineered approaches which are costly and often cause more habitat degradation. By giving the creek "space of liberty," or room to adjust, in certain, informed places, this plan could be a proactive model of stream management which relies on process restoration and landowner participation.

An anticipatory approach to stream management is valuable for many reasons. It avoids common practices in stream restoration and management, such as buffering the whole creek and treating all banks equally, or on the other hand, reacting to each bank failure as it occurs. These methods often involves hardening banks, which besides being costly, often propagate failures up and downstream. The anticipatory management approach values proactively managing for change and can potentially be a way to satisfy all stakeholders; farmers, fish, and California ecosystems.

This thesis elaborates on the creation of this anticipatory management plan, starting with the geographic, historic, political and ecological background of Carneros Creek in Chapter two. Chapter three explains the methods I used and the data analysis I performed. Chapter four explores the literature of several resource management strategies and how they are applied to watersheds. Chater five presents the results of my data analysis and chapter six lays out the management plan for landowners along Carneros Creek.

Chapter 2 | Background of Carneros Creek and Regulatory Framework

To assess the state of Carneros Creek and develop a management plan, it is important to understand the watershed from many angles and at many scales. I used several methods, across disciplines to achieve this understanding and to inform this anticipatory management plan. I focused this study on the following categories: geomorphology, specifically bank stability and incision; riparian vegetation; fish habitat and usage of the creek; land use patterns and history, as well as regulatory frameworks in place and in development regarding watershed management in Napa County.

Geography

Carneros Creek is the southern-most tributary to the Napa River, flowing from the western most side of Napa County and joining the main stem approximately 4 kilometers (km) above its confluence with San Pablo Bay. Over its 18 km stream length Carneros Creek drains a narrow, 17 km^2 basin. The highest elevation in the watershed is 506 m above mean sea level, while the confluence with the Napa River is at mean sea level and is tidally influenced (Pearce et al., 2003).

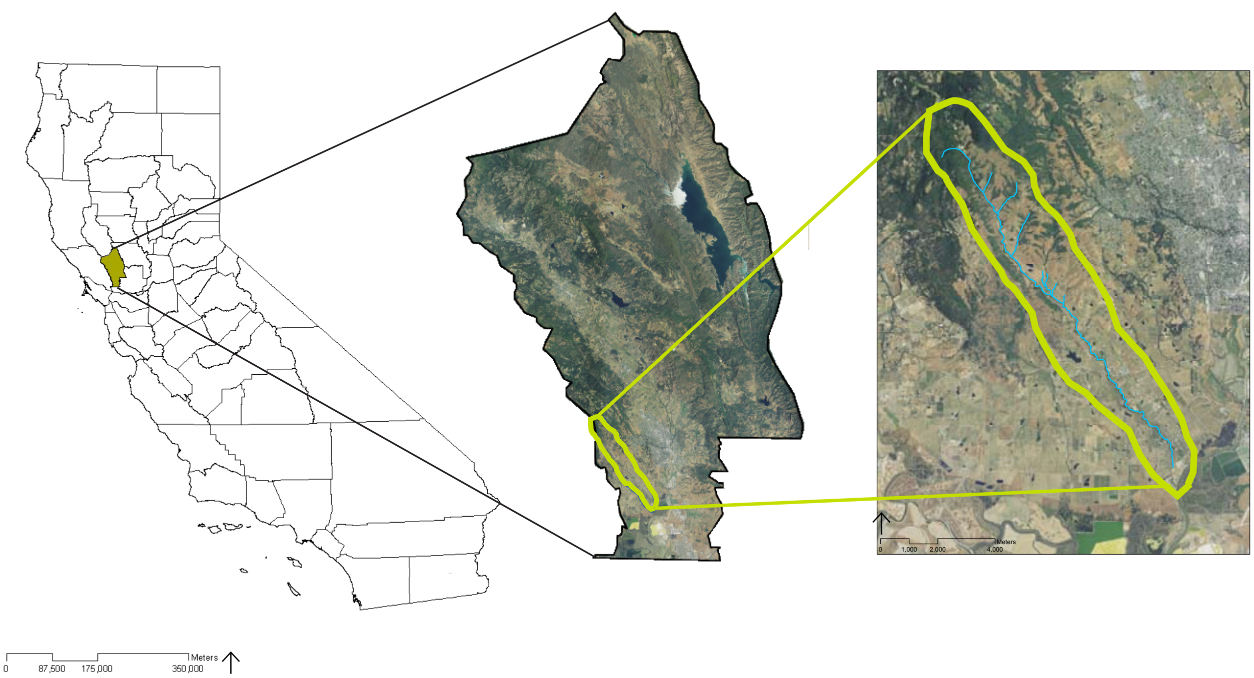
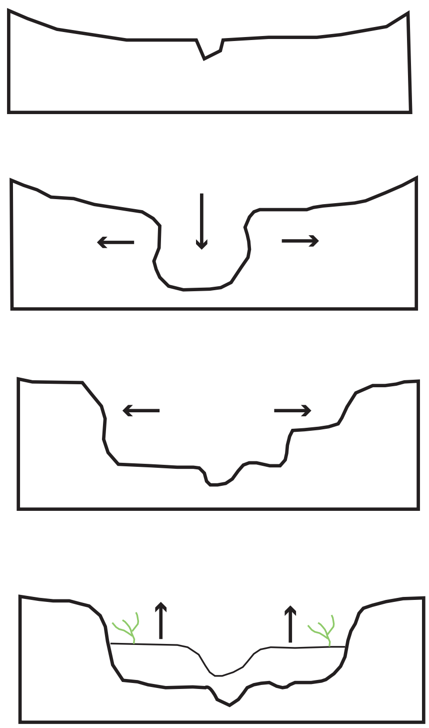


Figure 2.1. Location of Carneros Creek (Napa County, CA)

Geomorphology

One of the primary questions for this project hinges around the timing of channel incision: when did Carneros Creek incise, and is this process still occuring? Geomorphologists have made attempts to identify the causes of incision (geologic, geomorphic, anthropogenic); however it is most likely a combination of many forces, and is driven by a combination of a change or imbalance between sediment supply and discharge (Mount, 1995). Channel incision results in higher and often steeper stream banks and a smaller width-depth ratio. If sufficient down-cutting occurs, stream banks become susceptible to mass failure, resulting in channel widening (Simon et al., 2006).



- Channel section before incision
- Channel down-cutting, increased shear stress on banks
- Channel widening at critical width-depth ratio
- Channel aggrading and floodplain restoration

Figure 2.2. Diagram of channel incision, failure, widening process (adapted from Schumm, 1984)

Erosion of banks can supply enormous quantities of sediment to the flow, and sediments derived from these failures can be the dominant supply in a watershed containing incised channels (Knighton, 1998). Classifying banks based on their stratigraphy and soil structure is important for understanding what causes failure, and where failure is likely to occur (Simon and Rinaldi, 2006).

Bank Stability

Many factors influence bank erosion and failure in streams and rivers. The susceptibility of creek banks to mass failure often depends on geometry, structure, and material properties (Knighton, 1998). Alluvial systems, where bank structures are composed of silts, sands and gravels, have significant compressive strength but have no tensile strength or cohesion (Micheli, 2002). Vegetation has been shown to increase erosion protection by adding root cohesion (Schmidt et al., 2001). Bank sediment with a root volume of 16-18% and a 5 cm root mat was shown to provide 20,000 times more protection from erosion than comparable sediment without vegetation in a study by Knighton et al. (Knighton, 1998). This increase in protection from erosion is due to the increase in bank cohesion, and there is an observed and proven relationship between bank cohesion and the factor of safety that estimates risk of bank failure (Micheli, 2002).

The presence and gradual enlargement or movement of gravel bars can also affect the intensity and location of bank erosion. Bank erosion processes in the Carneros study reach are significant and naturally-occurring, and is likely to be the major process by which sediment and woody debris are recruited into the main stem of Carneros Creek (O'Connor, 2005).

Geology and Faults

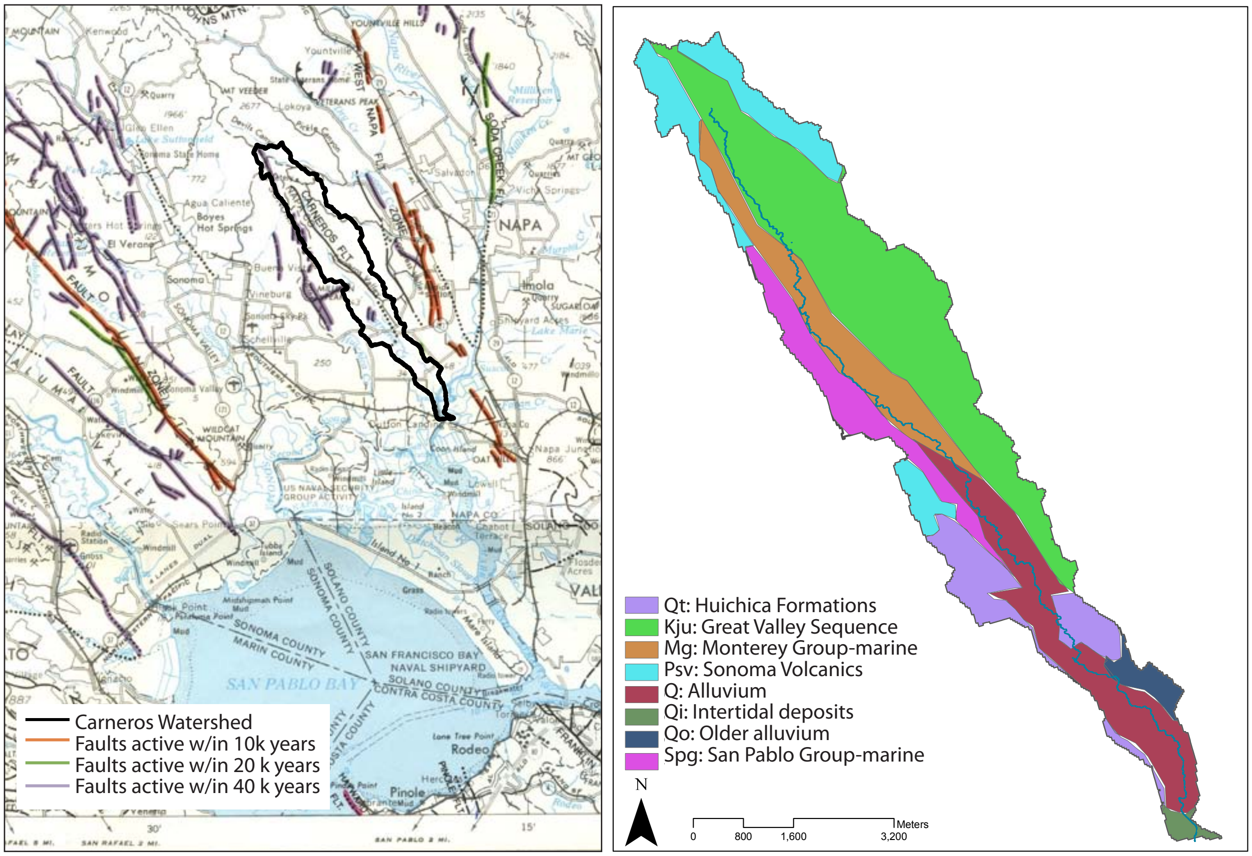


Figure 2.3. Fault lines and Geology of Carneros Creek watershed

Carneros Creek and its watershed are oriented along the Carneros Fault, which has been active in the past 40,000 years (Wagner et al., 1982). The lower portion of the watershed is mainly Quaternary Alluvium, with intertidal deposits from the Holocene at the confluence with the Napa River (Wagner et al., 1982). The west side of the creek in the middle reaches is Tertiary Miocene marine sandstone and shale of the San Pablo Group with mainly andesitic Sonoma volcanics. The upper eastern side of the watershed is rhyolitic Sonoma volcanics with marine mudstone, siltstone, sandstone and conglomerate from the Upper Jurassic Great Valley Sequence. A small outcropping of marine sandstone and shale of the Monterey Group protrudes above Old Sonoma Road (Wagner et al.,1982). The Great Valley Sequence of mudstones and siltstones and Miocene marine sediments are easily eroded, and likely contribute fine sediment to the channel though bank erosion and mass failures (Pearce et al, 2003; Dietrich, 2002).

Soils

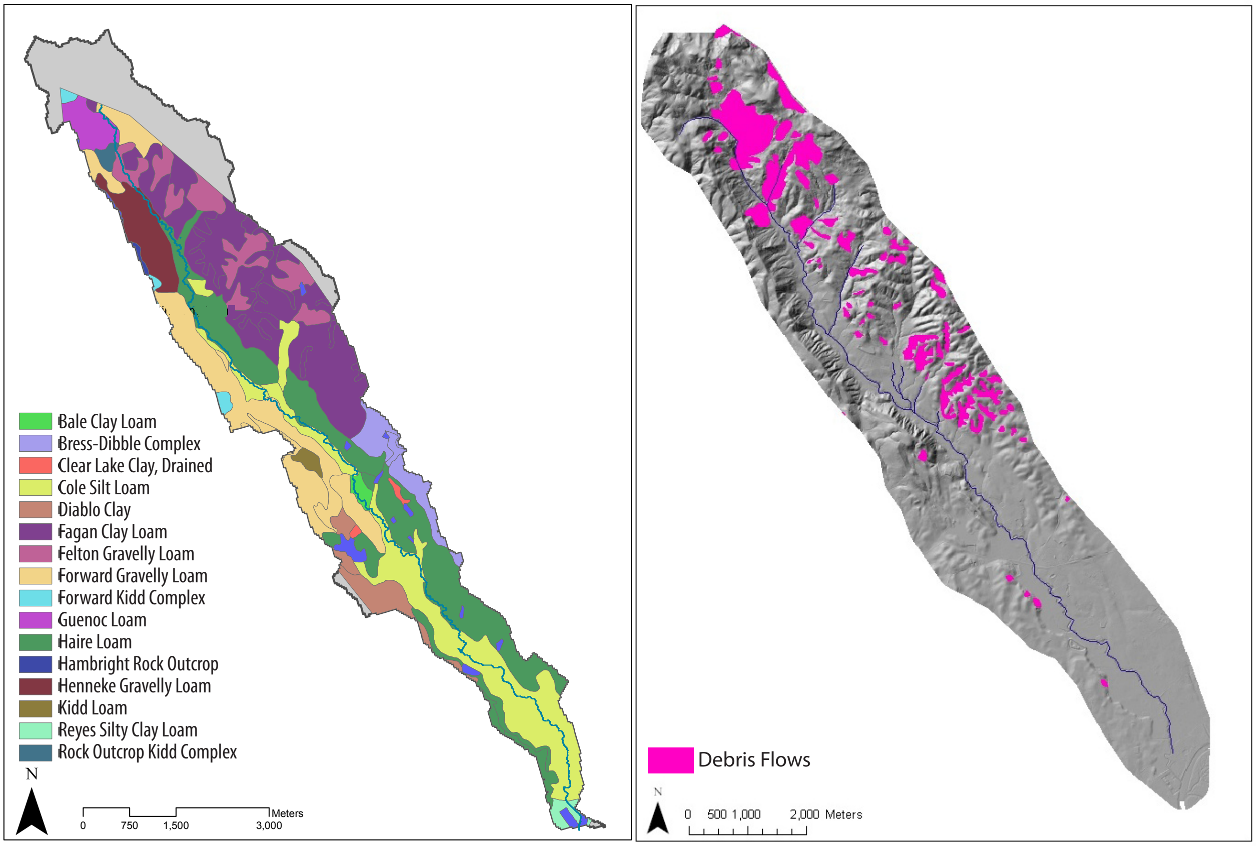
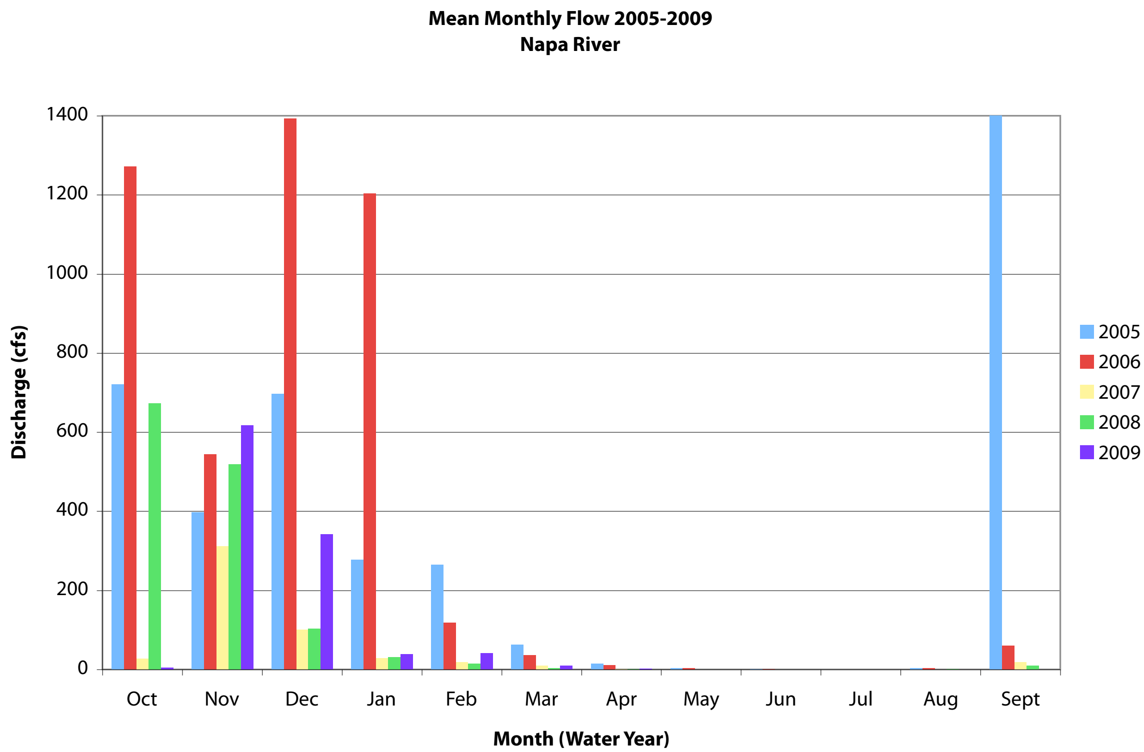


Figure 2.4. Soil map and mapped locations of debris flows in Carneros Watershed (Dietrich, 2002)

In the lower portion of the watershed, the dominant soil type is Cole silt loam, a soil that forms on low-sloped old alluvial fans and floodplains from weathered sandstones and shales, and is often farmed for wine grapes (Pearce et al., 2003; NRCS Soil Survey). The soils in the lower west side of the watershed are dominated by sandstones, are well drained, and are also popular for vineyard use. The soils of the east side of the valley are mainly clay and gravelly loams and are prone to shallow debris flows (Pearce et al., 2003; Dietrich, 2002).

Hydrology

Carneros Creek is a hydrologically 'flashy,' single-thread channel with connected flow for one to two months out of the year. High water marks and landowner interviews indicate that the channel fills and drains within hours of a storm (Knobloch, Pers. Comm. 12-1-09). From an analysis of peak discharge for channels in the Napa Valley, a basin the size of Carneros Creek can expect a peak discharge of 15 m^3/s, a recurrence interval of 1.5 years (Pearce, 2002).



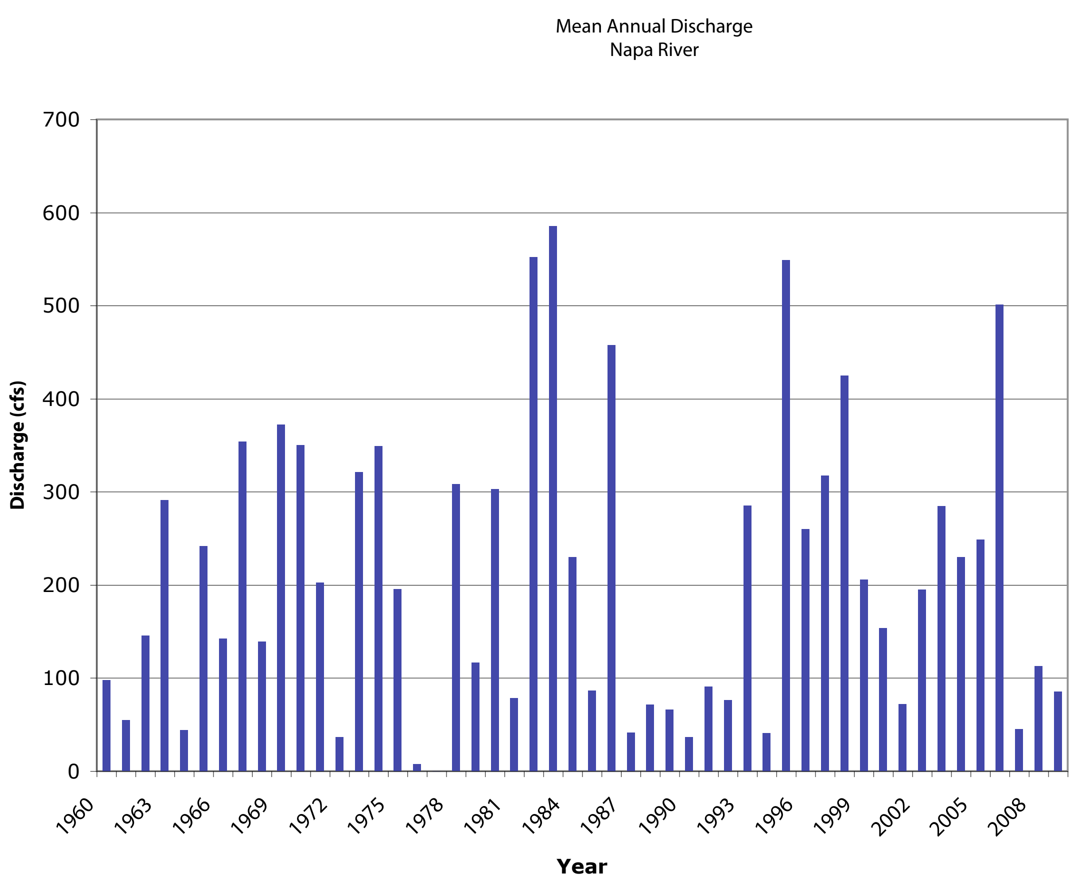


Figure 2.5. Mean annual and mean monthly hydrograph for Napa River, CA.

Riparian Vegetation

Carneros Creek supports a fairly intact, if narrow, riparian corridor often made up of a single row of trees. California bay laurel (*Umbellularia californica)*, live oak (*Quercus agrifola*), valley oak (*Quercus lobata*), California buckeye (*Aesculus californica*), red willow (*Salix laevigata*) and arroyo willows (*Salix lasiolepis*) are the dominant species. The tidal portion of the creek is largely without woody vegetation. In the middle reaches there are significant stands of non-native eucalyptus. The upper portion of the watershed has greater influence of upland vegetation such as coyote brush (*Baccharis pilularis*).

The role of riparian trees in stream restoration projects has primarily been understood as contributing to habitat by providing canopy cover streams, thereby maintaining cool water for fishes and other aquatic organisms. Riparian vegetation has also been shown to provide bank stability through root strength (Mount, 1995). Trophic interactions between contiguous habitats such as riparian forests and streams have been poorly understood and traditionally are thought to have been a one-way chain of nutrient passing, or "one-sided subsidies" (Nakano et al., 2000). Two-way passing of nutrients is important between forest and streams in northern temperate latitudes where temperature and light change dramatically with season, as with deciduous trees (Nakano et al., 2000). Inputs of particulate organic matter from riparian forests are shown here to be major sources of food for aquatic systems, especially macro-invertebrates, for consumption by fish particularly steelhead trout, though net flux direction can change seasonally (Nakano et al., 2000). This highlights the importance of the direct relationship of riparian vegetation on fish populations.

Riparian trees are also important for providing habitat and complexity as large woody debris (LWD). Once trees die and fall into the channel as LWD and logjams, they have a significant effect on hydraulics and channel form. In low gradient streams, organic debris can have a major effect on channel response, by changing the stability of stream banks and by creating scour pools and hydraulic complexities (Keller et al., 1979). In sinuous streams such as Carneros Creek, debris or log-jams may cause erosion which locally scour the stream bottom or increase channel width as water is diverted around the jam (Mount, 1995). In-channel LWD is also important in pool formation because the pieces provide objects for the channel to scour under and create new pools. Live trees that fall due to weight distribution and balance can help stabilize the banks and bars while also shaping the morphology of the channel, though long term they can encourage bank collapse (O'Connor, 2005). Tracking the location and state of debris jams or in-channel wood helps managers understand the development of channels in relation to fallen trees, and anticipate changes in channel form.

Fish Habitat

Carneros Creek is one of the few remaining unblocked steelhead streams draining to the San Francisco Bay, which is part of the motivation for creating an improved management plan for the creek. Riparian trees, log jams, and large woody debris are also important for salmonid habitat during their rearing years as fry and smolts and during out-migration (Leidy, 2007). Steelhead within the San Francisco Estuary may be classified as *ocean-maturing* or *winter* steelhead that typically begin their spawning migration during the fall and winter, and spawn from within a few weeks to a few months after they enter freshwater. Ocean-maturing steelhead typically spawn between December and April, with most spawning occurring between January and March. Unlike other salmonids, they do not die after returning to spawn, but are iteroparous and can travel out to the ocean and then return again, often up to four times in their life (Moyle, 2002; Leidy, 2007).

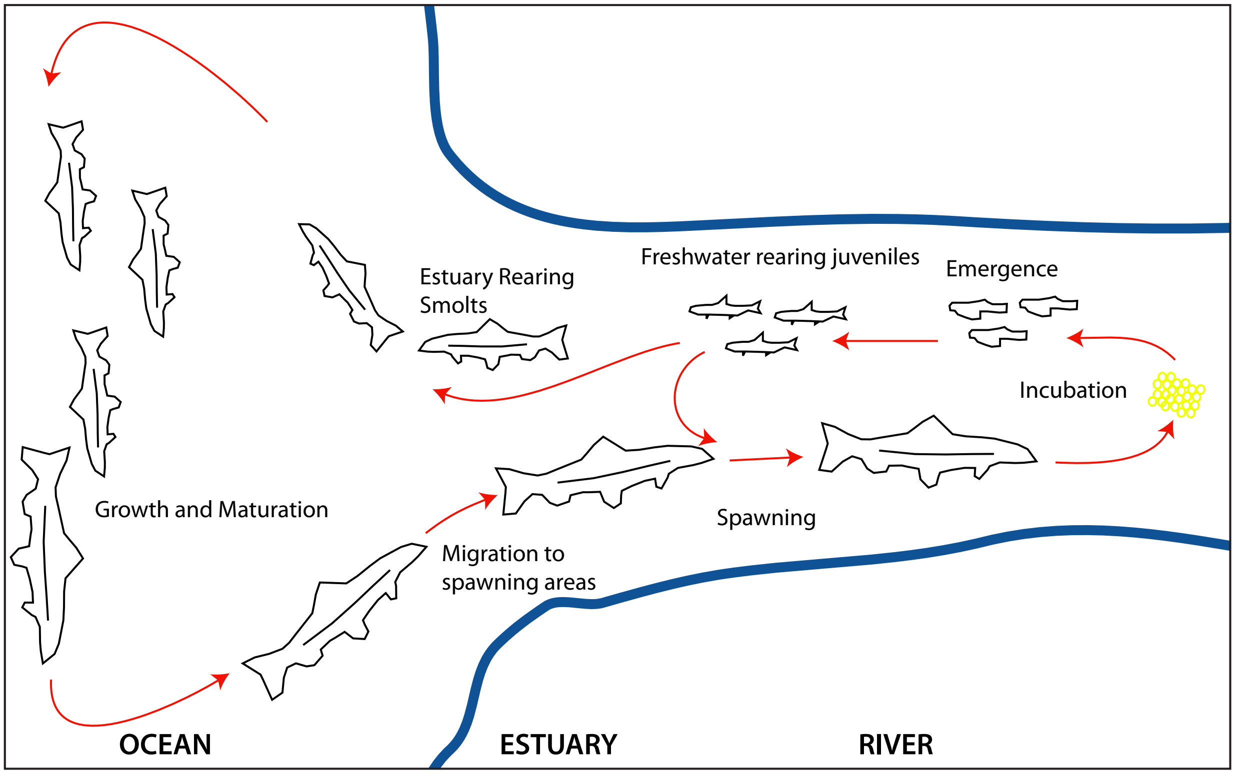


Figure 2.6. Life cycle of Steelhead trout

The abundance of rainbow trout/steelhead has been positively correlated with elevation, stream gradient, dominant substrate size, and percent native species which indicates that field mapping may be useful for locating critical habitat for fishes (Leidy, 2007). However, rainbow trout/steelhead abundances seem to vary depending on total estuary outflow and local stream flow conditions. Great variability in the abundance of fish often exists between years and between age classes (Leidy, 2007). Overall, the current population of steelhead in all estuary watersheds is poorly understood, yet the top causes listed as contributing to the decline of salmonids in California seem to include watershed degradation, diversions, pollution as well as oceanic conditions and over-fishing (Moyle and Williams, 1990).

The Napa County RCD performed snorkel surveys in 2007 and 2008, and found 166 steelhead in May 2007 and 2 in October 2007. They identified 337 individual steelhead in May 2008 and again 2 in October 2008. Surveys were not performed in 2009 (Koehler, J. Pers Comm. Jan 2010).

Land Use History

Human history has had a great influence on the geomorphology and ecology of Carneros Creek. The first recorded European contact in Napa Valley was by Padre Jose Altimira in 1823 on his way to the Sonoma Mission (Hanrahan, 1948). In 1831 there were between 3,000 and 6,000 Native Americans in Napa Valley, composed of several different tribal groups. The Soscol Tribe lived at the southern-most end, nearest to Carneros Creek (Hanrahan, 1948). There is no significant archeological evidence of sizeable settlements near Carneros Creek itself, which may reflect the absence of substantial perennial surface waters in comparison to the reliable source of nearby Napa River, where several permanent Native American settlements have been documented (Grossinger et al., 2003). However, there is evidence that the Soscol Tribe used Carneros Valley, or at least transversed it, as obsidian flakes were found near the current crossings of Las Amigas and Old Sonoma Road (Grossinger et al., 2003).

Fire was likely the most significant long-term change that the Native Americans imprinted on the region. There is ample evidence that the Pomo, Soscol, Miwok and other tribal groups employed fire to manage the Napa Valley to promote plant species that could be woven, made into nets and other products (Grossinger et al., 2003). Grossinger et al (2003) found documentation of a journey taken by Father Altimira in "midsummer" where he reported seeing Native American controlled burning in the hills between Sonoma and Napa, most likely in the Carneros watershed (Grossinger et al., 2003). The regular use of fire by Native Americans in Carneros and Napa Valley as a whole, was likely what maintained the open grassland mosaic, which eventually made the valley attractive to European ranchers (Grossinger et al., 2003)

Mexican History and Land Grants

The management of Napa Valley changed drastically when Mexican land grants were distributed and Native Americans were extirpated, bringing the burning to a stop. Hoofed animals were most likely introduced in 1823 with the establishment of the Sonoma mission (Grossinger et al., 2003). The influence of cattle constitutes one of the first major land use changes in the watershed. Several types of livestock grazed in Carneros watershed between 1827 and 1846, from sheep from the Sonoma mission from 1827-1834, to the thousands of cattle of General Vallejo (Grossinger et al., 2003), to horses in the 1850s (Weber, 1998). It seems plausible that the soil compaction from large numbers of hoofed animals and hardening of the landscape played a large role in the evolution of the watershed and incision in the creek, by increasing runoff and peak flows.

Between 1835 and 1846, the Mexican state parceled out much of Napa Valley in land grants mostly to Mexican citizens. In May 1836, Nicolas Higuerra was ceded two grants one of which was Rancho El Rincon de los Carneros (Hanrahan, 1848). Higuerra ran 2,000 head of cattle and 3,000 horses on his Carneros land, which consisted of 2,500 acres, for a relatively high density of 2 head per acre (Weber, 1998). In 1841, Jacob Leese, brother in law of Mariano Vallejo was granted "5 leagues of choice grassland" bounded by Carneros Creek on the east, extending into what is now Sonoma county (Weber, 1998). After the Mexican-American war (1846-1848) European-Americans bought, squatted on, or traded labor for land to acquire portions of the original land grants (Hanrahan, 1948). Agriculture replaced grazing in the lower watershed relatively quickly following the shift to European-American control of the region (Grossinger et al., 2003).

In the late 1840s and 1850s, Napa Valley was deluged by prospectors for gold, silver (1858) and mercury. Rapid urbanization of Napa City followed soon after, as well as the introduction of vineyards and small-scale wine production (Hanrahan, 1948). In the1870s and 80s, the vines that had become popular were lost to *phylloxera*, as imported rootstocks from France were susceptible to the disease (Weber, 1998). This pest feeds on roots and cuts the flow of nutrients throughout the plant. By this time, there were no longer any Native American communities in the Napa Valley, and the remaining individuals had been forcibly relocated to Lake County (Hanrahan, 1948).

Diverse Agriculture in Napa

In 1948, local historian Virginia Hanrahan observed, "…thousands of Napa Valley's more than 500,000 acres are planted annually in wheat, alfalfa, barley, hay, oats, potatoes, onions, tomatoes and other vegetables (Hanrahan, 1948)." There were also five active dairies in the Carneros Valley through the mid 20th century. The last dairy closed in 1993 (Grossinger et al., 2003).


Figure 2.7. Closed dairy in upper Carneros Watershed and vineyard monoculture (source: Caldwell Cellars)

Diverse agricultural efforts along with dairies and ranching continued in the Carneros Watershed until the 1960s, when another drastic shift in land use occurred; the rapid expansion of commercial vineyards (Grossinger et al., 2003).

Conversion from diverse agriculture to viticulture combined with expansion of vineyards into open space took place in the 1970s and 80s, and continued into the 2000s. Napa Valley has become characterized by vineyard monoculture. Conversion to a monoculture has many of the same impacts as urbanization, in that it creates a highly managed, impermeable environment. Impacts on Carneros watershed included possible incision due to an increase in reservoir storage, creating sediment-starved streams. Possible incision may be due to installation of subsurface and vineyard drainage systems which shunt runoff to the creek. Incision may also be due to increased surface flow from compacted soils in vine production. Episodes of incision can often be attributed to durations of extreme rain conditions over a period of several years. However, according to a study of precipitation patterns in California from 1600 to the present, there was an extended dry period in California from 1840 to 1880. This indicates that the first episode of incision was not due to intensive rainfall (Fritts et al.,1980).

The images below document these changes in these land uses over time. An increased riparian corridor between 1940 and 1993 indicates that when cattle are removed from a landscape, there may be a rebound effect of previously trampled vegetation and compacted soil. However between 1993 and 2009, the photographs exhibit the rapid expansion of vineyards, and of management of the tributary on the left in the form of step ponds, trapping sediment.

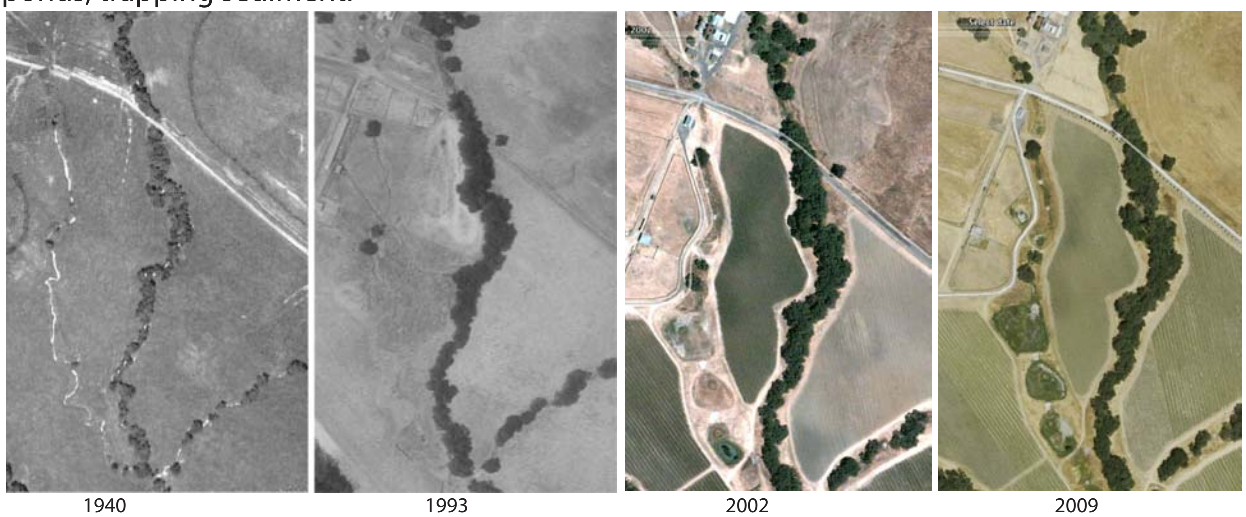


Figure 2.8. Change in land use over time in upper watershed (1940, 1993 from Grossinger et al., 2003) (2002, 2009 from Google earth)

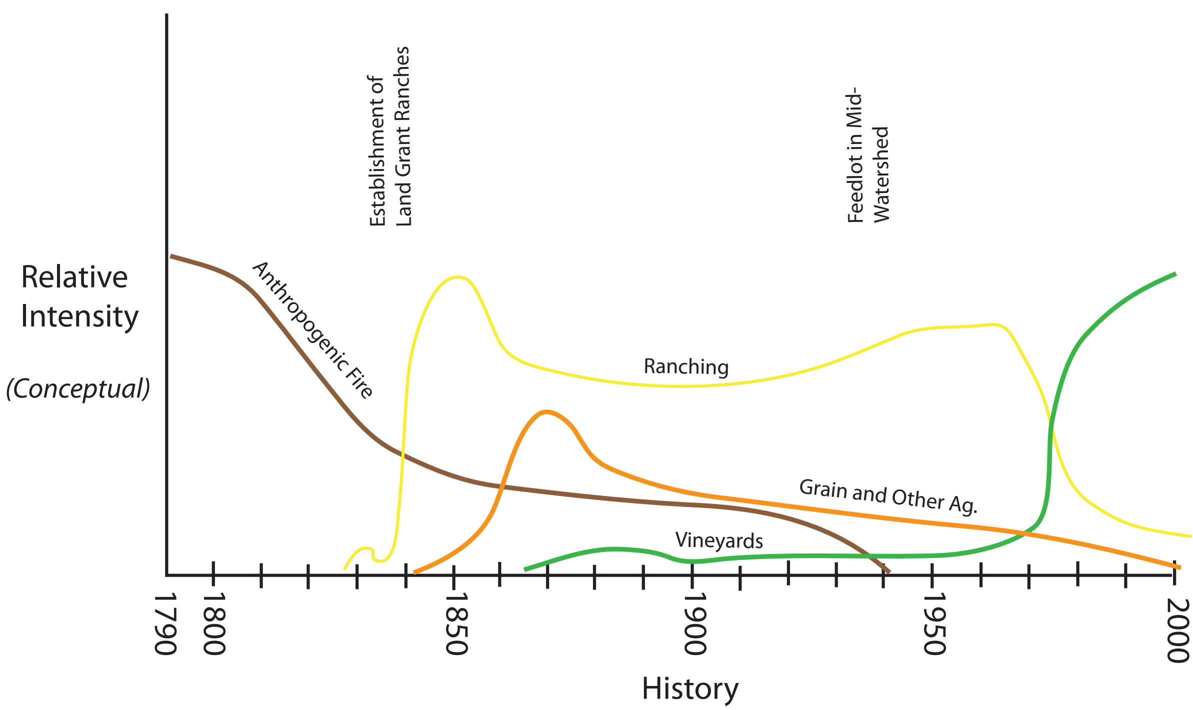


Figure 2.9. Conceptual diagram of land use history on Carneros Creek (Grossinger et al., 2003)

Current Land Use

Current land use in Carneros Watershed primarily consists of viticulture of in the middle and upper reaches of the watershed. There are numerous rural residential parcels in the tidal area of the watershed and in the lower portion of the creek below the Old Sonoma Road Crossing.

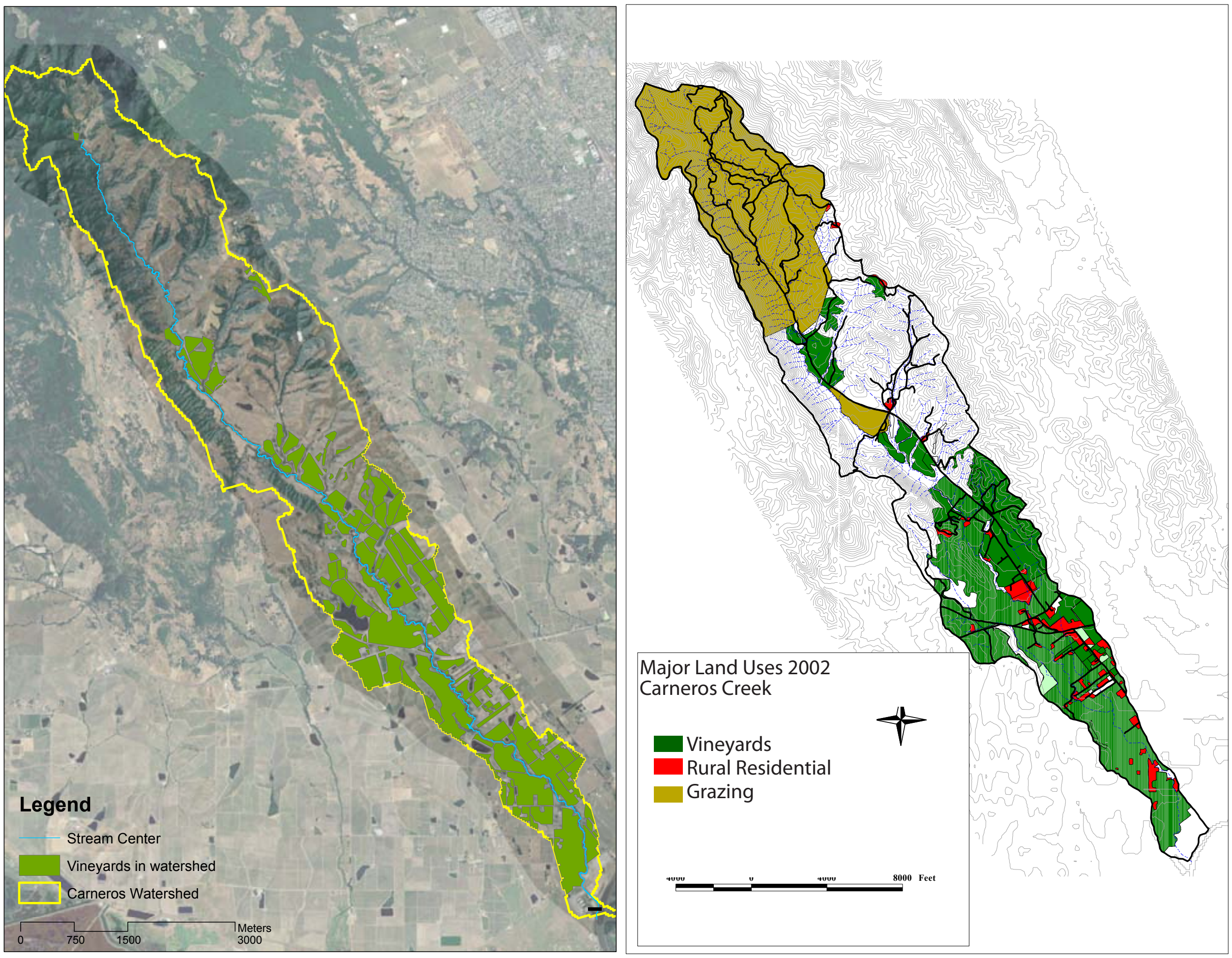


Figure 2.10. Acres of vineyard (Google Earth 2007), Land use map of Carneros Creek (Hagans, 2002)

Out of 6000 acres in the watershed, approximately 1425 acres or 23% is in vineyard production.

Regulatory Framework

Carneros Creek is listed as impaired for fine sediment as a non-point source pollutant under the Clean Water Act under the Napa River Total Maximum Daily Load (TMDL). Fine sediment as a non-point source pollutant covers spawning gravels, thereby limiting oxygen availability to salmonids eggs and larvae and other aquatic organisms.

The Clean Water Act of 1977 (CWA), and its precursor The Federal Water Pollution Control Act of 1972, set up a regulatory structure whereby public agencies are responsible for monitoring national surface and ground waters for acceptable levels of pollution. The Act sets standards for levels of toxicity in water bodies, and regulates waste load allocations for a particular effluent, for example, point source National Pollutant Discharge Elimination System (NPDES) discharge permit. This approach achieved significant results in improving water quality, however, water pollution from non-point source pollution still exists (EPA, 1999).

Section 303(d)(1)(A) of the CWA requires that "Each State shall identify those waters within its boundaries for which the effluent limitations...are not stringent enough to implement any water quality standard applicable to such waters." The CWA also requires states to establish a priority ranking for waters on the 303(d) list of impaired waters and establish Total Maximum Daily Loads (TMDLs) for such waters (EPA 1999). Thus, TMDLs have been developed by the EPA and the California State Water Resources Control Board to address the cumulative impacts of point and non-point source pollution (EPA 1999). TMDLs are targeted at a specific pollutant in question.

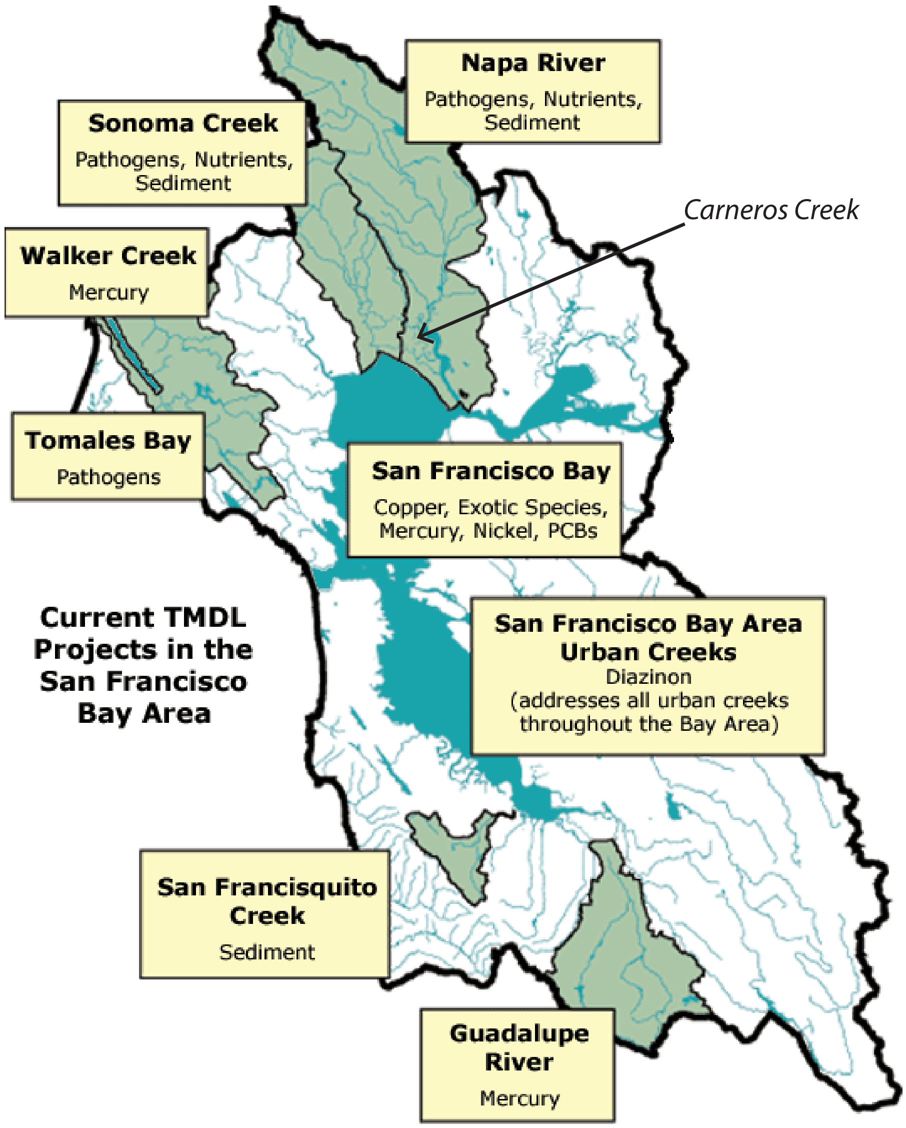


Figure 2.11.TMDL basins in the SF Bay Area (SRWQCB , 2002)

Developing a TMDL in a watershed requires an existing conditions study; quantification of pollution reduction targets; determination of the magnitude of reductions necessary to attain the reduction targets; an identified loading capacity of the stream; and individual load allocations for land use activities (EPA, 1999). To be implemented, a TMDL requires monitoring and enforcement, cooperation and linkage to a management component. Non-compliance can result in large fines. However, the cohesive watershed effort needed to successfully comply with a TMDL is rarely successfully implemented by regulatory agencies, and has yet to be tested in the Napa Watershed (RWQCB, 2006).

Conflict Resolution: Farmers and Regulators

Problems often arise from top-down punitive regulatory approaches to water management. Watershed or land management policy decisions, such as TMDLs, made without input and buy-in from "grass roots stakeholders" often suffer from a disjointed transition between policy, decision making, and successful implementation (Lubell, 2004). Farmer distrust for "regulators" and "government," and vice versa, create an ineffective and non-productive atmosphere. Colling and Christensen (2007) argue that the adoption of strategies that improve trust between regulators and stakeholders in tandem with compliance strategies can lead to an increased acceptance of compliance regulation.

Fish Friendly Farming as response to these issues

The threat of the Napa Sediment TMDL as a 'regulatory hammer' forces farmers to have a collective economic interest in improving water quality (Lubell, 2004). The Fish Friendly Farming Environmental Certification Program is an example of "grass-roots," non-punitive management as an alternative to regulation for solving environmental problems associated with non-point source pollution (Lubell, 2004).

The steps to becoming Fish Friendly Farming (FFF) certified are as follows: After voluntarily enrolling, vineyard managers or owners in Napa, Solano, Mendocino and Sonoma counties attend a series of four workshops, which cover regionally appropriate techniques for sustainable land management including: water and soil conservation; riparian corridor management and restoration; revisions to water systems to increase in-stream flow; and road repair and maintenance. Farmers then create a 'Farm Conservation Plan' to implement Beneficial Management Practices (BMPs) that guide the improvement of land management practices and the implementation of projects for a specific property. The plan is designed specifically to limit runoff of fine sediment. Often a component of the plan will include participation in a watershed planning effort, such is the case with the Carneros Creek Plan. The farmer must implement the actions and projects identified in the Farm Conservation Plan, prior to certification by NOAA, the Regional Water Quality Control Board, and the County

Agricultural Commissioner (FFF BMP Handbook, 2008). Participation in the FFF program allows farmers to comply with the fine sediment TMDL in Napa County and thus avoid from direct regulation or penalties. This approach to compliance with environmental regulations encourages ownership and pride in the ecological functioning of one's farm. It also can provide a marketing tool for small wineries (L. Marcus, Pers. Comm 12-1-09).

Regulatory agencies need to gain the trust of those being regulated in order to promote voluntary compliance of a mandate on a larger scale than parcel by parcel (Colling and Christensen, 2007). As Colling and Christensen (2007) assert, "Trust can form the basis of an effective regulatory strategy." Carneros Creek is an example of a "watershed wide" planning effort that begins with the individual farms going through the Fish Friendly Farming Environmental Certification Program. Five vineyards which border the creek have been Fish Friendly Farming Certified. "Participate in a watershed-wide restoration planning process on Carneros Creek" was a required action in all five plans. This provides the basis for the larger creek-wide study to take place.

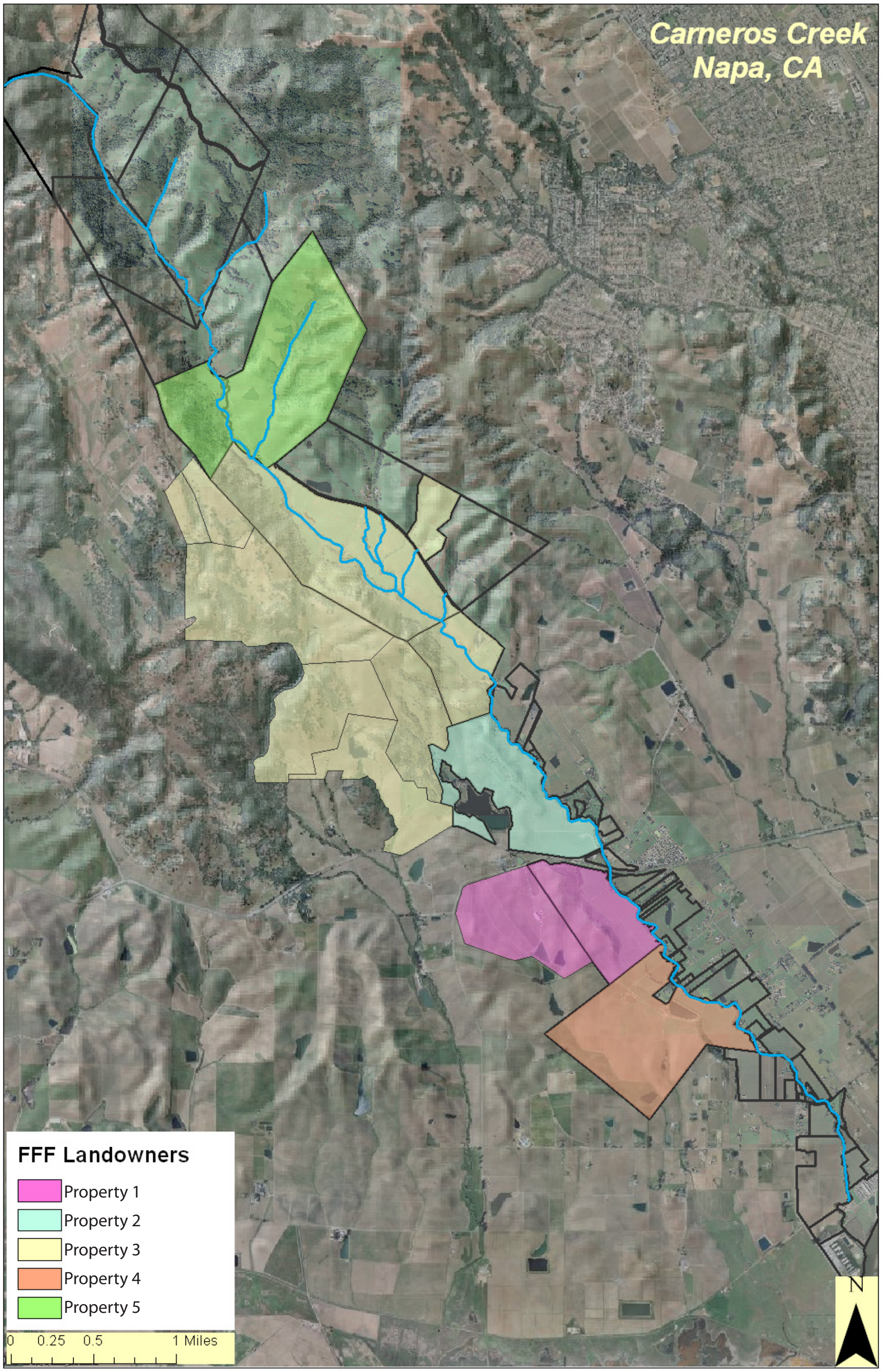


Figure 2.12. Fish Friendly Farming certified sites on Carneros Creek

Chapter 3 | Methods of Research

“Simply put, it is difficult to understand the condition of streams and to design effective restoration measures without understanding their spatial context, the nature of habitat-forming processes, and disturbance history” (Montgomery, 2003). In this pursuit, my fieldwork and methods encompassed three scales of examination: understanding the watershed scale; examining the channel and riparian zones on a reach scale; and, in the context established in the first two scales, looking more closely at several specific locations, or at a ‘point scale.’ I also reviewed the literature relevant to the field and historic documents. Finally, I conducted interviews with landowners. The watershed scale analysis involved using Geographic Information Systems (GIS) data. The reach scale focused on my own field data collection, both qualitative and quantitative in fall 2008 and summer 2009. The point scale, or finest scale, was an indepth look at certain reaches, and serves as an illustrative tool to represent and characterize the state of the creek in greater detail.

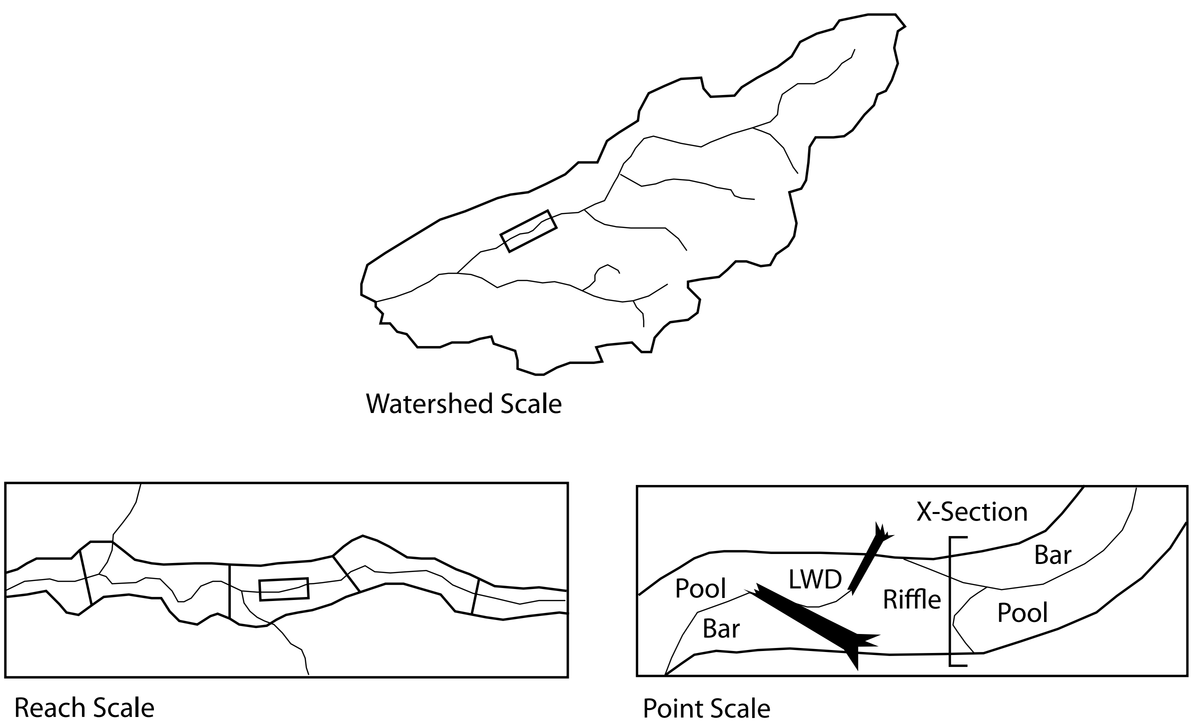


Figure 3.1. Hierarchy of spatial scales in river systems (adapted from Montgomery et al. 1998)

Watershed Scale

Carneros Creek has often been studied in the context of the greater Napa River system, as a part of the TMDL Limiting Factors Study (Dietrich, 2002), and because of development pressures resulting from the high value vineyard land and the creek's location in the threatened Steelhead trout migration zones (Moyle, 2002).

In order to understand the evolution of the channel and the current watershed planning challenges, I reviewed documents prepared by the San Francisco Estuary Institute (SFEI), Napa County Resource Conservation District (NCRCD), and Stillwater Sciences (Grossinger et al. 2003; Dietrich, 2002). These documents contained information on historical land use, anthropogenic effects on the channel, fish habitat, and channel geomorphology.

I used Napa County GIS data to create a base map for the watershed, including coverages of roads, parcels, current land use and soils. I used GIS ArcView 9.3 and the airborne laser scanning, often referred to as LiDAR or Light and Ranging data for Napa County to gain access to previously mapped slopes, debris flow scars, and reservoirs (Dietrich, 2002). LiDAR is an active remote sensing technique that measures the topography of the Earth's surface by gathering 3-dimentional coordinates for features on the earth's surface (Hollaus, 2005). This allows the generation of precise Digital Terrain Models (DTM), or Digital Elevation Models (DEM) for the areas covered by a LiDAR flight (Campbell, 2006). Pairing two or more remote sensing techniques has been shown to increase accuracy levels. For example, scientific researchers and regional planners using are increasingly using LiDAR data sets coupled with orthographic imagery (Hollaus, 2005).

I analyzed existing field data regarding fish habitat taken between 2008 and 2009 in two locations on the stream, and streamflow data taken from a gage on a private vineyard on the creek over an eight year period of record.

Finally, I used publicly available orthographic imagery for Napa County, at 1in: 200 ft. I geo-referenced the Dibblee Geologic quandrangles of the watershed to grasp the underlying geology. These data allowed me to look at processes acting on the watershed, and based on these data layers I split the creek into 4 zones; tidal (2.7 km), middle (4.7 km), upper/tributaries (4.6 km), and headwaters (3.3 km). The Fish Friendly Farming parcels fall into the middle and upper zones of the watershed.

Reach Scale

I used GPS technologies to document and map several aspects of channel geomorphology, riparian vegetation, fish habitat and human land use patterns that currently characterize the channel. Some of these features include failing banks, large woody debris, species of riparian trees and their proximity to the channel, vineyard drainage outfalls, and vineyard roads. I mapped in the middle and upper/tributaries, which was the area currently in vineyard production and to which I had access.

Using 1-meter resolution LiDAR data, I used spatial analyst in ArcView 9.3 to create 0.5m contours, and a slope gradient coverage. First, I created a polygon shapefile to outline the entire creek channel from top-of-bank to top-of-bank using the LiDAR slope data, and to outline the current active channel bed based on slopes and morphologies apparent in the Digital Elevation Model (DEM), using contours and slope as guidance. Second, I overlaid orthographic imagery, and outlined the riparian corridor based on tree canopy. These first two steps were important to determine a defined riparian area, and to differentiate between bed and banks.

As Carneros Creek is a deeply entrenched and sinuous stream, geomorphic features typically encountered along alluvial channels, such as floodplains, and side channels do not exist. However, as a channel incises, it may leave terraces as a legacy of past active channel elevation (Knighton, 1998). The relative height of river terrace sequences has been often used to determine the relative position in time of morphological features. This height is taken relative to the current bed elevation, with the assumption that the highest terrace is the oldest (Knighton, 1998).

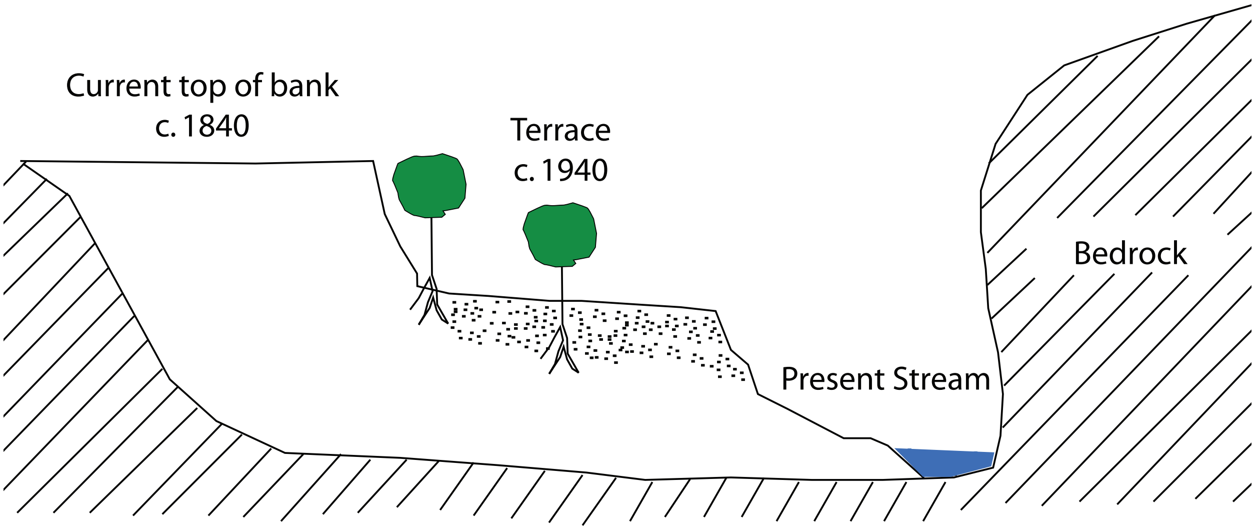


Figure 3.2. Diagram of terrace formation on Carneros Creek (adapted from Knighton 1998)

Within this defined riparian area, I identified terraces, or flat surfaces within the boundary of the riparian zone at least 1 meter higher than the current bed elevation and 1 meter lower than the elevation of the top of the bank, or ground plane.

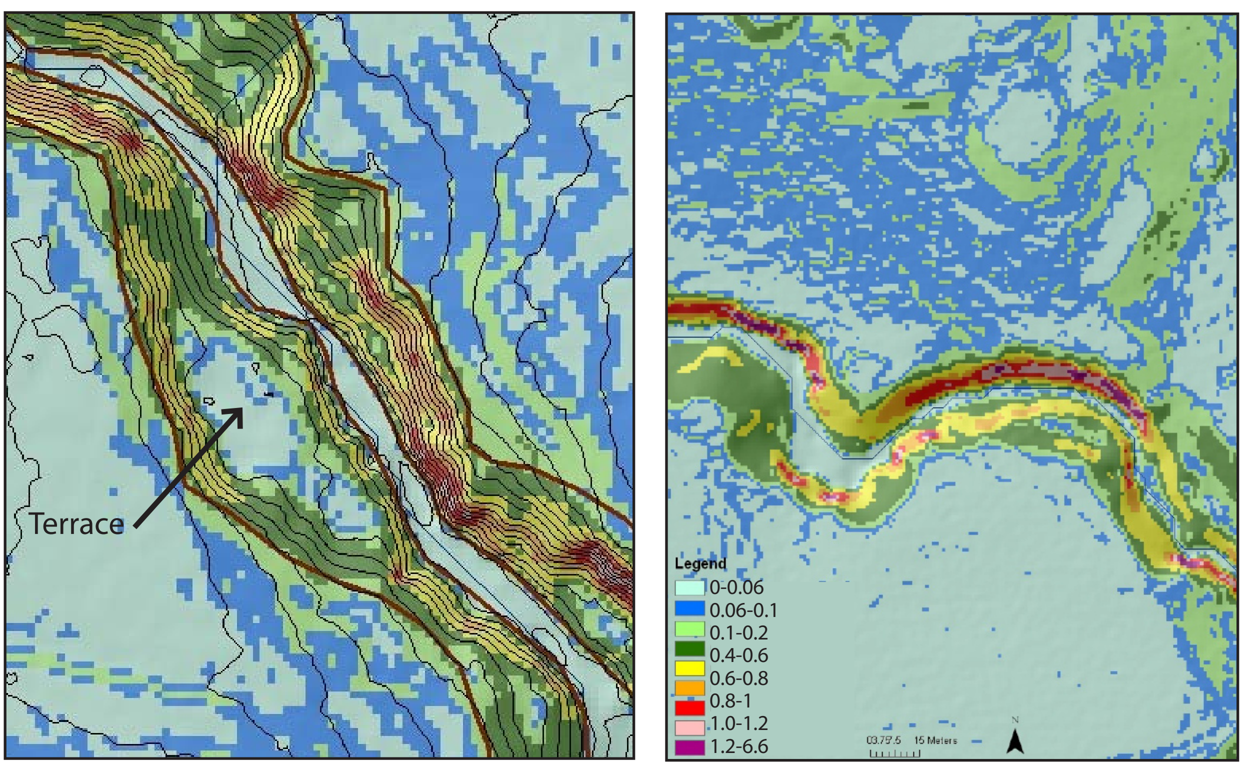


Figure 3.3. 1m LiDAR with 0.5 m contours and slope- terrace and steep banks

I also used this overlay to identify the steepest banks based on where the slopes were above 80% (Figure 3.3). I continued this process over the length of the creek. In this process I identified and delineated 35 terraces; flat areas, within the riparian corridor. I split the corridor into 154 approximately 50-meter long reaches, that were defined by areas of straight channel, or curved channel. Using the ortho-imagery, I mapped locations of vineyard roads as well.

Field Data Collection

I used the hand-help GPS Trimble XT as my primary data collection tool in the field. The Trimble allows the user to load desired editable shapefiles, and a background geo-referenced image, and has an interactive screen. The screen allows the user to view the unit's position with regard to previously geo-referenced features on the landscape, and show the data as it is collected as a map. For each feature collected, I created a "quick form" in ArcPad 7.0, which allowed me to enter pertinent information in the field, such as bankside, depth of pool etc. The features and attributes collected are listed in the table below:

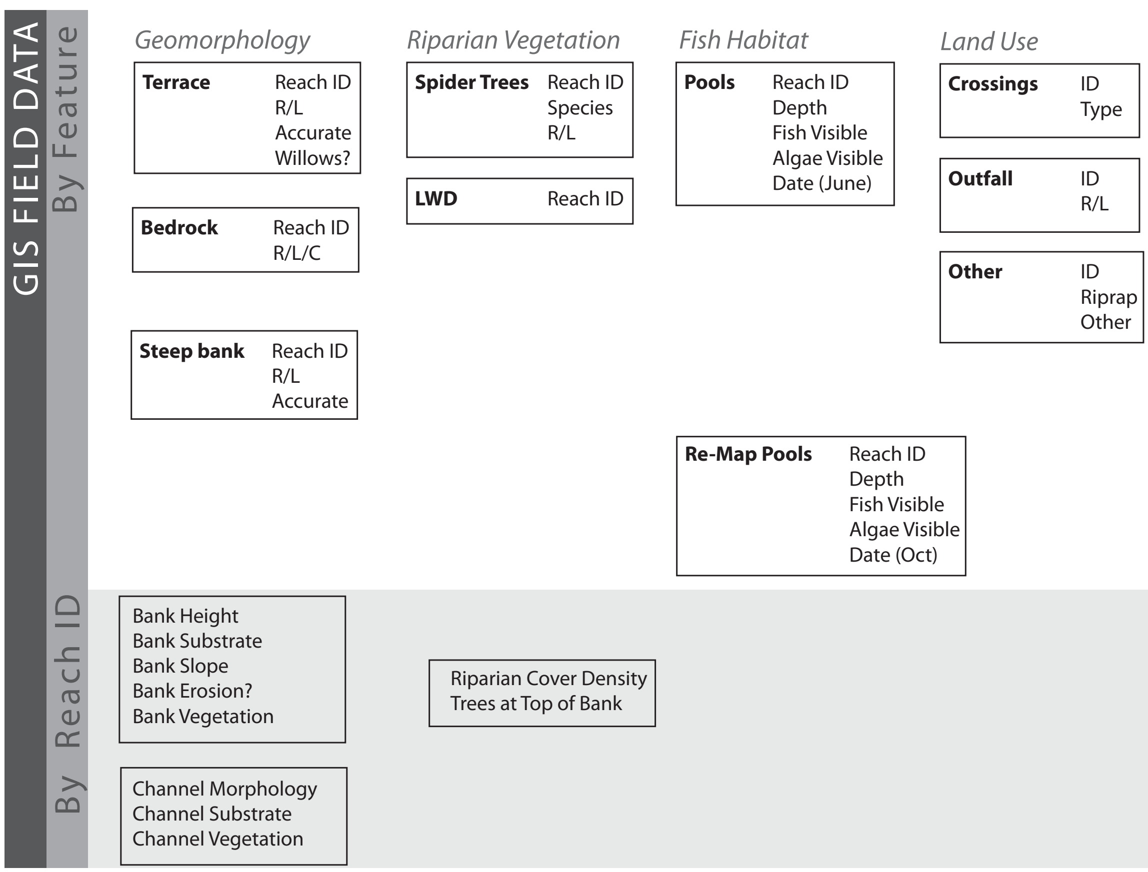


Figure 3.4. Organizational chart of data collected in the field

I began on June 12, 2009 at the most downstream reach labeled 'reach 1,' and moved upstream to 'reach 2,' and so on. I mapped a total of 154 reaches, covering approximately 9 km out of a 13 km total stream length. In each reach, I took GPS points, lines and polygons to map the location and size of the features shown in Figure 4.

GIS Geomorphology Mapping

In each reach, I mapped size, location and type of bedrock in the channel bed. I also ground-truthed each terrace and steep bank against how it was mapped on the DEM, recording bank material and stratigraphy exposed on steep banks, evidence of active erosion and vegetation established on steep bank tops. Banks of an 80% grade or steeper may not be actively 'failing,' but may be an indicator for liklihood of future bank instabilities. For terraces, I noted LiDAR accuracy by judging if 1) the terrace was at least 1 meter below the elevation of the top of bank elevation 2) the terrace was at least 1 meter above the current bed elevation 3) the terrace had vegetation and was not regularly scoured indicating it was abandoned and not hydrologically connected to the current channel, except during very large events. I also noted what kind of tree species were present, mapping the location of single-stemmed willows.

GIS Riparian Vegetation Mapping

In each reach, I mapped location and species of 'spider trees.' This describes a growth form that is common in entrenched river systems whereby a tree establishes on a river bank, and as the bank erodes away and the channel bed drops, the trees roots are left hanging over the edge of the bank, recalling the legs of a spider. I define a 'spider tree' as one whose roots are more than 1/3 exposed in mid-air, indicating that the soil structure originally supporting the tree has been eroded away. The spider trees on Carneros Creek are balanced at an equilibrium, where their roots hold them up on the banks and their branches splay out over the channel. I also mapped the location and angle of large woody debris that crossed at least half of the channel bed.

Figure 3.5. Example of spider tree (left) and fallen spider tree (right)

<u>GIS Land Use Mapping</u>

In the case of land use, I mapped location and type of crossing (bridges, at grade crossings, culverted crossings) as well as location of drainage outfalls. I also mapped the location and extent of riprap, and the location of weirs, both functional and non-functional. For each weir, I noted signs of deposition and aggradation of sediment, or incision and degradation around the base of the structure.

<u>GIS Fish Habitat Mapping</u>

Finally, I mapped the location, size and maximum depth of each pool in the reach, while noting visible presence or absence of fish, and algae. I completed this first pass between June 12 and June 26, 2009, and re-walked the creek in the first two weeks of October 2009 to remap only the pools, and note presence or absence of fish and algae. I measured in the same locations, and used this comparison to view where pools persisted over the summer. This inevitably changes each year, but as the 2009 water year was particularly dry, this year is a good indication of persistence patterns.

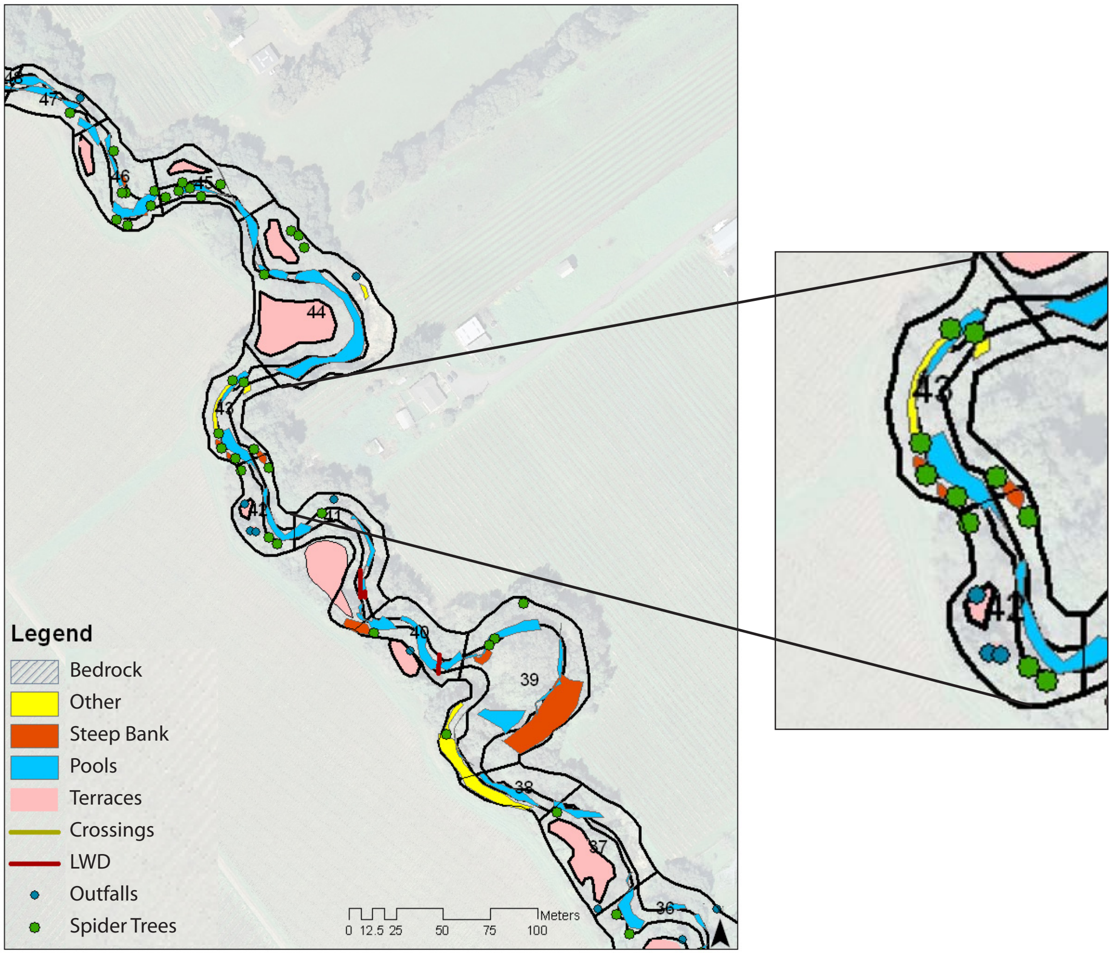


Figure 3.6. Example of reach scale GPS data collection, and detail

Reach Scale Qualitative Descriptors

Aside from collecting GPS data for each reach, I described the qualities of each reach qualitatively.

<u>Geomorphic Descriptors</u>

Using the data table shown in figure 7, I described the qualities of the channel bed morphology as bar-pool formations, glide formations, or step pools. I used bedrock as a descriptor in the upper reaches of the creek, where the channel was bedrock-dominated. I described the substrate of the channel as mud/silt, sand, gravel, pebbles and cobble. In each polygon I described the slope or position of the right and left bank as either vertical, laid-back or slumped. I used a meter rod made of PVC piping to measure the height of each vertical bank. I described the composition of the banks as siltstone, sandstone, stratified, gravel lenses, conglomerated silts and gravels, vegetated or obscured. For each bank side, in each reach, I described the condition of the bank as actively eroding, undercut, vertical but not eroding, or riprap. Designation as "actively eroding" was based on observed features such as sloughing, recent failures, or fallen blocks.

<u>Riparian Vegetation Descriptors</u>

I also described the vegetation conditions in the channel. Several reaches had large willows growing mid-channel, as well as horsetail (*Equisetum spp.*), sedges (*Cyparus spp.*) and other aquatic plants. I also noted the condition of vegetation on each bank, considering whether there were invasive plants, exposed roots, or no vegetation whatsoever. In terms of riparian forest cover, for each reach, I noted what types of trees, if any, were on the top of the bank, and qualitatively described the density of riparian cover as low, medium or high. Low density meant that more than 50 percent of the channel was exposed to the mid-day sun, medium density described a dappled condition with 75 percent shading, and high density tended to be in places that were confined, squeezed against hills, where 100 percent of the channel was shaded by riparian forest.

<u>Land Use Descriptors</u>

For each reach I noted if houses, sheds or vineyards were visible from my position in the channel, and any other signs of management such as willow walls.

In all reaches, there was a complex mix of all the factors of which I was taking note. I recorded the dominant characteristic, noted a mix of characteristics, or took what was average to classify the reach.

	Channel				Banks													Cover	
Reach	Morph	Substrate	Veg	Description	Height (m)		Substrate		Slope		Bank Erosion		Veg (sp)		Trees at top		Density	Notes
					R	L	R	L	R	L	R	L	R	L	R	L		
51 (check)	BP	C (big)	A EQ		3	same	S	S	V	V	—	—	BLM TBL OA EU	SB BB BL V OA	Q	LO BLM SB	H	banks not as high small slump on (L) bank

Figure 3.7. Data table for descriptive reach scale data collection

Point Scale

Channel Surveys (Geomorphology)

Since any management plan would encompass the wide variety of conditions mapped in Carneros Creek, I chose nine representative reaches, distributed throughout the creek, to examine more closely. After establishing baseline data for the channel, banks and riparian zone, from the GIS and field mapping, I selected the reaches as representative of the creek. Channel geometry changes dramatically from the wide, sinuous, undulating downstream reaches with banks up to 6m tall, to the bedrock-confined middle reaches, to the step pool, sandstone reaches near the top of the mapped section of the creek. I also selected the sites illustrating the variety of bank slope positions (some set back, some vertical). At each cross section, I surveyed cross sections, using an auto level and stadia rod, monumenting the cross sections with rebar on the top of each bank.

I surveyed a 50-meter long profile at each cross section, and surveyed high watermarks. I conducted pebble counts at each cross section using the Wolman method (Wolman, 1954). To do this, I randomly sampled approximately 100 stones from the cross section and determined the full grain size distribution, from which I derived the median grain size (D_{50}) for each section. I carried out this fieldwork from August 1 to August 15, 2009.

Tracer Gravels (Geomorphology)

In order to generally understand bed mobility and sediment entrainment, I surveyed two cross sections in the middle portion of the creek (reach 34 and 61), and after performing pebble counts, I set out tracer gravels (Wilcock, 1997). At intervals of 50 cm along the surveyed cross section, I replaced a cobble with a similarly sized rounded piece of quartz. When no quartz pieces matched the size of gravel to be replaced, I spray painted the rock in place, and noted its size. The result was a line of numbered rocks crossing the channel. After the few flow events of the winter of 2008-2009, I returned periodically to check if the bed had moved, thus dislodging, and transporting the painted or quartz clasts. During my point scale field work during the summer of 2009, I resurveyed these cross sections and mapped which clasts had moved in the storm of the year, and performed sediment transport analysis of what flows can move which sizes of rock in these reaches of Carneros Creek.

Temperature Data Loggers (Fish habitat)

Since part of the management plan involves evaluating fish habitat quality, I monitored water temperature over the summer to determine if high water temperatures in Carneros Creek are a limiting factor for over-summering steelhead. From the GIS data I had collected regarding pool depths, I selected the six deepest pools on the creek and returned to those reaches to deploy Hobo Temperature data loggers (June 15-17 2009). At each pool, I attached the Hobo Temp data logger to a rock with a zip tie, and connected the zip tie to a piece of fishing wire. I tied the fishing wire to a root or tree branch above the pool and flagged it. I measured the total depth of each pool, the depth of the data logger at deployment, width of the pool, and sketched the location of the data logger. I used a spherical densiometer to measure the tree canopy cover at each site. I also took coordinates of the data logger using the Trimble XT.

Dendrochronology (Riparian vegetation)

Ecology and plant communities are inextricable from geomorphic conditions found in a creek. Willow trees (*Salix spp*.) usually establish on or near the channel bed or lower banks, where their roots can easily reach groundwater. Because of this, their tree rings provide a proxy for dating channel morphodynamics including a minimum age of the terrace formation, and a relative rate of incision of the channel (Scott, 1996).

During the initial mapping phase, I identified terrace features, and whether or not they had been accurately predicted by the LiDAR data. At each terrace, I noted if there were single stemmed red willows (*Salix laevigata*) growing on the terraces.

On July 12, 2009, I cored 13 red willow trees (*Salix laevigata*) on 7 terraces in the middle reaches of the creek. Terraces occur only downstream of the sandstone control, and not all terraces had single-stemmed willows growing on them. Using borers, I took two to three cores per tree and stored and labeled them in paper tubes. I dried the tree cores for two days and then mounted the cores with glue onto balsa wood stands. Once the glue was dry, I used a microscope ring-reader to count the rings developed by the tree. Cores that hit the pith of the tree could render a more complete picture of the age of the tree. For cores that did not hit pith, the age of the tree is considered a 'minimum age' (Stokes, 1968).

Predictive Model

The challenge in using these three scales of examination was to integrate these data sets in order to develop a land use evolution theory for the channel, and evaluate its current state (aggrading or degrading). A further challenge was to connect reach-based qualitative data with the feature-based data, prioritize areas of bank which are most 'unstable' and prioritize areas which are most important for over-summering fish.

I used Microsoft Excel and GIS software to look at trends over the creek. I overlaid geomorphic and physical conditions aligned with the biotic and human interventions to evaluate poor fish habitat or potentially good fish habitat, and to direct management strategies for bank failures.

In order to combine these data, I used GIS and a suitability model, and a set of criteria for determining risk for bank instability or potential for fish habitat. The criteria and weighting scheme came from literature and in field observations.

<u>Suitability Analysis</u>

Suitability analyses, and specifically multi-criteria decision analysis (MCDA) use data as spatial interpretations, or predictors of an activity (Malczewski, 2004). This type of analysis involves input in the form of map layers, and spatial data, as well as user-defined values of importance prescribed to each layer. The aim in using MCDA methods is to provide a basis for evaluating a number of alternative choice possibilities on the basis of multiple criteria (Store and Kangas 2001). The decision maker directly assigns a weight of 'relative importance' to each attribute using the literature and expert opinions. We obtain a total score for each alternative by multiplying the importance weight assigned for each attribute by the scaled value given to the alternative on that attribute, and summing the products over all attributes.

When the overall scores are calculated for all of the alternatives, the alternative with the highest overall score is chosen (Malczewski, 2004). Sensitivity analyses are used to correct for error in the suitability model. By adjusting the weights by testing out different weighting scores the user hones the weights to be appropriate to the values of the factors as a decision is not usually directed by a single driver (Rohde et al. 2006). Habitat suitability modeling is often used to produce probability maps depicting likelihood of occurrence of certain species and to find out properties of preferred habitats, likewise, bank stability modeling is used to produce maps of likelihood of occurrences such as bank instability, as a general guideline for land managers (Store and Kangas, 2001) As Store states (Store et al, 2003), determining the weights is a political and value-laden decision based on combining different kinds of objectives. It is also a case-specific process and it has to be made separately for areas with different habitat and physical properties and objectives for the project.

Model development

Using MCDA methods and the data described above, I developed a set of weighted criteria to answer two questions: Where are banks most likely to be unstable, and where is Carneros Creek likely to support healthy steelhead populations. Habitat suitability can be measured by a habitat suitability index, which is a non-dimensional variable describing the priority of the habitat with respect to the needs of the species (or group of species) under consideration. Typically, it can be assigned values between 0 and 1, normalized to one, and estimated based on the measurable habitat characteristics. For producing habitat suitability indices for large areas methods enabling the management and analysis of large amounts of data are needed as well as the calculation parameters describing the most essential habitat characteristics (Store and Kangas, 2001).

Criteria for Suitability Analysis and Primary Weighting Scheme

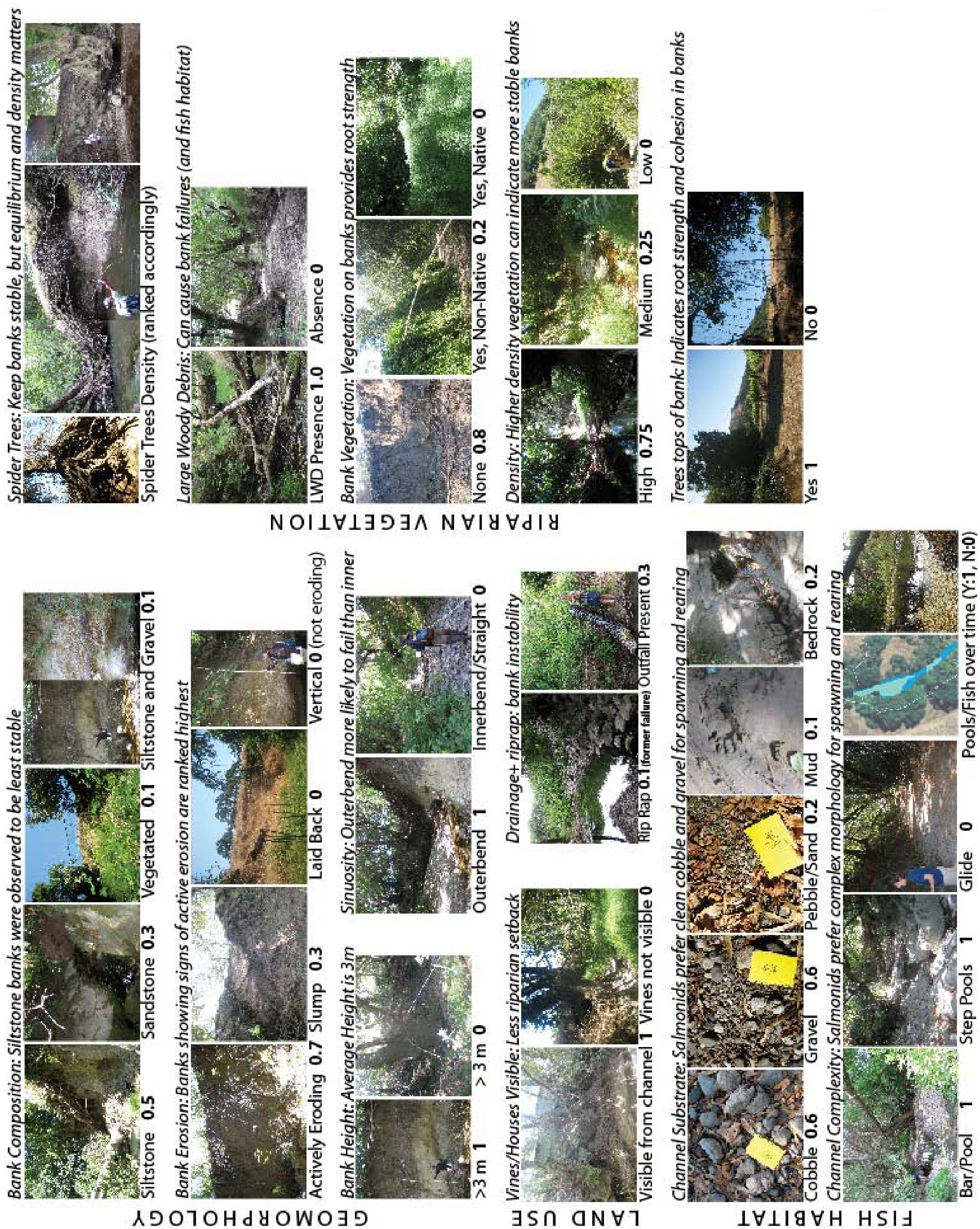


Figure 3.8. Criteria weighting scheme based on field observations and literature review

When considering a specific place within the study area, the MCDA model sums the criteria present and outputs a score. The scores are then broken down into five categories using natural breaks, and classified as falling of a spectrum between 'most stable,' to 'least stable.'

Meeting with landowners

Finally, after the initial data analysis was completed, I met with several of the landowners involved in the project to show them my initial results, gain their insights and feedback, and determine if the GIS results matched their on-the-ground experience.

Chapter 4 | Watershed Management Strategies

You cannot step in the same river twice, for the second time it is not the same river
-Heraclitus (535-475 BC)

This Carneros Creek project is a composite of adaptive management and passive restoration, driven by natural processes and implemented by the landowners. Because the project is entirely voluntary, and the land privately held, the Carneros Creek project has the flexibility for a successful mesh of adaptive management, passive restoration, and the 'erodible corridor concept,' to create an 'anticipatory management' strategy.

It is useful to understand trends in river and watershed management over time in an attempt to understand how new philosophies of management can take hold. The degradation of riparian and aquatic ecosystems in the U.S has been well documented. The effects of degradation include loss of native species, changes in magnitude and timing of seasonal flows, loss of riparian forests (Kondolf, 1995). The causes of riparian degradation include dams, land use changes, climate changes, increased populations, timber harvesting and other resource extractions (MacIver, 2001). However, solutions to such widespread degradation have been the source of much contention among scientists, and water resource managers. Fine-scale assessments of degraded rivers and streams are largely unfeasible due to personnel and funding constraints. Most importantly, river systems are dynamic. In order to be successful, restoration and management professionals and practitioners must understand and plan for expected variability in the hydrologic, geomorphic, and vegetation processes, as well as acknowledging the temporal and spatial variability in watersheds (Montgomery, 2003).

There have been many ways of managing and remediating streams throughout the 20^{th} century, ranging from classifications, spot and large-scale engineering approaches, adaptive management and others. Most have had limited success and new approaches and methods of evaluation continue to evolve (Kondolf, 1995).

Adaptive Management

The1980s and early 1990s experienced a shift from engineered approaches to adaptive management. Holling's 1978 *Adaptive Environmental Assessment and Management Adaptive Management of Renewable Resources* was extremely influential (Walters, 1986). Holling found conventional environmental management methods at odds with the emerging model of ecosystem dynamics (Ruhl and Fischman, 2010*)*. Under such a dynamic model, management policy must prioritize collecting data, establishing measurements of success, monitoring outcomes, using new information to adjust existing approaches, and experimentation, or a willingness to change (Ruhl and Fischman, 2010*)*.

In other words, adaptive management is a strategy that acknowledges that scientific research could go on forever, and that scientists might never study the system in question 'enough' or completely. Adaptive management allows for management actions to proceed in the face of uncertainty and certain change (Downs and Kondolf, 2002). The strategy is comprised of a multi-phase adaptive management cycle that is iterative in nature. The cycle begins with (1) definition of the problem; (2) determination of goals and objectives for management of ecosystems; (3) determination of the ecosystem baseline; (4) development of conceptual models; (5) selection of future restoration actions; (6) implementation and management actions; (7) monitoring and ecosystem response; and (8) evaluation of restoration efforts and proposals for remedial actions. (Stankey et al., 2005 ; Ruhl and Fischman, 2010*)*.

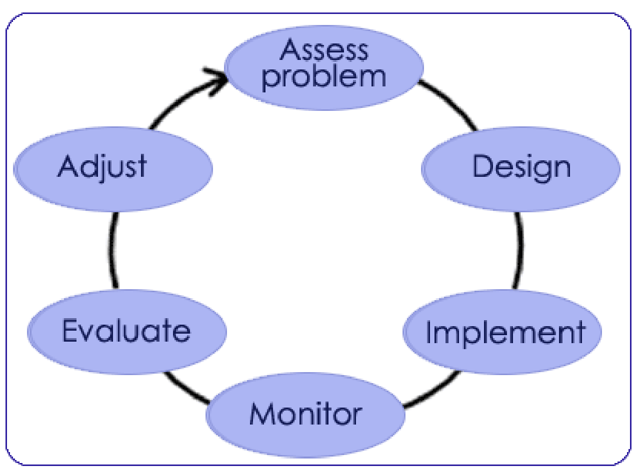


Figure 4.1 Adaptive managment conceptual model

Criticism of Adaptive Management

While adaptive management set out to underscore uncertainty in trying to control, restore or manage nature, it quickly became bottle-necked in the timing of phases, permitting and procedures of policies. Monitoring and evaluation provide the key for feedback to determine progress, and this pace of decision-making does not match with the pace of policy formation, implementation, or permitting (Walters, 1997).

Ruhl and Fischman (2002) argue that although the mantra of "learning by doing" may capture the essence of adaptive management it hardly conveys how to do so. Thus, adaptive management has been stigmatized as being an approach of 'muddling through,' and trial and error. There have been many attempts to implement adaptive management with few measurable successes (Schreiber et al., 2004). Drawbacks include risk aversion by land managers, inadequate institutional structures or stakeholder participation, as well as a lack of commitment to monitoring, evaluating and reporting. Most of these result from the uncertainty of funding sources and institutional memory loss which often accompany large projects (Walters and Holling, 1990; Schreiber et al., 2004). Another criticism is that adaptive management projects take too long (Habron, 2003). Finally, most agencies seem to prefer to fund tangible construction projects rather than monitoring projects. Completion of a construction project is easy to report while an ongoing adaptive project does not fit into an agency's yearly reporting cycle (Kondolf, 1995).

Passive Restoration

"Passive restoration," or process restoration represents a shift away from the confines of both engineered approaches and adaptive management. Passive restoration is an alternative approach that aims to restore ecosystem function by allowing the system in question to recover without engineered solutions and over-management.

While active restoration includes such techniques as planting, engineering and in in-stream interventions, passive restoration in rivers is defined as removal of the stresses that cause degradation, or letting the river adjust as it would if no anthropogenic constraints existed, such as changing land uses, or moving buildings and activity away from the river corridor (MacIver, 2001).

There are many types of passive restoration techniques. Many riparian and stream ecosystems have largely been degraded by ecosystem-wide, off-channel activities. They cannot be restored by focusing solely on manipulations within the channel (Kauffman et al., 1997). The use of enclosures by fencing has been a successful example of passive restoration. It has been found that riparian areas within enclosure fencing have more heterogeneity of vegetation, and thus greater sources for large woody debris (Opperman et al., 2004). Farmers often fence their vineyards to create a buffer between wildlife and the grapes, such as deer, turkeys etc. However, it may be that fencing is a form of passive restoration in the absence of buildings or houses, or stored chemicals on the creek banks. It forcibly maintains a riparian corridor. Opperman et al. found that in-stream engineered restoration projects are more expensive than riparian enclosures or riparian fencing (Opperman, 2004). However this also excludes people from interacting with the stream. This technique applies strongly to the properties in the tributary reaches of Carneros creek, on both sides of the creek, as well as the property just upstream of the Hwy 121 bridge, which is indeed already fenced. Along this part of Carneros Creek, the right bank is either fenced to protect the grapes from wildlife or unfenced but with a wide riparian forest. The left bank in the lower reaches is dominated by rural residential land uses or a golf course, which are very close to the bank, compromising fish habitat and bank stability.

Another type of passive restoration is known as "Espace de Liberté" or the 'erodible corridor concept', which recognizes the role of bank erosion in restoring geomorphic process and providing ecosystem services, allowing the river corridor to adjust itself. Piegay (2005) argues that this concept might be most useful for managers of "free-moving meandering and braided rivers in alluvial plains that can reasonably be expected to remain within a defined corridor on the time scale of interest (several decades)." It seems also most applicable in undeveloped areas such as open space or where landowners experience a cost benefit to allowing the banks to fail, such as farmers who pay each year to riprap their banks, only to have them fail again (Piegay et al., 2005).

Passive restoration requires an understanding of the geologic, geomorphic, hydrologic and vegetative influences acting on the fluvial system. However, passive restoration may take an unacceptably long time given that there are species at risk. Trees often take a century or more to recover from logging, and land use changes, such as damning of streams and changes in surface permeability, cannot be undone (Montgomery et al., 2003).

Case studies: Napa River and Rutherford Dust

There are two prior examples in Napa County of such voluntary watershed management on private land, for a common purpose. Project staff and participants acknowledge that the dynamism of rivers can not be fixed by a single landowner, and that cooperative action allows for a better chance at long term solutions. These two projects are the Rutherford Dust Restoration project on the main stem of the Napa River and the second, the Napa Sediment Reduction and Habitat Enhancement project, also on the main stem.

The main stem Napa River was an alluvial multi-thread channel channelized and bermed for agricultural reclamation and flood control. This change has altered fluvial geomorphic processes and has had degrading effects on the habitat value, flood protection capabilities and also leads to continued downcutting and bank collapse. The drivers are largely the same as on Carneros Creek and the degradation of the Napa River also concerns local landowners. Bank erosion and slumping have resulted in the loss of valuable vineyard land and damaged infrastructure such as roads and bridges. Economic implications include the direct costs for private efforts to prevent and repair flood damages, as well as indirect effects resulting from lost vineyard productivity (County of Napa, 2008).

<u>Case Study: Rutherford Dust</u>

In 2002, landowners in the Rutherford appellation organized to address problems in the Napa River channel. They created the Rutherford Dust Restoration Team to spearhead the project. The project had similar objectives to the proposed approach to Carneros creek, minimizing the need for on-going channel stabilization and repair work by establishing a preventative maintenance program consistent with long-term objectives; and re-establishing geomorphic and hydrologic processes to support a self-sustaining, continuous, and diverse native riparian corridor. The project also involves working closely with landowners to address their interests in adjacent farmland and property (County of Napa, 2008). The practitioners suggested performance of a yearly survey to document any large scale changes in the channel and are in the process of designing in-stream structures such as rock weirs and large woody debris in order to create channel complexity (County of Napa, 2008).

Case Study: Napa River Sediment Reduction and Habitat Enhancement Plan

This effort continued the landowner collaboration started by the Rutherford Dust project. It is an enhancement plan covering nine miles of the Napa River between the Oakville Cross Road bridge and the Oak Knoll Avenue bridge, the reach south of the Rutherford project area. Numerous landowners along this reach of the Napa River were enrolled in the Fish Friendly Farming program and experienced bank erosion and flooding. The Oakville to Oak Knoll Reach suffers from channel incision with bank collapse, erosion of channel bedforms important to salmonids, and a reduced riparian corridor due to the lack of a functional floodplain. The field methods undertaken by the Napa River Sediment Reduction Plan were very similar to the Carneros Creek methods (Laurel Marcus, Pers. Comm. Nov. 2009).

These two nascent projects are some of the few examples of management strategies being implemented in California over large areas of privately owned land with multiple landowners. Both projects focus their restoration and funding efforts on 'nodes' or priority areas, though they vary in the implementation philosophy. The Rutherford Dust project is incorporating in-stream structures in their plans while the Oakville to Oak Knoll project takes a more passive approach. The Carneros Creek project can learn from these projects, specifically the monitoring program of the Rutherford Dust plan and from the fact that landowner relationships are the most important component in both of these projects.

Carneros Creek Comparison

This is not the first study and plan for Carneros Creek. In 2001, landowners, managers and residents of the Carneros Creek Watershed formed a stewardship group (Carneros Stewardship) to promote an open dialogue among interested individuals regarding local natural resource concerns and issues (ACE, 2006). In March 2002, the CALFED Bay-Delta Program granted funds to the Napa RCD to provide support to the Carneros Stewardship in conducting a watershed assessment and developing a watershed management plan.

The Army Corps of Engineers led a design team to prepare a conceptual restoration plan on a 1-mile reach of Carneros Creek, as a demonstration project, from highway 12/121 upstream (ACE, 2006). The issues raised were the same as they are currently; bank erosion and protecting fish habitat, but the approach was much different. Objectives of the project were to stabilize bank erosion to limit potential property damage, in consideration of the habitat value of such erosion; and to maintain existing riparian vegetation to promote suitable aquatic and terrestrial habitat (ACE, 2006).

The Army Corps funded the field work on the creek which consisted of nine cross sections and field analyses, but did not include comprehensive mapping. The plan addressed restoration at specific cross sections. The proposed approach by the Army Corps was to excavate the upper bank and mechanically lay it back to an angle of 1.5 horizontal to 1 vertical. The toe of the restored bank would lie at the top of the cohesive silt-clay strata found in the lower bank. The restored bank would be treated with a variety of bio-engineering approaches such as willow mattresses and geotextiles, and rock barb at the toe of the banks.

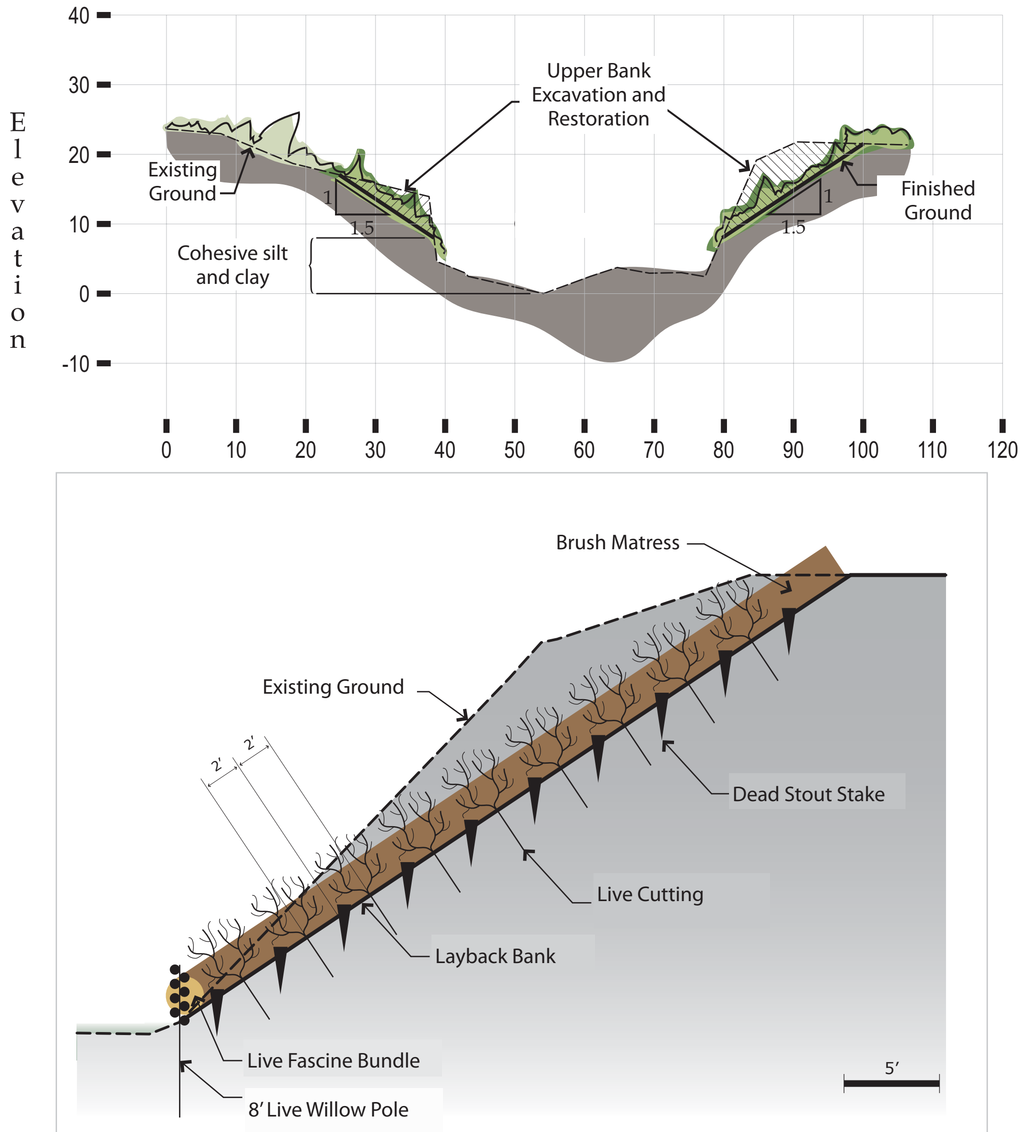


*Figure 4.3. Examples of Army Corps approach to Carneros Creek (*ACE, 2006*).*

Slopes of 1.5H:1V are relatively steep by design standards, however the Army Corps consultants O'Connor Environmental reported that the proposed improvement in slope angle to 1.5H:1V would provide bank slopes comparable to the angle of repose of typical alluvial material. They expected the combination of laying banks back to a more stable angle and the establishment of root strength would prevent further bank retreat over a period of decades (O'Connor, 2005).

This approach to bank treatment and restoration would have incurred a loss of 15-20 ft of land along the upper bank, as well as the enormous cost of operating heavy equipment for excavation along the entire channel. The approach also involved cutting down most of the existing riparian vegetation and replanting, which would have significantly disrupted habitats and removed the canopy cover of the stream, increasing water temperatures (ACE, 2006).

According to the consultants who worked on this plan, it did not move to an implementation phase because of the enormous cost. This project is emblematic of many river restoration and management plans that incur more financial and environmental costs than benefits. It is for this reason that we are attempting to outline a new approach to river management that is less engineered, less costly, and that benefits farmers, fish populations and river dynamics over time.

Anticipatory Management

The Carneros Creek project is a composite of adaptive management and passive restoration, driven and implemented by the landowners, creating what I term '*Anticipatory Management.*'

Anticipatory management focuses on areas along a creek corridor that are most likely to change, and prioritizes treatement around these areas. It involves working with landowners and farmers to identify these areas ahead of time, and to move crops, houses and roads away from the creek in these specific places in anticipation of change. This avoids piecemeal management because, although the creek is managed property by property, all landowners agree to a set of principles of anticipating change based on a comprehensive study.

This may prove to be a less disruptive and less costly option for managing rivers, by focusing efforts on allowing the river enough space to make anticipated changes in strategic places. Anticipatory management does not include use of grading or heavy machinery, but is as passive an approach as possible, though it includes revegetation of riparian species. It falls within the traditional definition of 'adaptive management' in that there must be constant monitoring and evaluating of stream changes and bank conditions, and changes made accordingly to management strategies based on the evaluation. This rests on a continued relationship between FFF with the vineyards in question, as well as an agreement by the vineyards to the upkeep and maintenance of the plan.

Anticipatory management is self-enforced and relies on a commitment from each landowner participating in the watershed. Thus it is not overseen by a larger agency, nor does it have a penalty (or stick) to entice landowners to 'follow the rules.' However, Elinor Ostrom writes that contemporary political theories frequently presume that individuals cannot make credible "ex ante" commitments unless they are enforced by an external agent (Ostrom, 1992). This theory, she writes, emerges from a Hobbsian view of the world in which "mere words are frail" (Ostrom, 1992). However, in common pool resources there is evidence that appropriators develop credible commitments, monitor each others behavior, and impose sanctions on those who break their commitments, without relying on an external authoritative force. Ostrom calls this covenanting without a sword (Ostrom, 1992). On private land, such as Carneros Creek watershed, self-governance and enforcement is a viable way to involve farmers in management over the long term. There are many examples of common pool resources, including grasslands and fisheries resources, which have been more sustinably maintained by small scale, group-property informal institutions as opposed to large government enforcement techniques (Ostrom, 1999).

A second goal of anticipatory management is to apply the principles to other agricultural communities in the North Coast region of California, where similar problems to those on Carneros Creek exist. Since most farmland in Northern California is privately owned, this management strategy combines the processes of managing watersheds, through understanding the forces acting on the watershed as a whole, and assigning management actions on a property-by-property basis to farmers who have voluntarily agreed to participate in the planning process, and to implement the management strategies over time.

Chapter 5 | Results

The results of the literature review, historical analyis, fieldwork and data analysis and predictive model are detailed here.

Channel Evolution Model

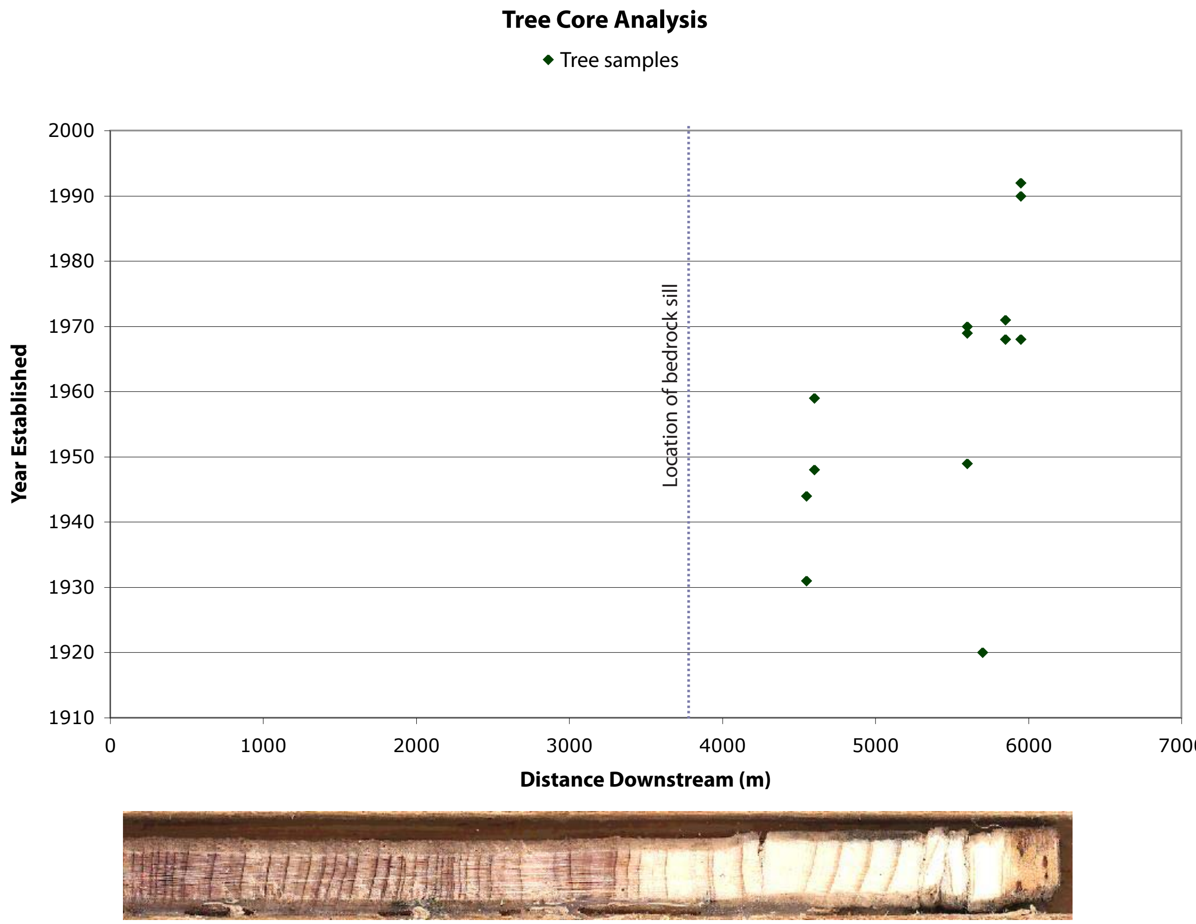


Figure 5.1. Results of dendrochronology study

The results of this tree core analysis show that the willows established between 16 and 88 years ago, between 1921 and 1993. The average age of the trees are between 50 and 65 years, corresponding to the transformation from diverse agriculture to vineyard, from 1960-1975. This suggests that the terraces correlate to the second episode of incision, indicating that two episodes occurred.

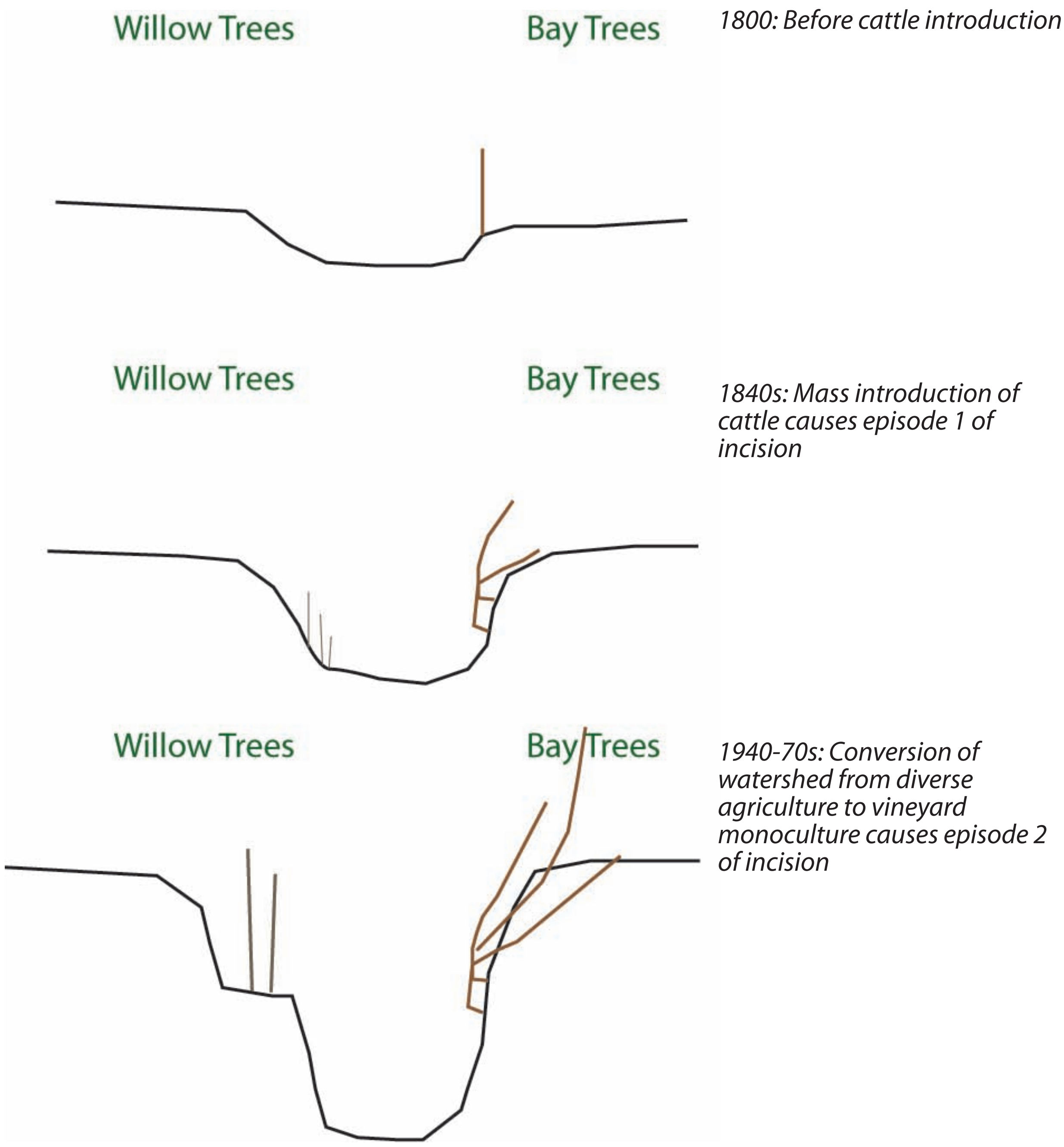


Figure 5.2. Diagrammatic sections showing evolution of channel over time

The legacy terraces are left from the second wave of incision that took place as vineyards were introduced on a commercial level to the watershed. Increasing cultivated land, subsurface drainage and the introduction of small reservoirs for water storage and frost control limited sediment transport and increased runoff, causing the channel bed to drop in elevation.

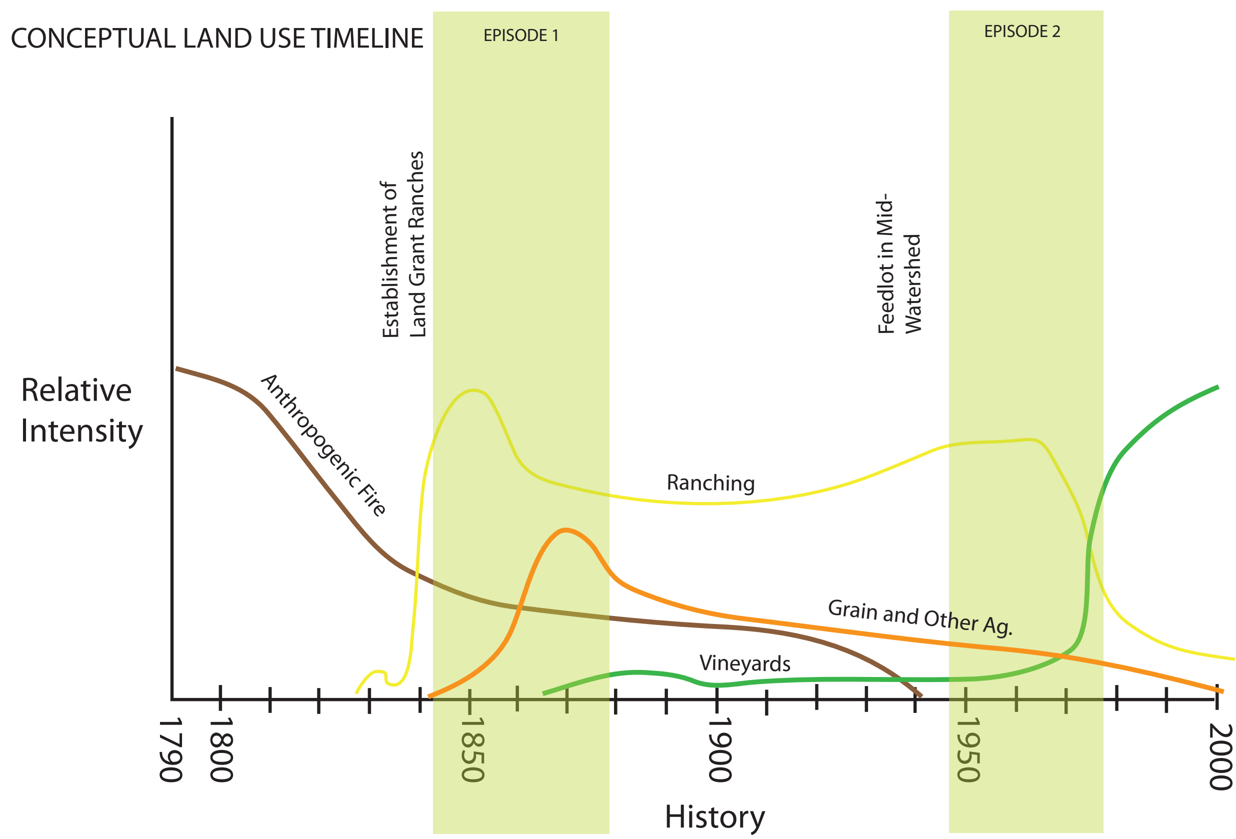


Figure 5.3. Land use conceptual timeline with episodes of incision (adapted from Grossinger et al., 2003)

Another way to understand the evolution of channel form is shown by looking at the long profile of the creek in relation to land use over time.

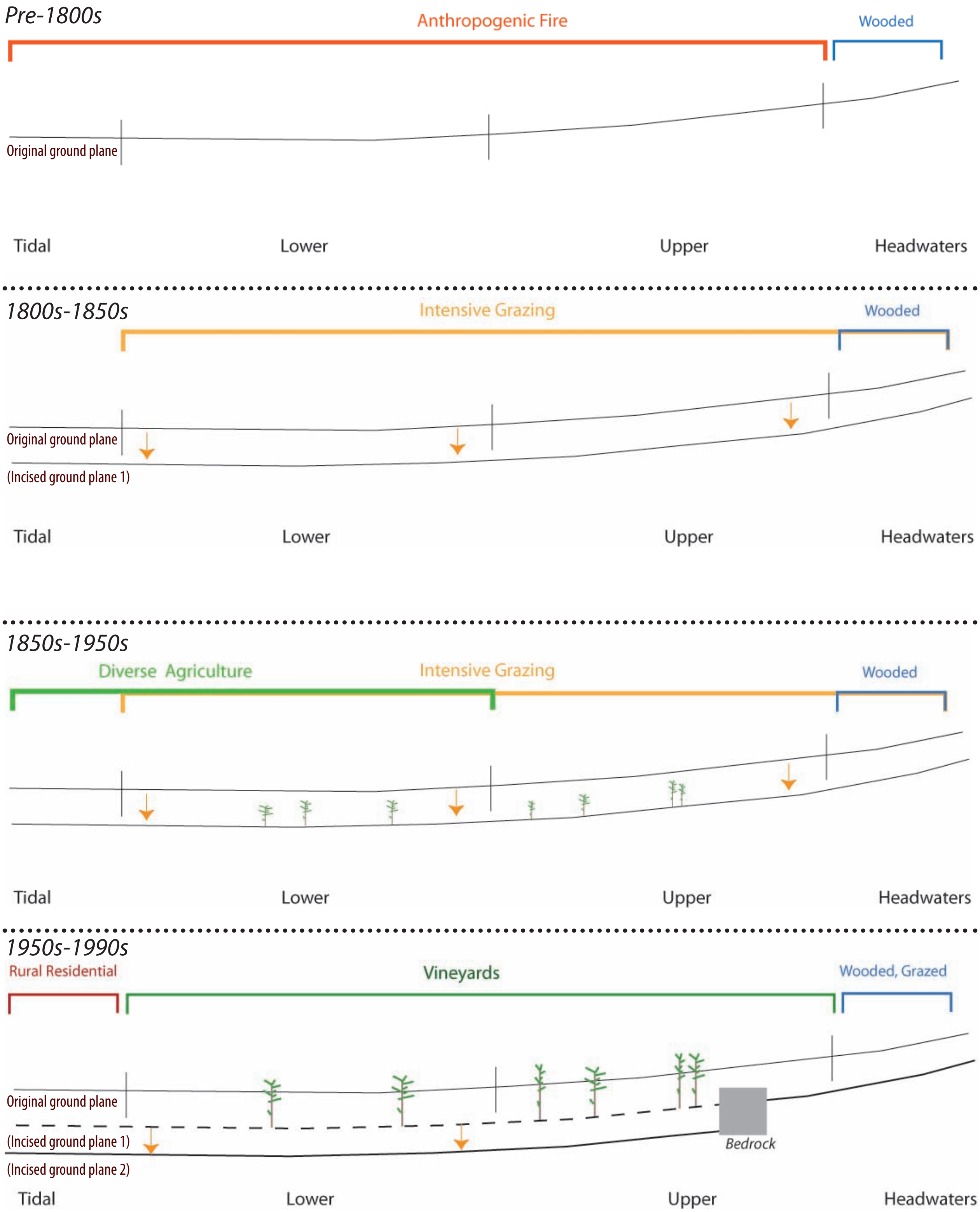


Figure 5.4. Long profile schematic of channel incision over time

The sandstone bedrock sill, in the middle part of the watershed below the tributaries (polygon 80), seems to be acting as a control against the second wave of incision. There are no terraces upstream of the sill and bank heights are significantly lower, averaging 1-3 m. Given this theory of land evolution, and that the sandstone sill acts as a grade control, it is important to look at the current trends within the channel.

Figure 5.5. Bedrock Sandstone sill in reach 80. It is 75 m long

More evidence for the timing of down-cutting is seen in the shape of the "spider trees," usually California Bay Laurel (*Umbellularia californica*) which dominate the riparian corridor. Bay trees are members of the avocado family and are legacies of a warmer climate in California. This growth form allows their roots to slowly adapt to changing bank structures. This is unlike most oak species whose roots do not adapt as well to changing bank structures. The rootballs of the Bay Laurel trees throughout the channel have rotated to allow the roots to grow up onto the banks.

Figure 5.6. Roots of Umbellularia californica (California Bay Laurel)

This rotation takes decades and is most likely a remnant of the primary down-cutting which took place in the mid 1800s (T. Dawson, Pers. Comm. May 2009). In the downstream reaches of the channel, below the bedrock sill, the bay trees have rotated their rootballs and are now suspended between 1 and 3 meters above the channel bed. Above the sill, the rootballs have rotated, indicating that this happened uniformly across the channel at one time. However, the rootballs are flush with the channel bottom, indicating that the bottom of the channel has not dropped in these areas as they have in the areas downstream of the sill.

Figure 5.7. Typical Bay Laurel downstream of sill. Upstream of sill (both with rotated rootballs)

Results of Reach Scale Mapping

I mapped a total of 154 polygons, each 50 m in length.

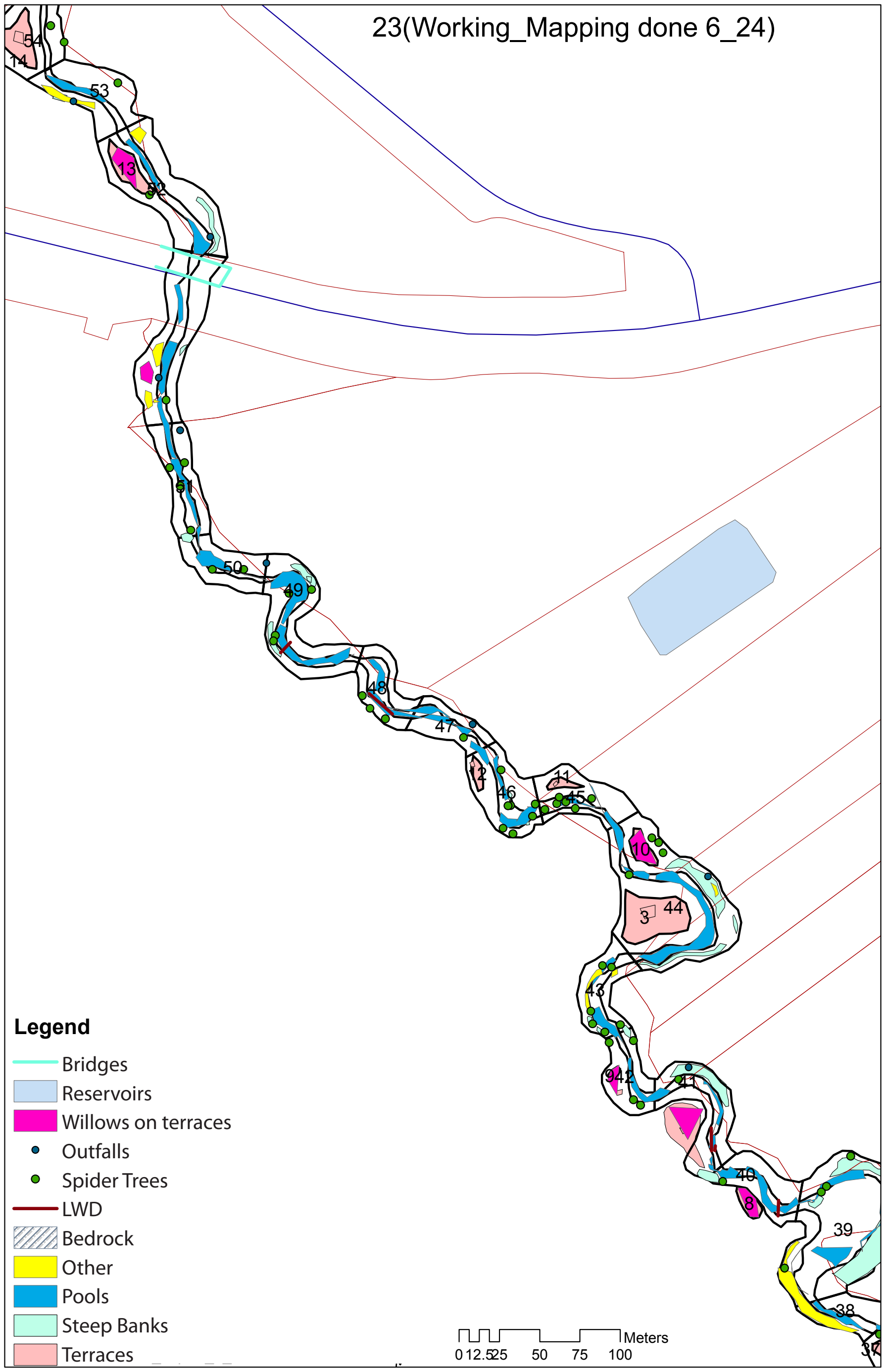


Figure 5.8. Example of GIS mapping results of reach scale data

Much of the data was collected spatially using the Trimble XT, but much was also collected descriptively by reach using data sheets. Data was collected referenced to each polygon, and to each bank side.

By looking at trends over the whole creek, I was able to make several observations of patterns and processes acting on the watershed. For example, Figure 5.9 shows spider tree frequency as a function of distance downstream. There is not a distinct pattern of distribution of spider trees upstream or downstream. They are a constant feature on the creek as a whole.

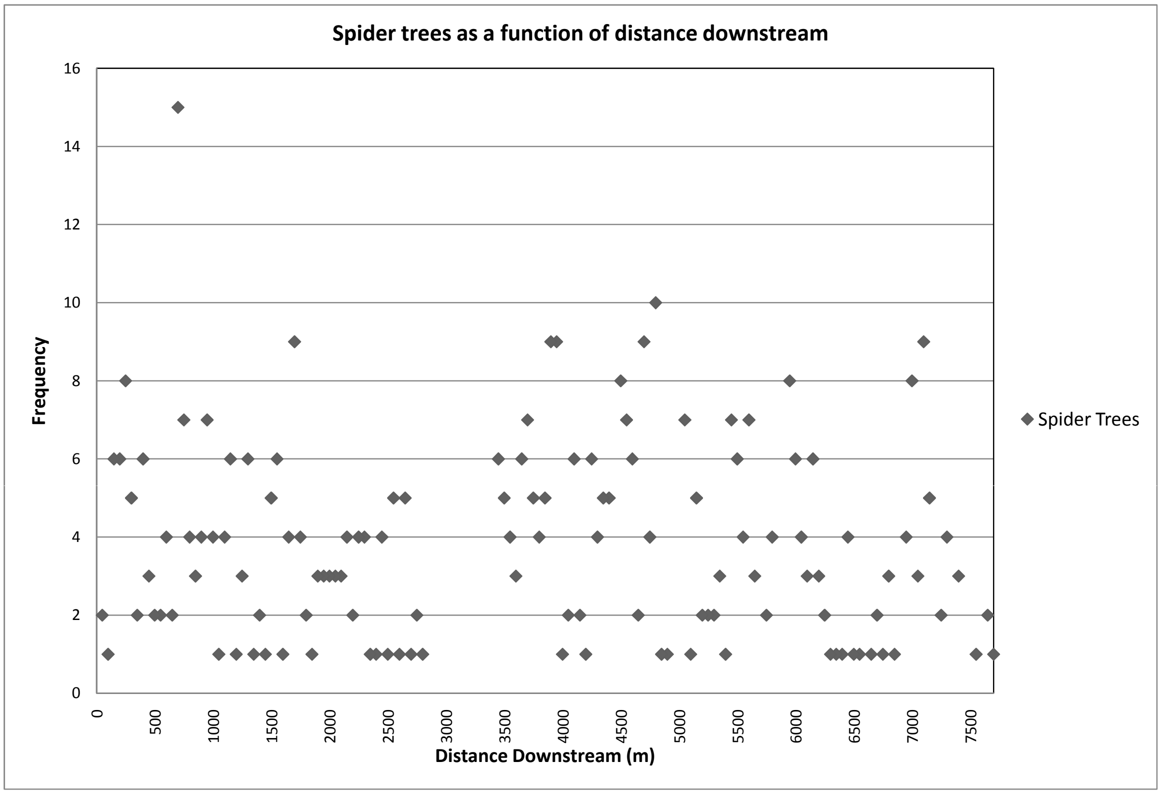


Figure 5.9. Spider trees as a function of distance downstream

Currently, the channel is not uniformly degrading or aggrading. Field observations show that old weirs and structures downstream of the sandstone bedrock sill show signs of aggradation. There is evidence of deposition on the channel bed, hiding the bottom of the weirs that were once flush with the channel. On the other hand, upstream of the sandstone sill, there are several structures crossing the creek which show signs of continued degradation, often displaying a drop of 1-2 feet between the bottom of the structure and the channel bed. This field evidence shows a general difference in geomorphic process between the areas of the channel that are downstream of the sill from those that are upstream of the bedrock sill. Management strategies must therefore take into account the difference in trends.

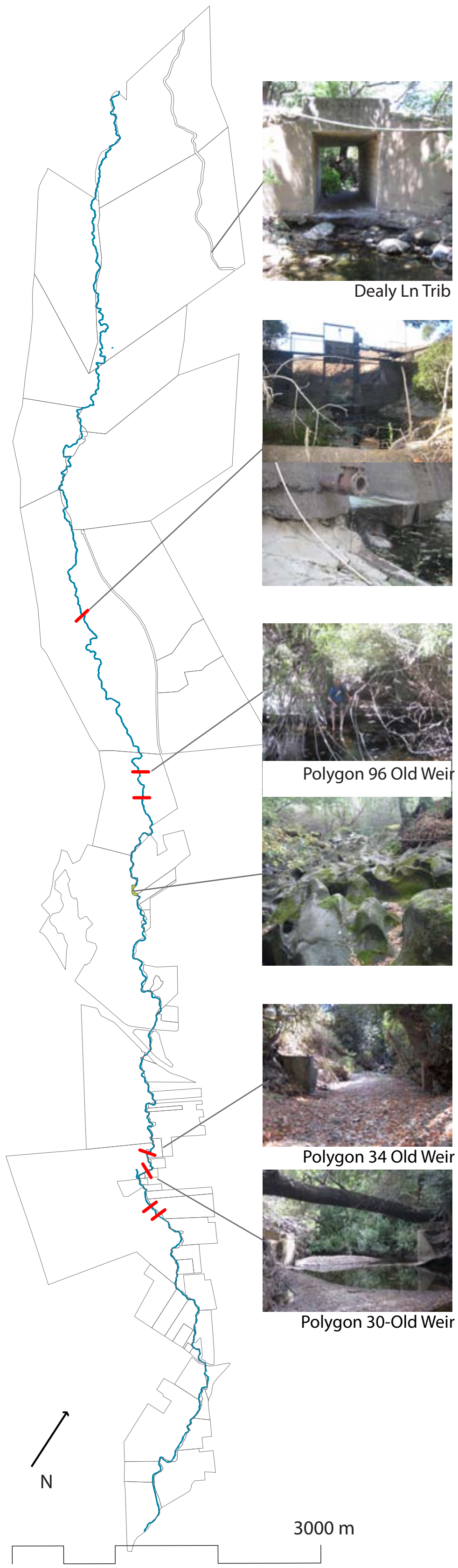


Figure 5.10. Carneros Creek with weirs and structures showing aggradation or degradation

Results of mapping water pools from June-October 2009

By remapping the remaining pools in October 2009, I was able to determine where, in a drought period, fishes would be able to survive over the summer. The majority of pools that persisted were perched in bedrock. Many of these did not change depths over the summer, indicating that they may be spring fed or filled by irrigation drainage. These perched pools tended to be upstream of the sandstone sill. Below the sill, pools that persisted tended to be near large woody debris, or near a spider tree, which indicates that the scour occurring at these two features creates an environment where water can remain over the summer. Of a total of 275 pools (average depth 0.61m) mapped in June 2009, 96 pools remained (average depth 0.25 m). Total surface area in the pools decreased to only about 1% of the extent of water in June. I saw fishes in 63% of the pools in June, and only 22% of the pools in October, though this may have been because of the time of day, or life stage.

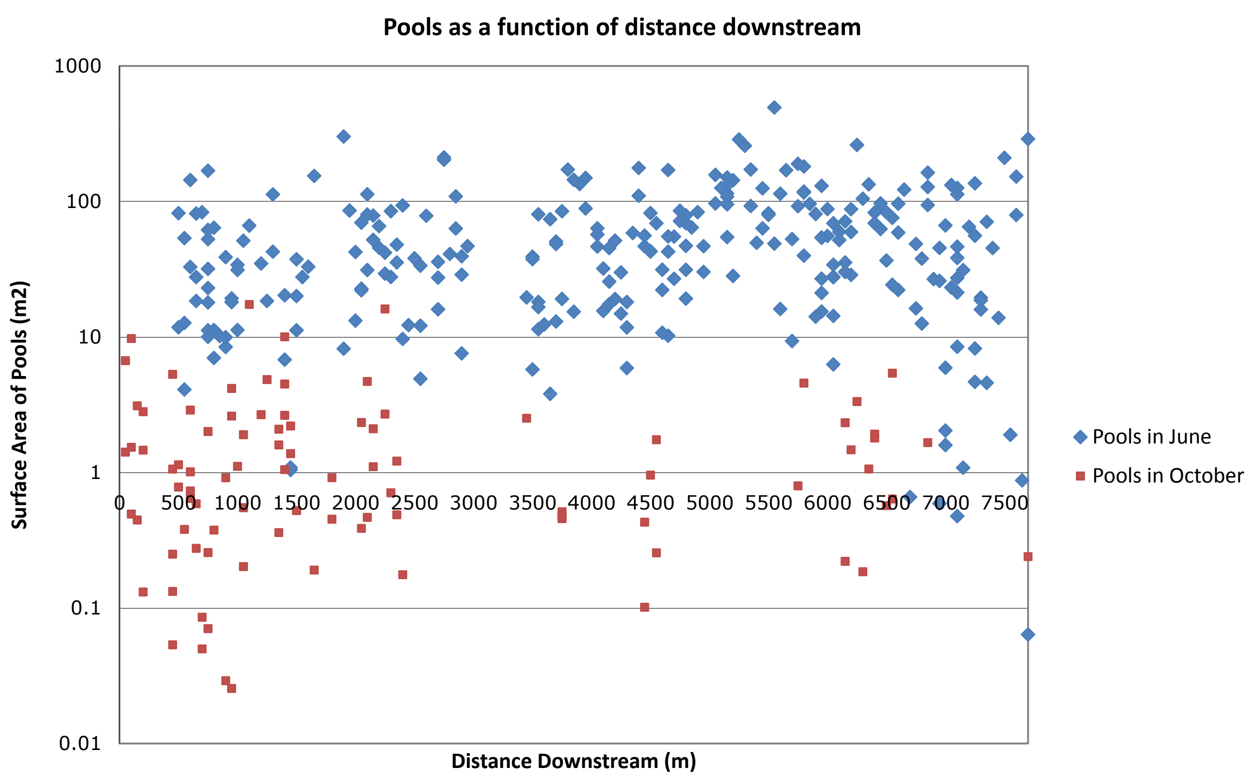


Figure 5.11. Pools as a function of distance downstream

Figure 5.12. Pools persisting through October 2009 correlating with LWD and bedrock

Results of predictive model

The suitability analyses for fish habitat and bank stability were iterative in that the results changed slightly depending on the weights given to each criteria (see chapter 3 on methods for criteria descriptions).

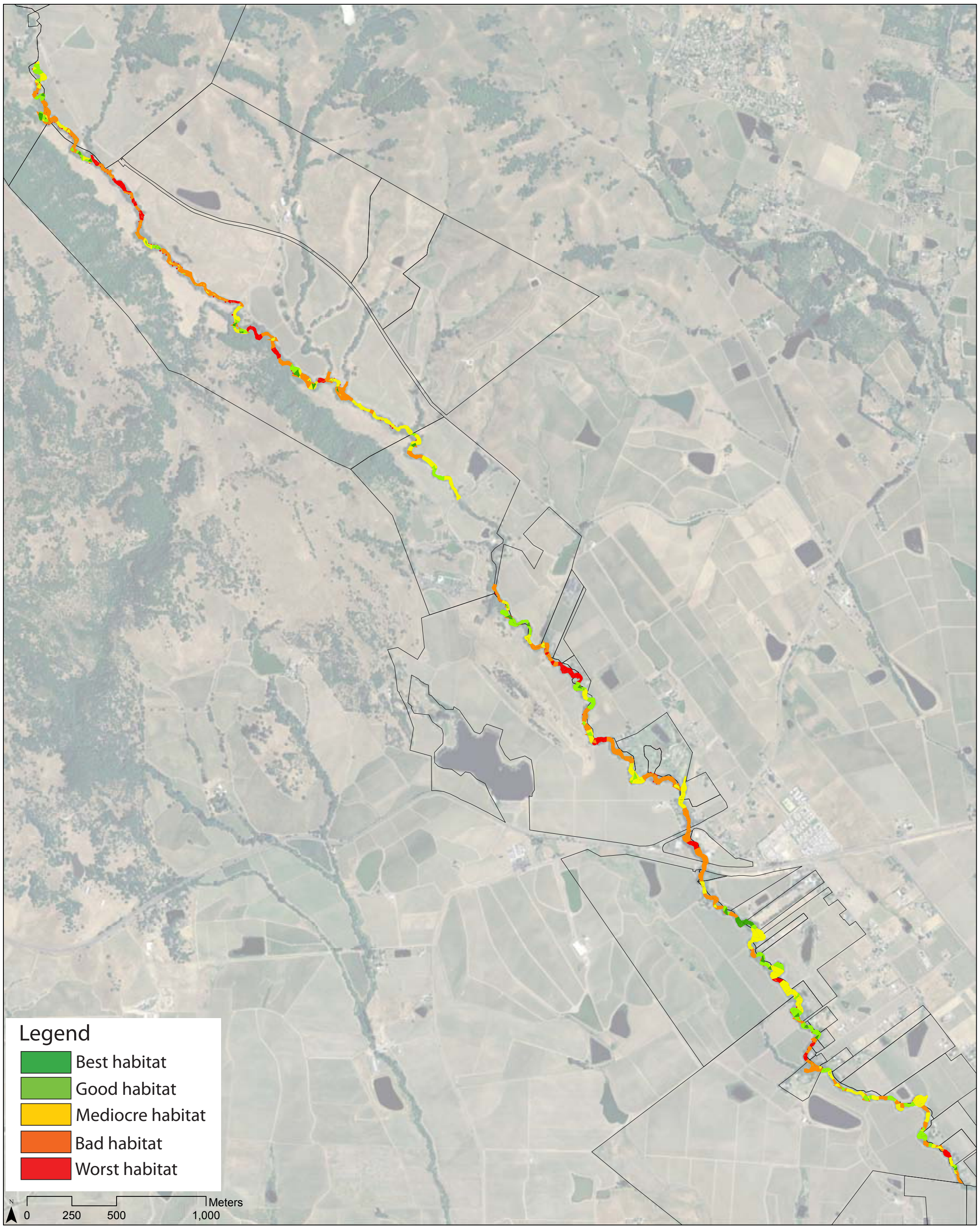


Figure 5.13. Fish habitat priority areas from predictive model

Discussion of optimal fish habitat

The "best" areas for fish habitat are found in 18 polygons on the mapped portion of the creek (out of 154) which showed high scores. The majority of these areas are in the upper part of the watershed, or in the areas downstream of the Highway 121 crossing. These high-scoring areas often had channel complexity, and large woody debris and spider trees, which create scour pools. Persistence of pools over the summer was a major limiting factor for good fish habitat, and the "high" areas most often correspond to where pools were able to persist.

From a management perspective, it may be worth protecting the dark green areas of the creek but focusing the revegetation efforts on the yellow "mediocre" and light green "better" areas, in order to make best use of resources. The majority of these were found in the upper section of the creek, as well as interspersed throughout the lower and upper sections. This information is useful for an anticipatory management plan in that it gathers together the current conditions of aquatic habitat as a baseline for ongoing monitoring as the management continues.

Sources of error

I ran a sensitivity analysis to certify that the weights given to certain criteria did not sway the results excessively. Aside from remapping the persistence of pools in October 2009, the rest of the data was collected during the summer 2009. The 2009 water year was the second in a set of record setting drought years. It follows that my data collected represents the more extreme conditions, which makes it a particularly good time to perform a suitability analysis.

Predictive Model for Bank Failure

As described in Chapter 3, I ran a multi-criteria decision making analysis through GIS with data collected in the field along with the watershed scale GIS data available for Napa County. Sample equations show the model's ranking system whereby each category is ranked normalized to one, and based on its likelihood of contributing to bank instability. The rankings were determined based on expert opinions, and precedents discussed in the literature of the field.

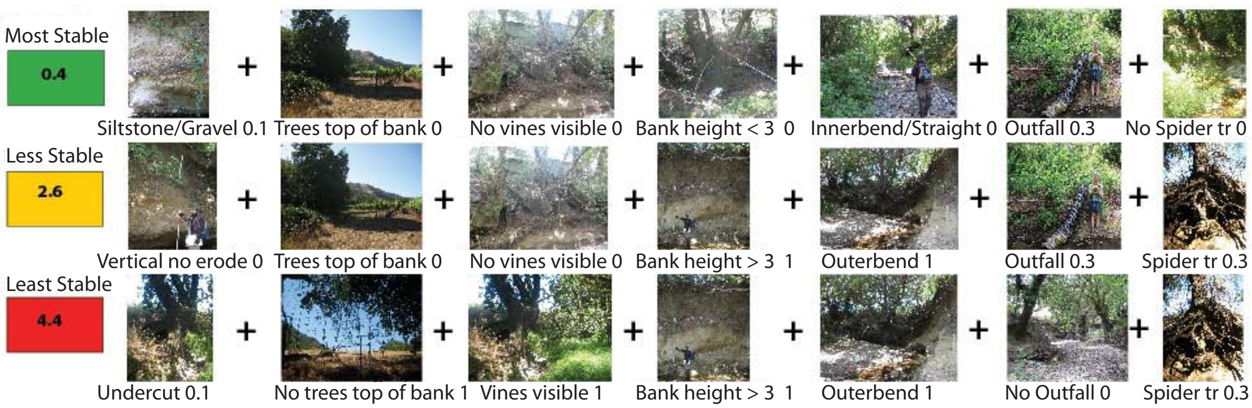


Figure 5.14. Sample equations for predictive model

Failing banks and bank erosion is one of the largest problems throughout Napa County in general, and these problems are exacerbated by the fine sediment TMDL. Results for priority areas for the right and left bank stability are shown in Figure 5.15.

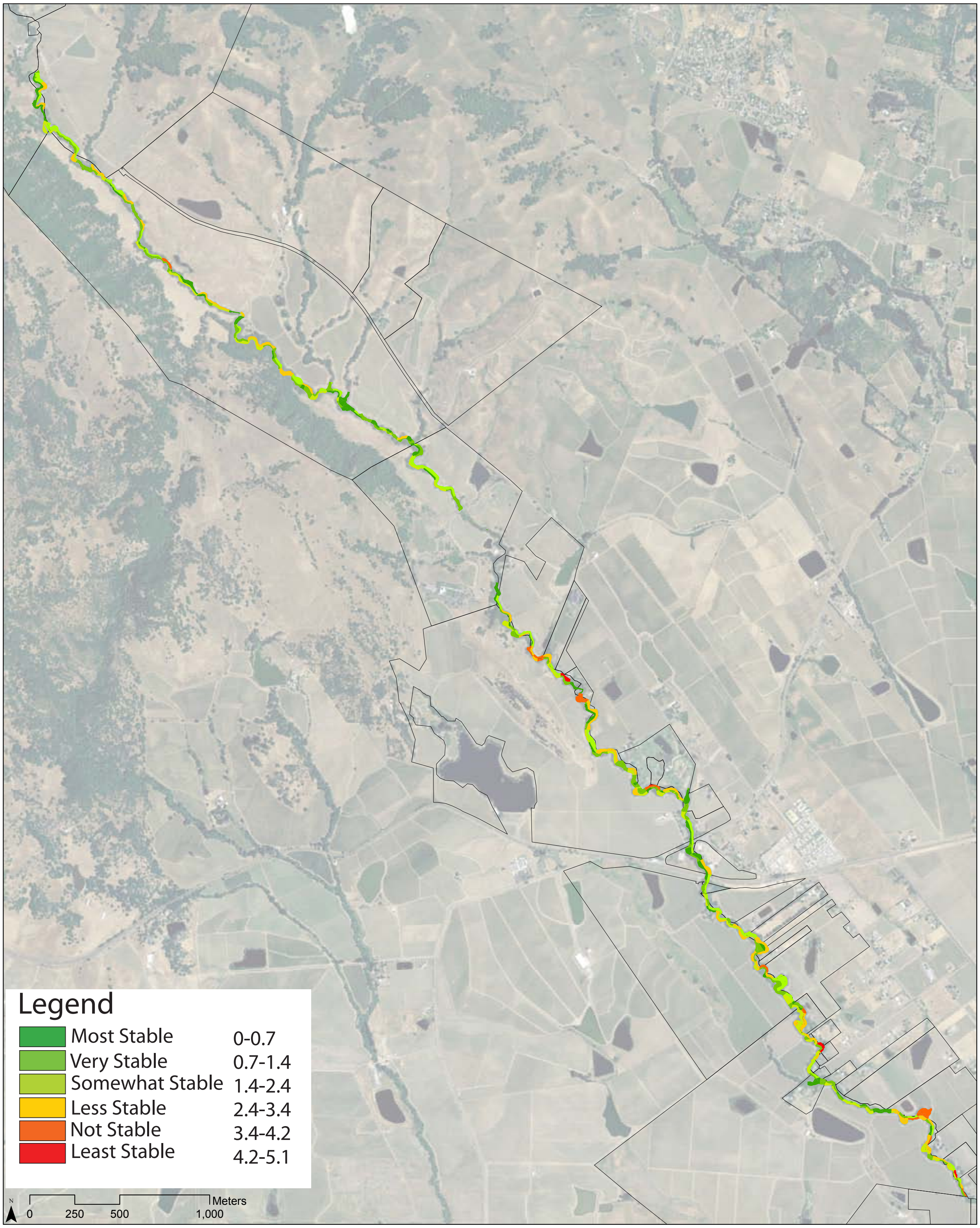


Figure 5.15. Results of predictive model for bank stability

Location of most severe bank instability

The majority of highly unstable banks appeared to be on the left bank, downstream of the sill, where landowners are not participating in the project. Rural residential land uses tend to have less riparian buffer space than do vineyards, with houses and sheds often built atop creek banks. There may also be a correlation between presence of riprap and absence of riparian cover and increased steep/failing banks. While fences, or grazing exclosures, have been shown to increase riparian forest health, they do not necessarily ensure bank stability on Carneros Creek. The least stable bank conditions are just downstream of the sandstone sill, and towards the downstream end of the project where the channel is the widest.

Sources of error

The ranking and weighting of categories in the suitability analysis produces the largest source of error. In interviews, the land managers remarked that they were surprised there were not more areas of highly unstable banks, and often pointed to areas that were scored "moderately stable" or "less stable" as areas they considered "problem areas." This indicates that the weighting was not high enough for certain parameters. There is error involved in how I weighted discrete points such as outfalls and spider trees. They can either be weighted individually or grouped together in Thiessen polygons, which I decided was most accurate. Finally there is a lack of consideration of natural process inherent in a suitability analysis, which needs to be addressed in order to be used on a dynamic creek like Carneros. The results of both suitability analyses need to be field checked after each storm, as major changes can occur in a relatively short period of time. This will be addressed in the plan and would be monitored and maintained by the landowners.

Results of Point Scale Data Collection and Analysis

In order to understand and characterize the entire Carneros system, a watershed and reach scale approach was augmented with a finer scale or "point scale" approach, which looked strategically at representative sections of the creek.

Cross sections were sited to be representative of the channel conditions over longer reaches of the stream. I surveyed nine cross sections and long profiles in July 2009 (Appendix A). The cross sections are meant to serve as a baseline dataset and should be resurveyed in the future. The highly sinuous nature of the stream does not lend itself to generalization of hydrology data or 1-dimensional modeling such as Hec-Ras. The two lines of tracers placed in the lower part of the watershed respectively, following a flood with return interval of about 1.5 years (2/9/2009), showed partial and complete mobility. The cross-sections and long profiles are illustrative of the varying forms of the channel geometry.

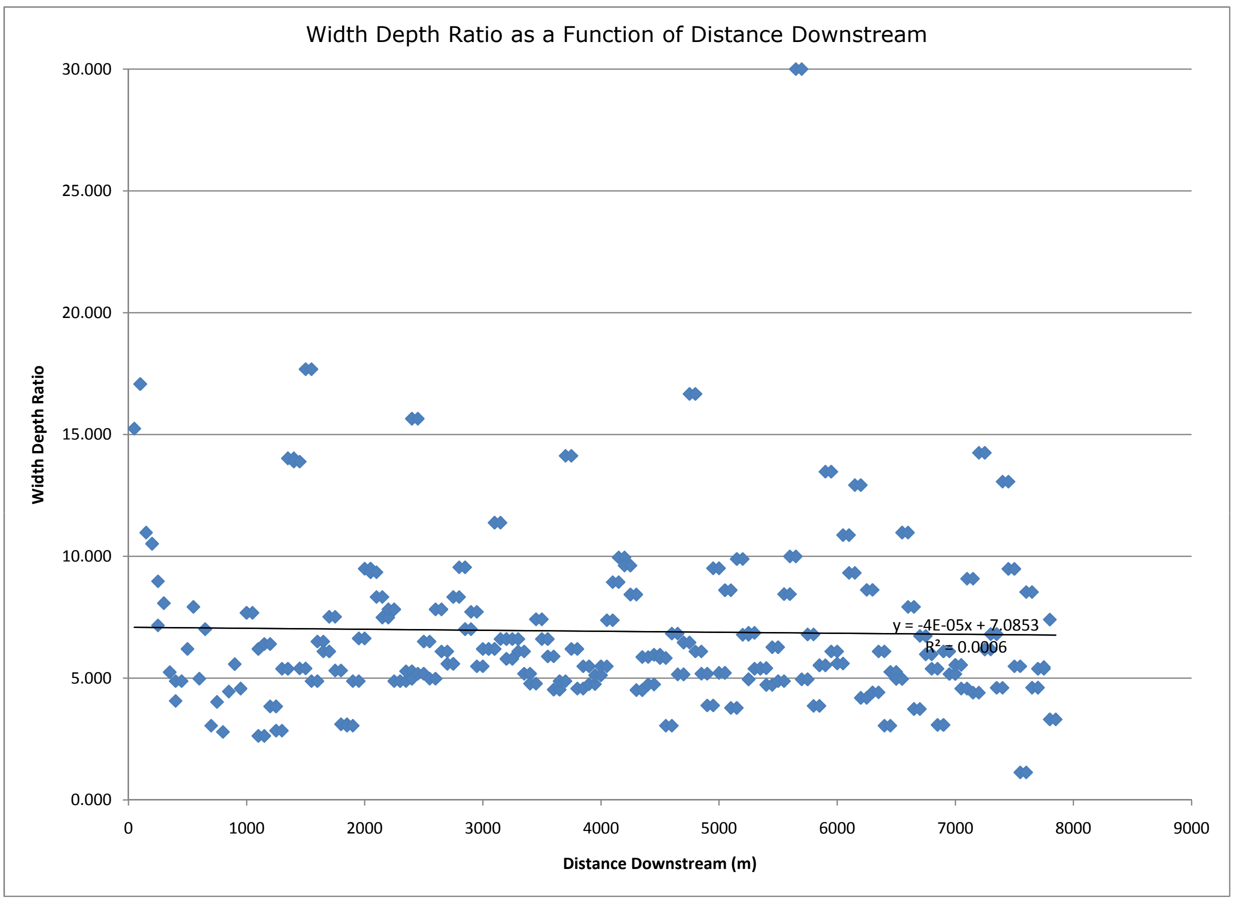


Figure 5.16. Width-depth ratio shows no clear trend with distance downstream

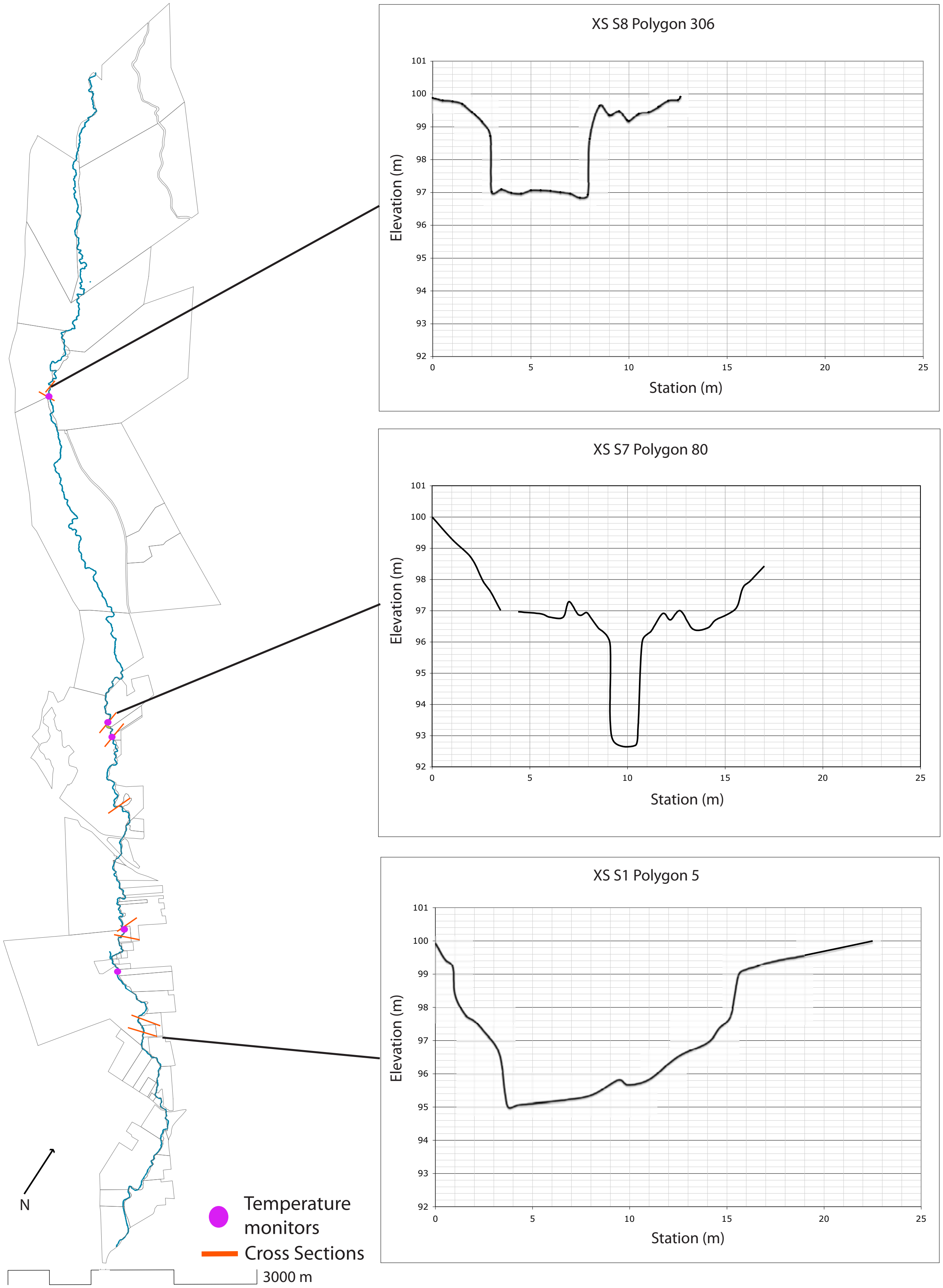


Figure 5.17. Sample cross sections surveyed summer 2009 and location of temperature loggers

Temperature Monitors

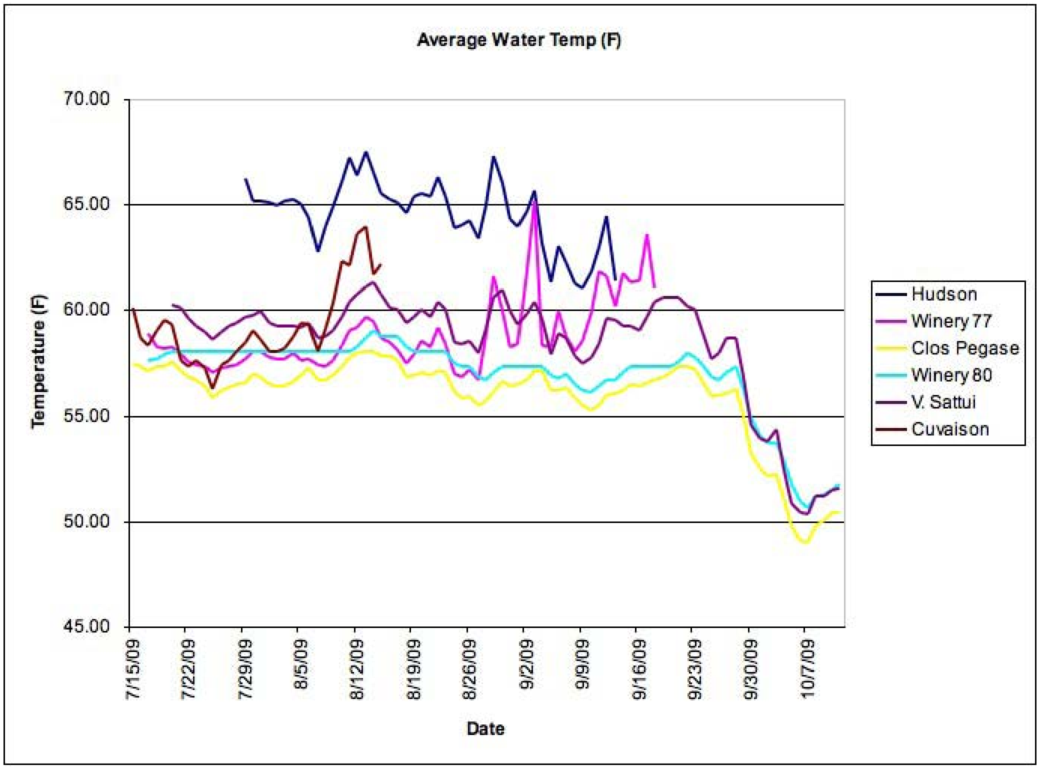


Figure 5.18. Results of water temperature surveys

Data loggers were distributed in the six deepest pools and logged data every 30 minutes between the months of June/July and October 2009.

Site (downstream to upstream)	*Distance from confluence (km)*	*Date extracted*	*State at time of extraction*
Polygon 24-Under spider tree	*3.6*	*10/11*	*In pool**
Polygon 36-Inner bend	*4.2*	*9/17*	*Dry by 8/15*
Polygon 77-Bedrock/sand bottom	*6.9*	*10/2*	*Dry by 9/19*
Polygon 80- Sandstone sill	*7.1*	*10/11*	*In pool*
Polygon 201-Under eroded bank	*9.4*	*10/11*	*In pool**
Polygon 306- Under LWD	*11.8*	*10/11*	*In pool*

Temperatures did not surpass 70 degrees F (between 49-67 on average) in the six pools. However, the raw data showed that temperature did not fluctuate within 0.01° F for a week and a half in certain data loggers. Even with questionable quality of the equipment, the average readings were below 70° F, the threshold for steelhead trout, demonstrating that temperature is not a limiting factor for fish on Carneros Creek (Moyle, 2002).

Interviews

Landowner buy-in and engagement with this plan throughout the process was and will continue to be necessary. I spoke to three different types of land managers on December 1, 2009 with different relationships to the property and creek; a vineyard manager for a small company, a vineyard manager for a large publicly traded corporation and the son of a landowner/farmer who farms and bottles his own wine grapes. The vineyard managers had both worked in the Carneros region for at least a decade and knew the stream and its meanders, as well as how the vineyards had changed under different styles of management, while the farmer's son had just returned to the area, was not as familiar with the landscape.

I presented the results of the predictive bank stability model to the land managers to check the accuracy of my predictions. In general, the model seemed accurate, though it may have underpredicted the severity of the bank instability conditions. Both vineyard managers linked the principles of geomorphology and farming by remarking that it makes very little economic sense from a farming standpoint, to run a tractor around the many point rows that jut out into the meander bends of the stream. They yield poorly because of shading and competition from the oaks in the riparian corridor, and get flooded. Interviewees claim that it is instead the finance department in their companies who pressure them to farm every acre possible.

Figure 5.19. Example of "point rows" in a meander bend, and example of landowner feedback

Economics plays an important role in the land manager's willingness to participate in a watershed plan and response to the plan itself. The anticipatory yet passive nature of this approach means that there is no cost stated up front. Having some sense of the cost of anticipatory management over time would be helpful in making its case for it. A vineyard manager is still responsible for his client's farming budget.

A final concern shared by all three farmers was the desire for a plan that would lessen the headache of bouncing between regulatory agencies when managing the creek. For example, when large woody debris accumulates in the channel, the Napa flood control agency instructs farmers to remove the log-jam as it creates a flooding hazard, and is more likely to cause bank collapse. However, NOAA fisheries requires large woody debris to be left in place as fish habitat and the Department of Fish and Game require a 1603 permit for anything involving stream-bed alterations. The inconsistent requirements speak to the unclear nature of the problem, but catch the landowner in the middle. All three land managers requested a plan that would instruct them as to what to do that would satisfy the requirements of the agencies and allow them to "do the right thing."

Critical Setbacks

The goal of the management plan is to inform farmers of areas most likely to fail, so that proactive management can be worked into the vineyard management practices, and so that reactive and degrading management practices can be avoided. I used the predictive model for bank stability calibrated with the concerns and observations of the landowners, separating the two most likely to fail categories, "not stable" and "least stable" and re-titled them "critical setbacks"

Setbacks in this case refer to a three to one ratio of set back to height that would give a conservative distance away from the bank that would be affected by a failure. It is not to suggest that the bank be mechanically laid back, or that any action be taken, only that the distance is an estimate of how far roads and vines would need to be set back.

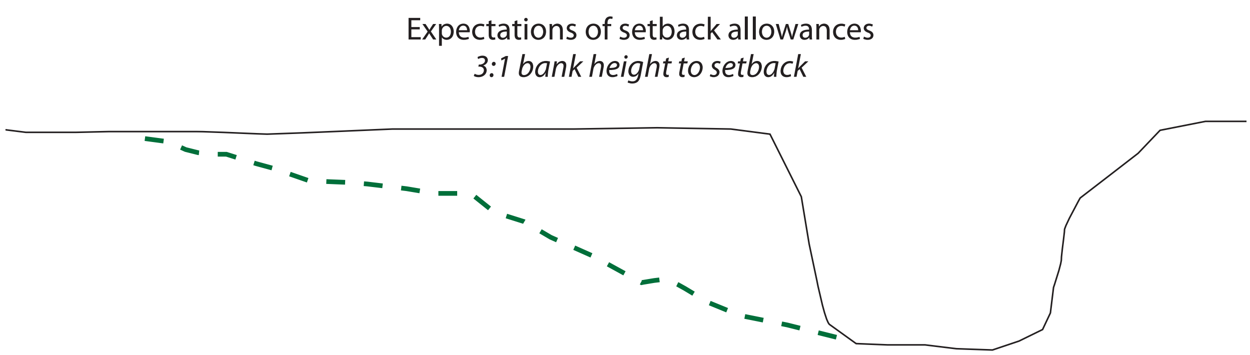


Figure 5.20. Diagram of 3:1 setback ratio of banks

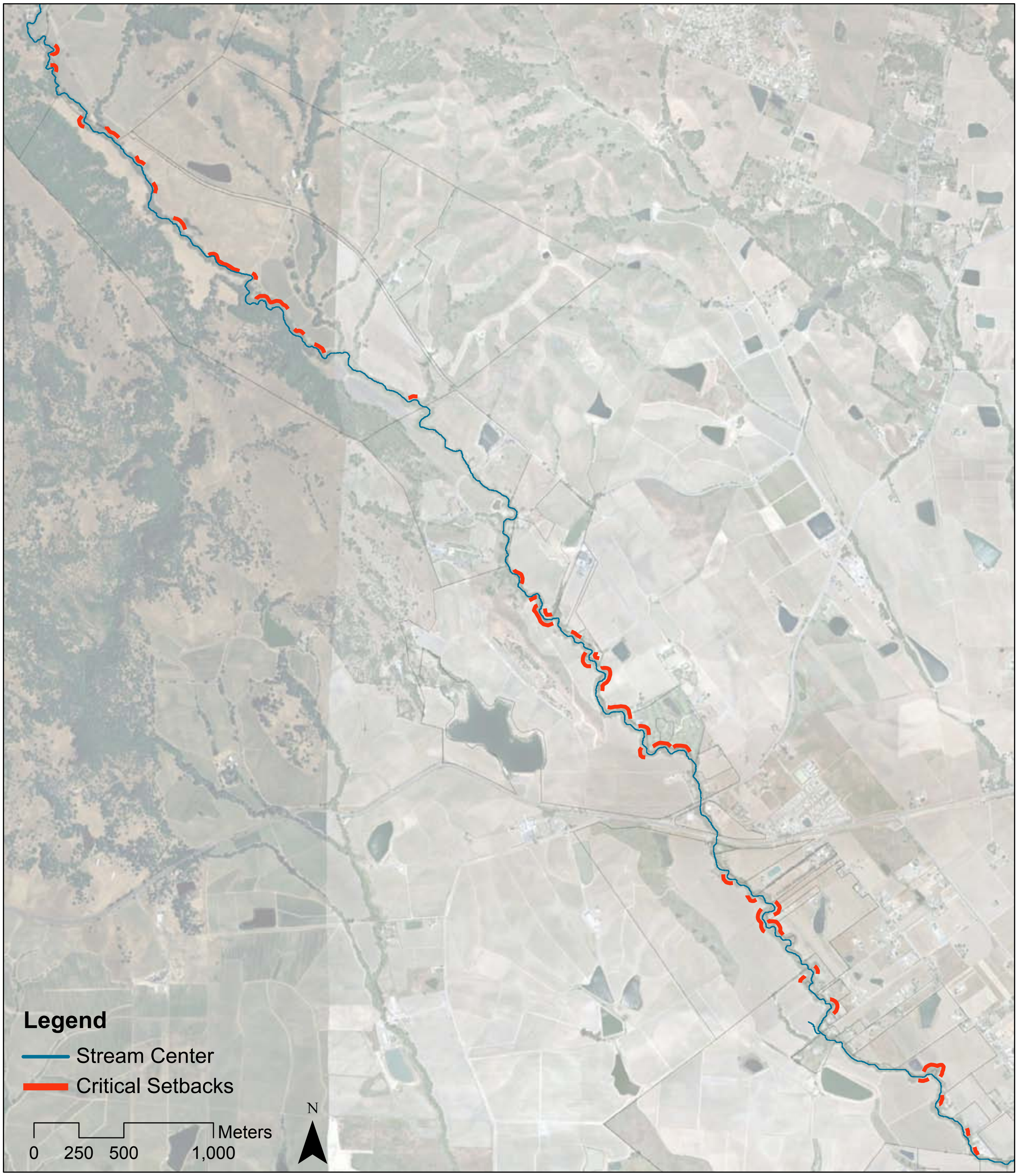


Figure 5.21. Map of critical setbacks with setback measurements at a ratio of 3:1 (three times the bank height is the distance to setback)

A total of 10.94 acres of land, 1.74 acres of vineyard and 3.63 acres of roads would be affected by the critical setbacks. Three houses along the creek would need to be moved for safety reasons.

Comparison with Traditional Management Practices

Many management strategies involve imposing a standard setback along the entire creek to manage and mitigate for possible bank failures. When comparing the acreage given to an 100 ft or 50 ft setback against the acreage lost using the predictive model method, it is worth the farmers prioritization of setbacks in anticipation of change as opposed to a set buffer distance, or suffering from an unexpected failure if no management is applied.

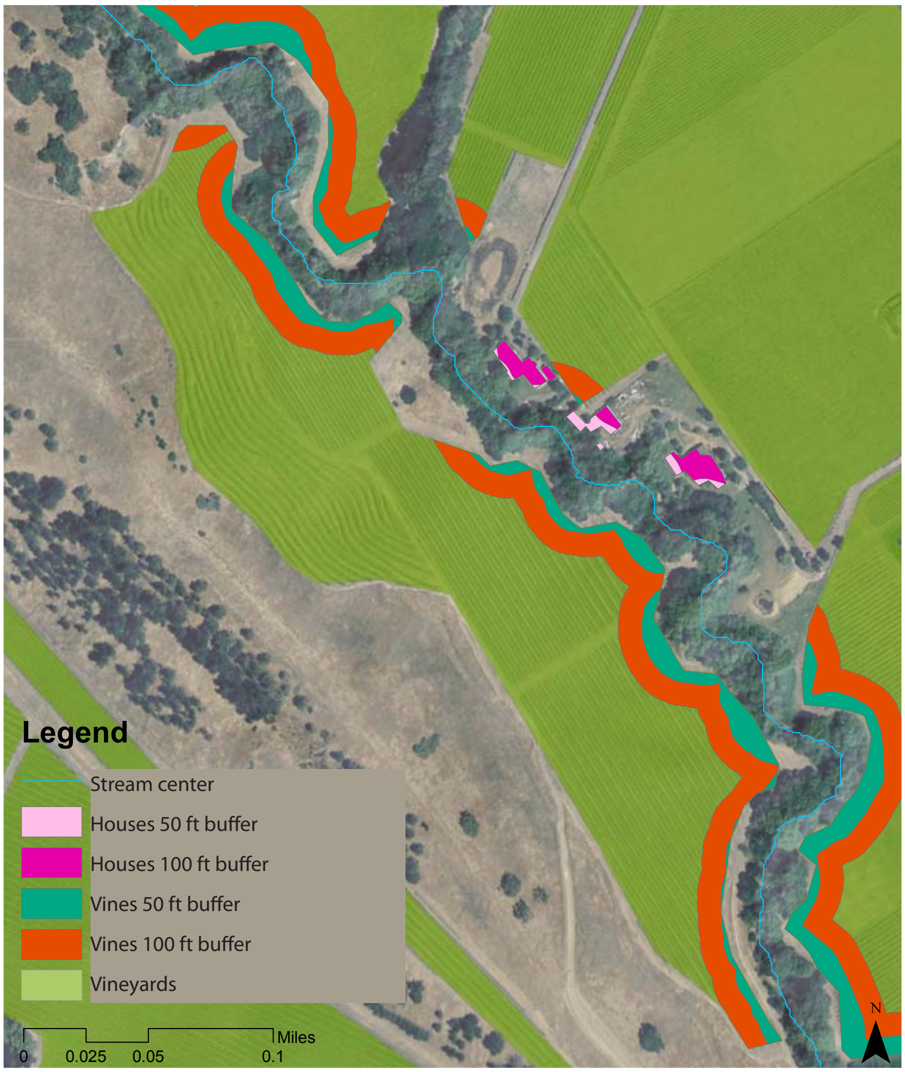
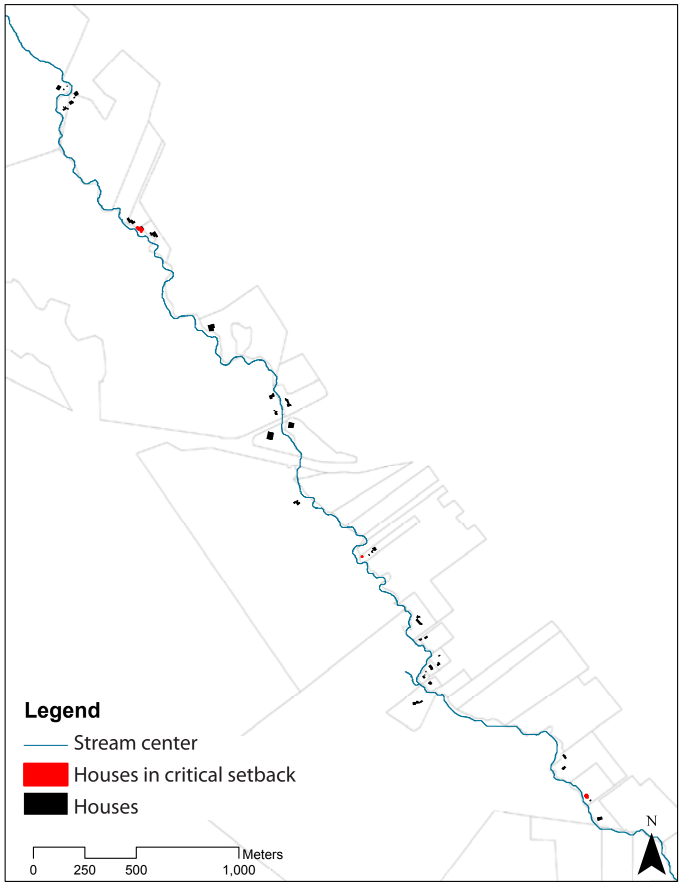


Figure 5.22. Images of buffer (50 ft and 100ft)

Total Vineyards (in watershed)	1425.44 ac
Vineyards within 100 ft buffer	67.94 ac
Vineyards within 50 ft buffer	20.06 ac
Vineyards within critical setbacks	1.74 ac



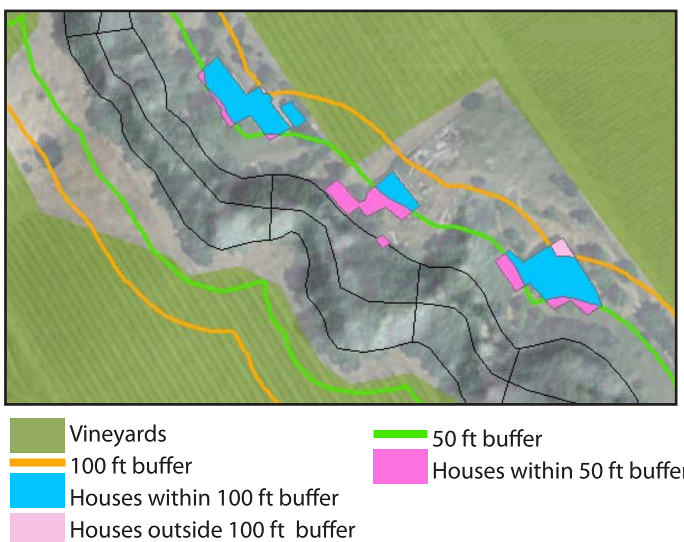


Figure 5.23 Figure grounds of houses along creek and close-up of houses affected by hypothetical 100 ft and 50 ft buffer and critical setbacks

Houses along creek	2.30 ac
Houses within 100ft buffer	1.60 ac
Houses within 50 ft buffer	0.28 ac
Houses within critical setbacks	0.01 ac

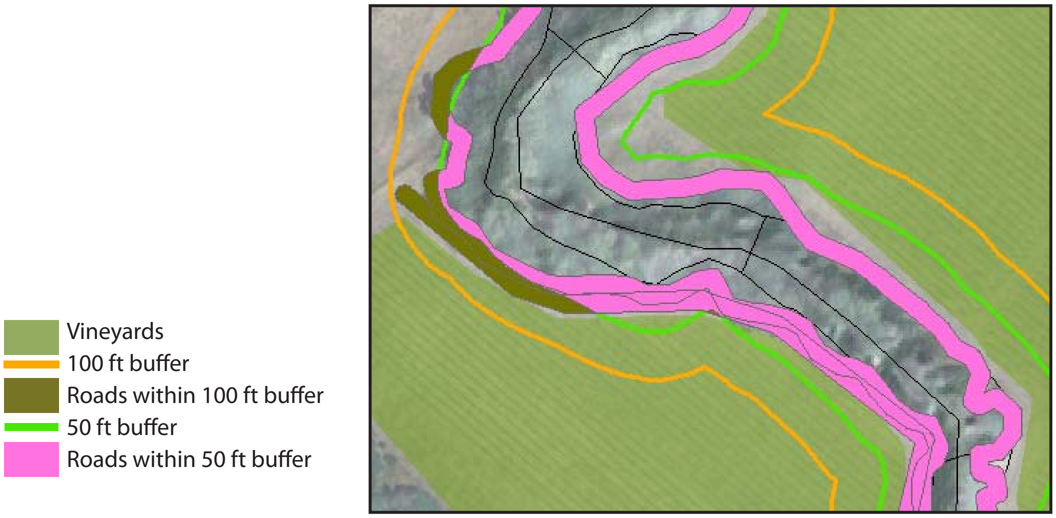


Figure 5.24. Roads along creek affected by 100 ft and 50 ft buffer and critical setbacks

Total Vineyard Roads	63.66 ac
Roads within 100 ft buffer (20ft)	49.64 ac
Roads within 50 ft buffer (20ft)	43.01 ac
Roads within critical setbacks	3.63 ac

Buffers and continuous setbacks are common ways of protecting streams from erosion and degradation. However when comparing the results of an anticipatory approach of critical setbacks or priority areas, to a blanket 100 ft or 50 ft setback across the stream, the feasibility of implementation and economics involved becomes clear. It is less daunting and more inclusive to ask a farmer to monitor specific areas of the stream, and remove vines and implement buffers when necessary than to regulate and enforce a uniform setback requirement. Giving the creek room to move and adjust allows landowners to continue to live in concert with the creek, which will most likely prove more sustainable in the long run.

Chapter 6 | Anticipatory Management Plan and Recommendations

Anticipatory management is a forward-reaching management strategy that allows for uncertainties while positing a 'best-guess' scenario of events 'likely' to take place. It draws from understanding the creek at a watershed scale but directs action on a property by property basis, given the nature of land management.

It is impossible to predict exactly when and where banks will fail in the Carneros system, but the results of this study have directed management to critical areas that are most likely to fail. In these areas, the plan advises farmers to take a two-pronged approach. The first is proactive management; where banks are shown to be "likely to be unstable," land managers are encouraged to move their roads, vines and infrastructure back to an advised distance, revegetate the top of the bank with native woody species, and then let the channel meander and the bank fail as it would do in a more natural state. In areas that fail before such a change in management has taken place, land managers are encouraged to let the slump or bank failure occur, to stake the bottom of the failure with willows, and move the road and vines back as necessary. They are explicitly discouraged under this philosophy from using the emergency permit loophole of the 1600 permits under CA Department of Fish and Game to rip rap the bank and temporarily stabilize it. Letting the bank fail and the channel readjust, is necessary for long-term stabilization of the channel.

The conclusion of this thesis is a detailed management plan for the five major landowners of Carneros Creek, with specific set of guidelines for each property owner for management of the creek for the next 20 years. It details the existing conditions of the creek, and then proposes antipatory and restorative actions by reach. The plan will also submit guidelines for monitoring after rain events and after the winter, as well as yearly surveying of the study reach.

Although data was collected on a reach scale, the necessary unit for implementation is by parcel or property. Description by property starting with the most downstream property:

<u>Property 1</u>
Geomorphology (failing bank focus): large width to depth ratio
Fish: Many fish seen in June, some water in October
Vegetation: High vegetation on right bank, though road is close
Land use: Right bank vineyard with road on top of bank. Left bank rural residential (car jacks)

<u>Property 2</u>
Geomorphology: Very great width to depth ratio.
Fish: Many fish seen in June, some water in October
Vegetation: Mixed, right bank has high vegetation, some vegetation in channel
Land use: Right bank vineyard with road on top of bank. Left bank rural residential, riprap

<u>Property 3</u>
Geomorphology: Varying Width to depth ratio, from the most incised parts of the channel (poly 60-65) to the sandstone sill (poly 80)
Fish: Very little water persisting from June to October, Less fish seen in June
Vegetation: Right bank high riparian cover, left bank low riparian cover
Land use: Left bank is rural residential, golf course, sheds hanging over the edge

<u>Property 4</u>
Geomorphology: Varying width to depth. Mostly bedrock channel
Fish: Pools in October. Some fish, though lack of DO.
Vegetation: Medium cover, no vegetation in channel
Land use: Far away from vineyards/roads. No buildings on creek

<u>Property 5</u>
Geomorphology: Smallest width to depth ratio
Fish: Fewest pools in June (or October). No fish
Vegetation: Upland vegetation, high cover
Land use: Far away from vineyards/roads but several at grade crossings

Principles of Management

Farm until it fails

Using the predictive model, land managers should expect "least stable" and "not stable" areas to slump at a 3:1 H:W ratio. Most failures in the Carneros system are likely to be cantilever failures. The banks will not repose at a 3:1 ratio but the distance provides a conservative estimate of the area of land that might be affected by such erosive processes.

When the failure occurs, land managers should stake willows at base of failure. The zone of contact between the overlying alluvium and the underlying silt-clay strata is expected to provide a relatively moist substrate for riparian plantings on the restored bank. Irrigation may be necessary for initial establishment of plantings. Willow (*Salix spp*.) is very effective in rapidly extending roots to stabilize the soil, and should be considered as a primary planting over several feet of slope above the silt-clay strata. Some locations may be too well-shaded for optimum willow growth, and other native species may be evaluated on a case-by-case basis to develop a suitable planting palette. Bay laurel, live oak, and other native overstory trees should also be considered as part of the revegetation plan for treated banks (O'Connor, 2005).

Proactive setbacks

When vineyard companies and managers are replanting vines, which happens on a 10-15 year cycle, they should move road and vines back (using 3:1 ratio) in the areas marked as critical setbacks and revegetate with oaks and bays to maintain riparian forest. This is a proactive and anticipatory measure that takes advantage of crop rotations, and favors forgoing profit from a few vines in order to anticipate and plan for stream geometry changes and bank failures,

Streamwide management

Large Woody Debris

Managers downtream of the bedrock sill should let large woody debris fall, allowing pools to scour and form slow water habitat for over-summering fish. Managers should expect the 3:1 failure distance from deflective shear forces and manage accordingly by following the proactive setback strategy.

Clear Passage

Managers should remove fences and small dams that block flow and hinder fish passage. There are several fences and weirs in the middle and upper reaches of the stream.

Outfalls

Managers should make sure drainage outfalls to the creek have energy dissipaters so the energy is not erosive.

Monitoring

Monitoring and preparedness after each storm is an essential component of the plan. Each land manager will receive a map with the critical setback areas, and they must check these areas after each major rain event. Monitoring for fallen trees is also an essential component of the plan.

Fish Friendly Farming participants are recertified every five years, and participants in a watershed anticipatory management plan would be subject to this recertification, including evaluation of their adherence to the critical setbacks and bank management principles.

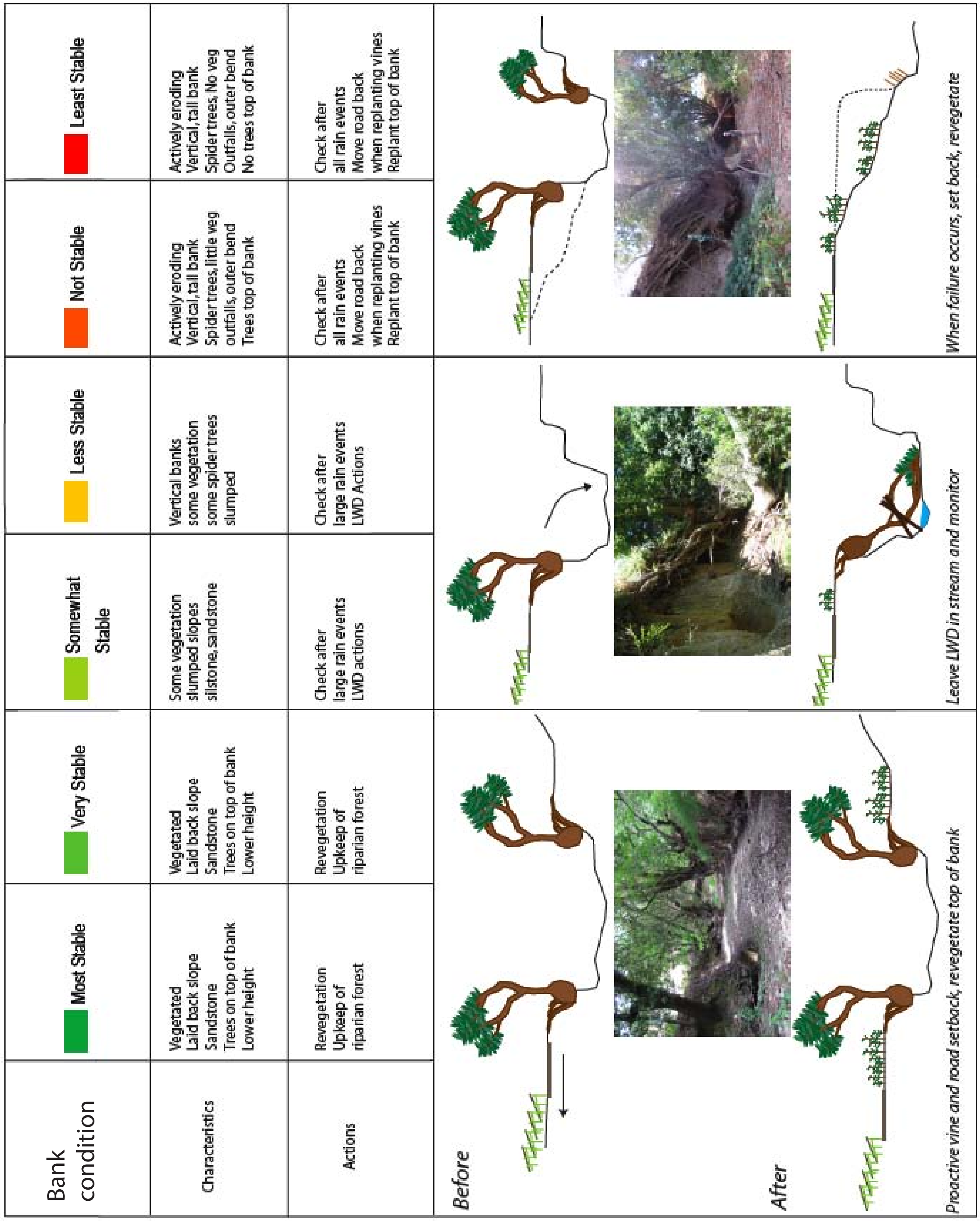
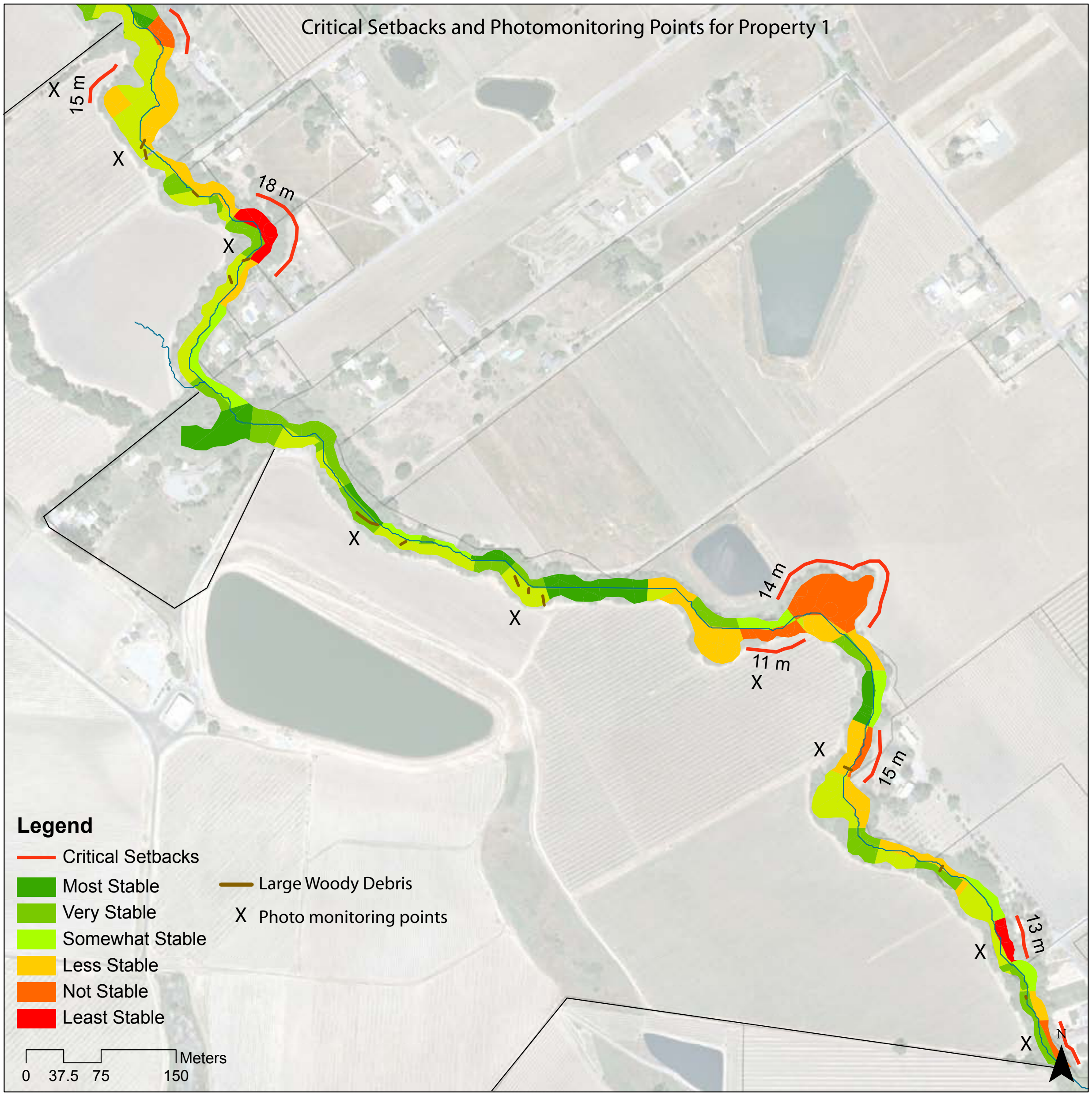


Figure 6.1. Matrix of actions based on predictive model results



Figures 6.2. Map of property 1 with critical setbacks and predictive model results

Chapter 7 | Conclusion

Proactive and anticipatory planning of stream management is an important contribution to watershed management. It requires a comprehensive understanding of the system, landowner cooperation and extensive fieldwork that leads to a synthesis of information and a predictive model, allowing application on the ground by individual land owners. It is different from adaptive management in that it includes a 'wait-and-see' component, but with emphasis on proactive management and anticipation, yet allowing the changes to take place uninhibited. The goal is to give a creek the room it needs to meander, adjust and restore its own fluvial and biotic processes, while making farming and other compatible land uses economically feasible.

Part of the management requires land managers to proactively move their activities away from the creek in anticipation of stream changes in specific locations. The other main component sets standards for anticipated bank failures or retreats, so that treatment of such failed banks follows a passive restoration approach as opposed to a reactive "emergency" approach, though encouraging active revegetation by land managers. In this way, anticipatory management breaks the cycle of spot restoration treatments and rip-rapped or hardened banks. This has been shown to lead to improved aquatic habitat, with soft edges and naturally occurring in-stream complex habitat. By allowing the creek to restore itself, and giving it room to do so, land managers may save money in the long run, as well as foster ownership and pride in their restored fish-bearing creek.

Towards improving the approach

There are many areas in this approach which need improvement. Monitoring is essential for successful management of fluvial systems. Management strategies, especially those that include predictive or proactive components, must include observations and data collected over time. Data was collected and analyzed at many scales, as well as cross-checked between LiDAR and GIS and the field however this anticipatory management approach is founded on a baseline level of data collected over just one summer (2009) on Carneros Creek.

The results of the predictive model show areas that are likely to suffer bank failure, but this has not been calibrated with which banks actually experience bank failure, or by watching banks fail over time and adjusting the model. Long term monitoring and resurveying is necessary for improving this approach both to determine the likelihood of bank failure as well as the effect of large woody debris in the channel over time. This study has set a baseline of existing debris jams and wood in the channel. The management principles could be more refined if monitoring was done over a longer period of time on effects of large wood in Carneros Creek on bank stability and fish habitat.

In terms of participants, my findings showed that rural residential parcels were often the most likely to experience bank failure, and yet this project addressed only large landowners and farmers with whom Fish Friendly Farming had a working relationship.
In the future, rural residential landowners should be brought on board using a means of collaboration such as a re-invigorated watershed group, or another non-regulatory approach. This would involve a trust-building process, but would be necessary for this plan to be a true watershed plan.

Application of study to other watersheds

The approach in this plan has the potential to be applicable to similarly-sized watersheds. Counties often reject proposals to enforce a 100 ft riparian buffer regulation, and in the absence of broad riparian protection, this method can be used to prioritize areas most in need of setbacks or buffers. This process requires landowner participation, trust and buy-in because they self-enforce these setbacks, in part because they are convinced of the economic and possibly the ecological benefits as well.

Complex contradictory permitting standards by regulatory agencies are a disincentive for landowners to manage creeks responsibly. Using anticipatory management on a watershed scale, there could be efforts to permit the entire project for a period of time under the same 1600 DFG permit. This would increase the coordination of management throughout the watershed and would provide an incentive for farmers to follow the management strategies listed in the plan.

Anticipatory management is different from traditional or adaptive management because it is voluntary and done in anticipation of stream changes on a larger scale than parcel-by-parcel. Because of time and personnel challenges, many watershed projects are a compilation of 'spot treatments.' However, walking and assessing the entire creek qualitatively and quantitatively using a variety of methods, is essential for holistic watershed management to be valuable. Yet, given the nature of privately held land along a creek such a Carneros, the management implementation takes place on a property scale.

Environmental planning and natural resources management must expand its scope given state of our environment, the changing climate and the downward trend in both fisheries ecosystems and open space. By involving landowners, and anticipating change before it occurs, resource managers and scientists can give the reins of science-based management to the stewards of the land, the people who live there, thus making it a valuable endeavor for farmers, fish populations and California landscapes.

In conclusion, like floods, bank erosion and bank failure are 'expected events,' which often creates the most complexity for fish habitat in incised streams. If landowners and land managers are able to anticipate these changes and prepare for them, the stream can adjust and restore itself, which may be an attainable goal long term for stream management.

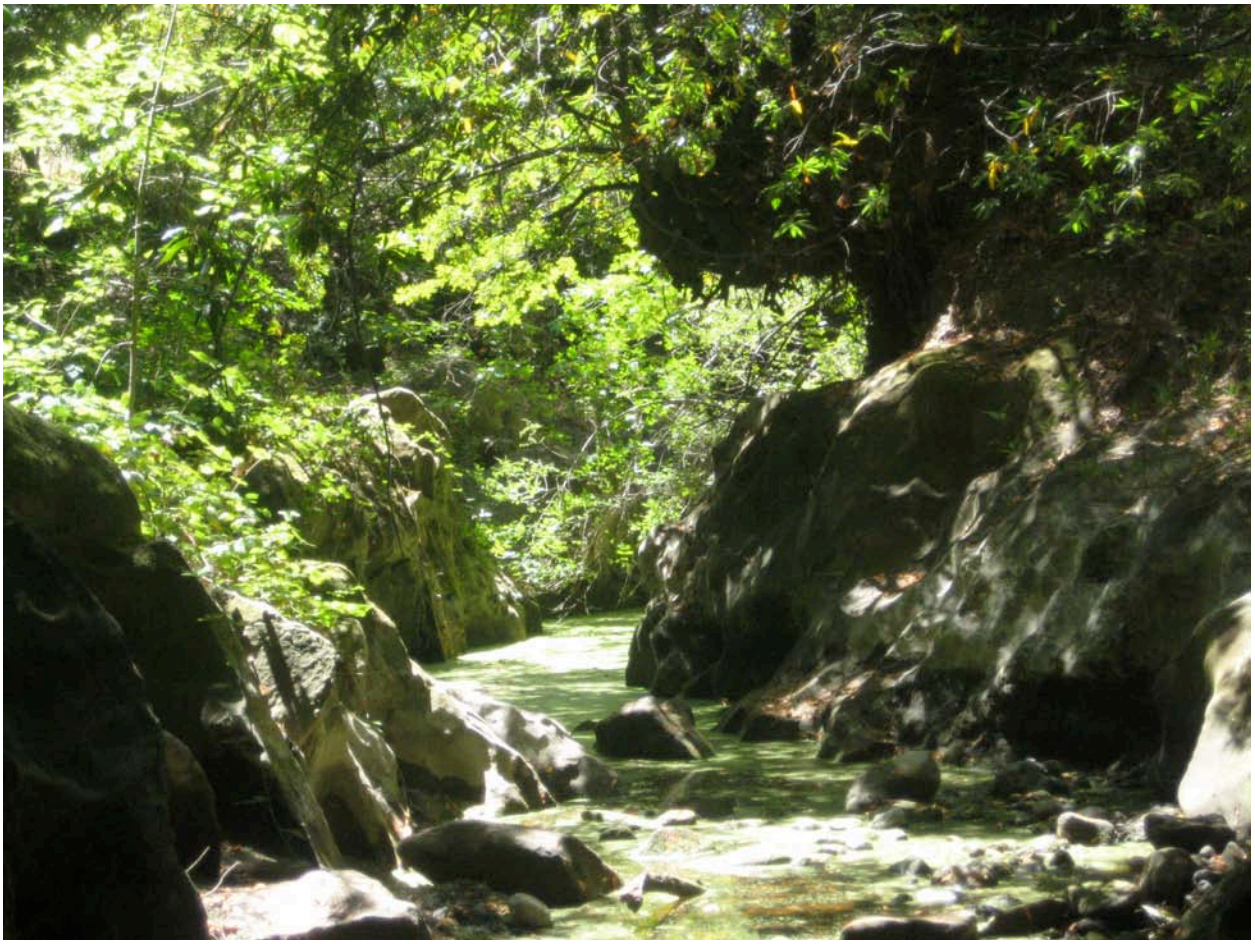


Figure 7.1. Carneros Creek

References

Army Corps of Engineers, 2006. Attachment 2 Carneros Creek Restoration Demonstration Project Conceptual Restoration Recommendations Draft Report Prepared By:CDM Sacramento, CA Prepared For: Napa Resource Conservations District Napa, CA San Pablo Bay Watershed Restoration Program San Francisco District, Army Corps of Engineers September 2006

Campbell, James B. 2006. Introduction to remote sensing. Edition 4. Guilford Press.

Cancienne et al. 2008. Influence of seepage undercutting on the stability of root-reinforced streambanks. Earth Surf. Process. Landforms 33, 1769–1786 (2008)

Colling, Troy and Warren Christensen. 2007. Regulating our Natural Resources - Farmers Friend or Farmers Foe? Have Regulators got the mix Right? 10 Flinders Journal of Law Reform. Australia

County of Napa. 2008. Initial Study and Mitigated Negative Declaration: Napa River Rutherford Reach Restoration Project. August. (J&S 05390.05) Napa, CA. Prepared by ICF Jones & Stokes, San Jose, CA.

Dietrich, W. E. and Stillwater Sciences. 2002. Napa River basin limiting factors analysis. Final technical report. Prepared by Stillwater Sciences, Berkeley, California and Department of Earth and Planetary Sciences, University of California, Berkeley for San Francisco Bay Water Quality Control Board, Oakland, California and California State Coastal Conservancy, Oakland.

Downs, Peter, and G. M. Kondolf. 2002. Post-Project Appraisals in Adaptive Management of River Channel Restoration. Environmental Management Vol. 29, No. 4, pp. 477–496

Fritts, Harold C. and Geoffrey A. Gordon. 1980. Annual Precipitation for California Since 1600 Reconstructed from Western North American Tree Rings. Laboratory or Tree-Ring Research. University of Arizona. CA DWR Agreement No. B53367. July 1980

Grossinger, R., C. Striplen, E. Brewster, and L. McKee, 2004. Ecological, Geomorphic, and Land Use History of Carneros Creek Watershed: A component of the watershed management plan for the Carneros Creek watershed, Napa County, California. A Technical Report of the Regional Watershed Program, SFEI Contribution 70, San Francisco Estuary Institute, Oakland CA. 48 pp.

Habron, Geoffrey. 2003. Role of Adaptive Management for Watershed Councils. Environmental Management Vol. 31, No. 1, pp. 29–41

Hagan, Danny. 2002. Land use map of Carneros Creek 2002. Pacific Watershed Associates. Arcata, CA.

Hanrahan, Virginia. 1948. Napa County History 1823-1948. Napa County Library. Produced and Distributed by the Napa Chamber of Commerce.

Hollaus, M., Wagner, W., Kraus, K. 2005. Airborne laser scanning and usefulness for hydrological models. Adv. Geosciences, 5, 57-63, 2005.

Kauffman, J. Boone and Robert L. Beschta, Nick Otting, Danna Lytjen. 1997. An Ecological Perspective of Riparian and Stream Restoration in the Western United States. Fisheries: A Special issue on Watershed Restoration. May 1997. Vol. 22 No 5

Keller, E. and Frederick Swanson. 1979. Effects of Large Organic Material on Channel Form and Fluvial Processes. Earth Surface Processes, Vol. 4 361-380.

Knighton, David. 1998. Fluvial Forms and Processes: A New Perspective. Hodder Arnold Publishing. Great Britain.

Kondolf, G. Mathias. 1995. Five Elements for Effective Evaluation of Stream Restoration. Restoration Ecology Vol 3. No. 2 pp. 133-136

Leidy, R.A. 2007. Ecology, Assemblage Structure, Distribution, and Status of Fishes in Streams Tributary to the San Francisco Estuary, California. SFEIContribution #530. San Francisco Estuary Institute. Oakland, CA.

Lubell, Mark. 2004. Collaborative Watershed Management: A View from the Grassroots. Russell Sage Foundation, Initiative on Trust. UC Davis

MacIver, James and Lynn Starr. 2001. Restoration of degraded lands in the interior Columbia River basin: passive vs. active approaches. Forest Ecology and Management 153 (2001) 15-28.

Malczewski, J. (2004). GIS-based land-use suitability analysis: A critical overview. Progress in Planning, 62(1), 3-65.

Marcus, Laurel. 2008. Fish Friendly Farming: Beneficial Management Practices Workbook and Farm Conservation Plan. California Land Stewardship Institute. Napa, CA. Fish Friendly Farming BMP Handbook. Version 2006-2007. 2006. California Land Stewardship Institute

Micheli, E. R., Kirchner, JW. 2002. Effects of wet meadow riparian vegetation on streambank erosion 2. Measurements of vegetated bank strength and consequences for failure mechanics. Earth Surf. Process. Landforms 27, 687 – 697 (2002)

Montgomery, D. R., and J. M. Buffington. 1998. Channel processes, classification, and response. Pages 13–42 in R. J. Naiman, and R. E. Bilby (Eds.) River Ecology and Management: Lessons from the Pacific Coastal Ecoregion. Springer-Verlag, New York, NY.

Montgomery, D. R., and S. M. Bolton. 2003. Hydrogeomorphic variability and river restoration. Pages 39–80 in R. C. Wissmar, and P. A. Bisson (Eds.) Strategies for Restoring River Systems: Sources of Variability and Uncertainty in Natural and Managed Systems. American Fisheries Society, Bethesda, MD.

Mount, Jeffrey. 1995. California Rivers and Streams: The Conflict between Fluvial Process and Land Use. University of California Press. Berkeley, CA.

Moyle, Peter. 2002. Inland Fishes of California.University of California Press. Berkeley.

Moyle, Peter and Jack Williams. 1990. Biodiversity Loss in the Temperate Zone: Decline of the Native Fish Fauna of California. Conservation Biology, Vol. 4, No. 3 (Sep., 1990), pp. 275-284

Nakano S. et al. 2000. Reciprocal subsidies: Dynamic interdependence between terrestrial and aquatic food webs. Kyoto University

O'Connor, Matt. 2005. Carneros Creek Geomorphological Study Existing Conditions Report, Prepared by: O'Conner Environmental, Inc. Prepared for: CDM and San Pablo Bay Watershed Restoration Program San Francisco District, Army Corps of Engineers, In Support of Napa Resource Conservation District

Opperman, Jeff J. and Adina Merenlender. 2004. The Effectiveness of Riparian Restoration for Improving Instream Fish Habitat in Four Hardwood-Dominated California Streams. North American Journal of Fisheries Management 24:822-834, 2004.

Ostrom, Elinor, Joanna Burger, Christopher B. Field, Richard B. Norgaard, David Policansky. 1999. Revisiting the Commons: Local Lessons, Global Challenges. Science. Vol 284. April 1999.

Ostrom Elinor, James Walker, Roy Gardner. 1992. Covenants With and Without a Sword: Self-Governance is Possible. The American Political Science Review, Vol. 86, No. 2 (Jun., 1992), pp. 404-417

Pearce, S., O'Connor, M., McKee, L., and Jones, B., 2003. Channel Geomorphology Assessment: A component of the watershed management plan for the Carneros Creek watershed, Napa County, California. A Technical Report of the Regional Watershed Program, SFEI Contribution 67. San Francisco Estuary Institute, Oakland, CA.

Piegay, H. et al. 2005. A Review of Techniques Available for Delimiting Erodible River Corridor: A Sustainable Approach to Managing Bank Erosion. River Research and Applications. 21:773-789 (2005)

Rodhe, S., Hostmann, M., Peter, A., & Ewald, K. C. (2006). Room for rivers: An integrative search strategy for floodplain restoration. Landscape and Urban Planning, 78(1-2), 50-70

Schmidt, KM et al 2001. The variability of root cohesion as an influence on shallow landslide susceptibility in the Oregon Coast Range. NRC Research Press Web site at http://cgj.nrc.ca on October 5, 2001.

Schumm, SA. 1984. Incised channel: morphology, dynamics and control. Water Resources Publications.

Scott, Michael L. Jonathan M. Friedman and Gregory T. Auble. 1996. Fluvial processes and the establishment of bottomland trees. Geomorphology. Vol 14. Issue 4. Jan 1996, Pages 327-339

Screiber, Sabine G. et al. 2004. Adaptive management: a synthesis of current understanding and effective application. Ecological Management and Restoration. Vol. 5 No. 3 December 2004 p 177-182.

Simon, A. M. Rinaldi. 2006. Disturbance, stream incision, and channel evolution: The roles of excess transport capacity and boundary materials in controlling channel response. Geomorphology 79 (2006) 361–383

Stokes, Marvin A. 1968. Title An introduction to tree-ring dating [by] Marvin A. Stokes and Terah L. Smiley. Imprint Chicago, University of Chicago Press

Soil Survey Staff, Natural Resources Conservation Service (NRCS), United States Department of Agriculture. Web Soil Survey. Available online at http://websoilsurvey.nrcs.usda.gov accessed [12/10/08].

Stankey, George H.; Clark, Roger N.; Bormann, Bernard T. 2005. Adaptive management of natural resources: theory, concepts, and management institutions. Gen. Tech. Rep. PNW-GTR-654. Portland, OR: U.S. Department of Agriculture, Forest Service, Pacific Northwest Research Station. 73 p.

State Water Quality Control Board. 2002. Total Maximum Daily Loads (TMDLs) and the 303(d) List of Impaired Water Bodies. www.swrcb.ca.gov/sanfranciscobay/water_issues/programs/TMDLs/. December 2002.

Store, R., & Jokimäki, J. 2003. A GIS-based multi-scale approach to habitat suitability modeling. Ecological Modelling, 169(1), 1-15.

Store, R., & Kangas, J. 2001. Integrating spatial multi-criteria evaluation and expert knowledge for GIS-based habitat suitability modelling. Landscape and Urban Planning, 55(2), 79-93.

U.S. Environmental Protection Agency. 1999. Protocol for Developing Sediment TMDLs. EPA 841-B-99-004.Office of Water (4503F), United States Environmental Protection Agency, Washington D.C. 132 pp.

Wagner, DL and EJ Bortugno. 1982. Santa Rosa Geologic Quadrangle. Produced by USGS National Ocean Survey.

Walters, CJ. and C.S Holling. 1990. Large-Scale Management Experiments and Learning by Doing. Ecology, 71(6). 1990, pp. 2060-2068

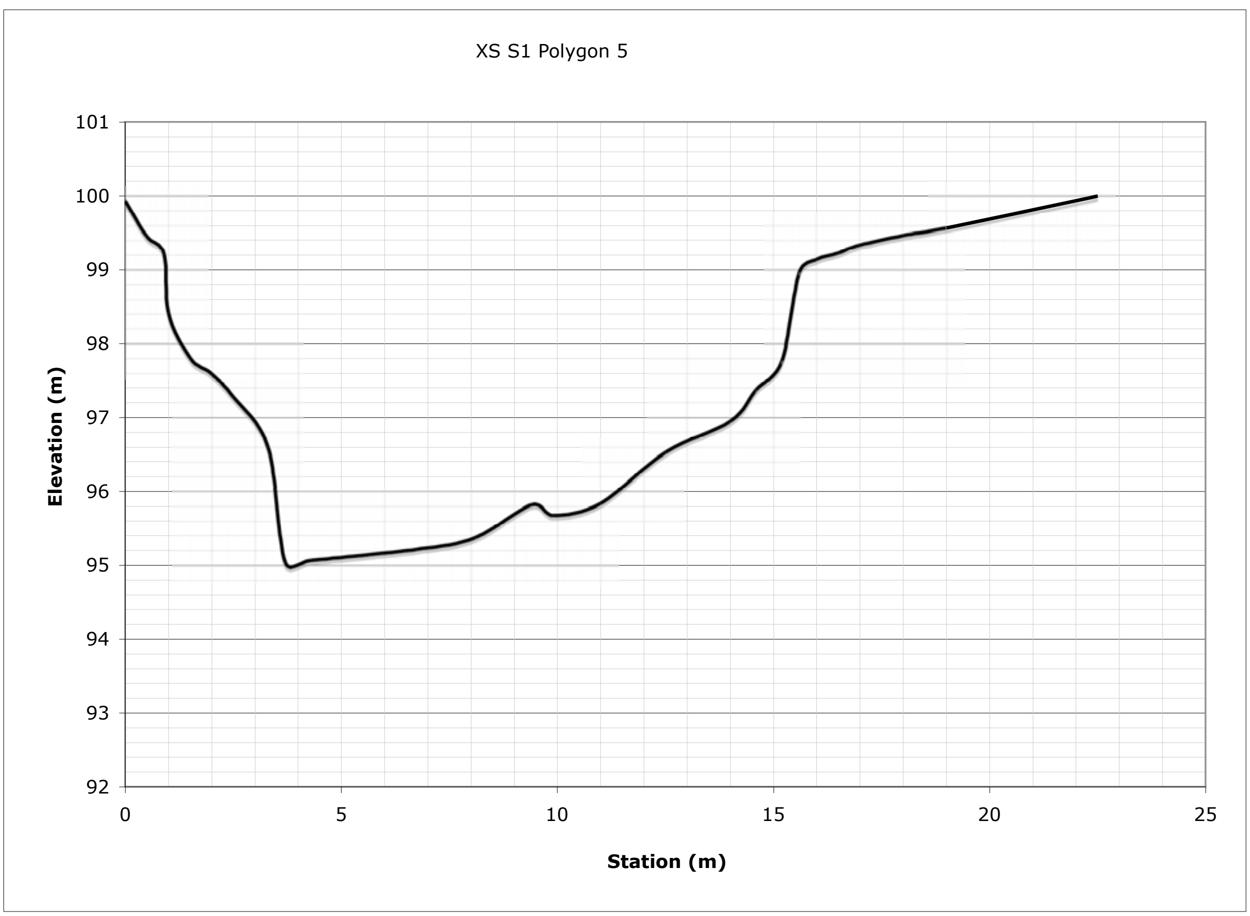
Walters, C. 1997. Challenges in adaptive management of riparian and coastal ecosystems. Conservation Ecology[online]1(2):1Weber, Lin. 1998. Old Napa Valley: The History to 1900. Wine Ventures Publishing. St. Helena

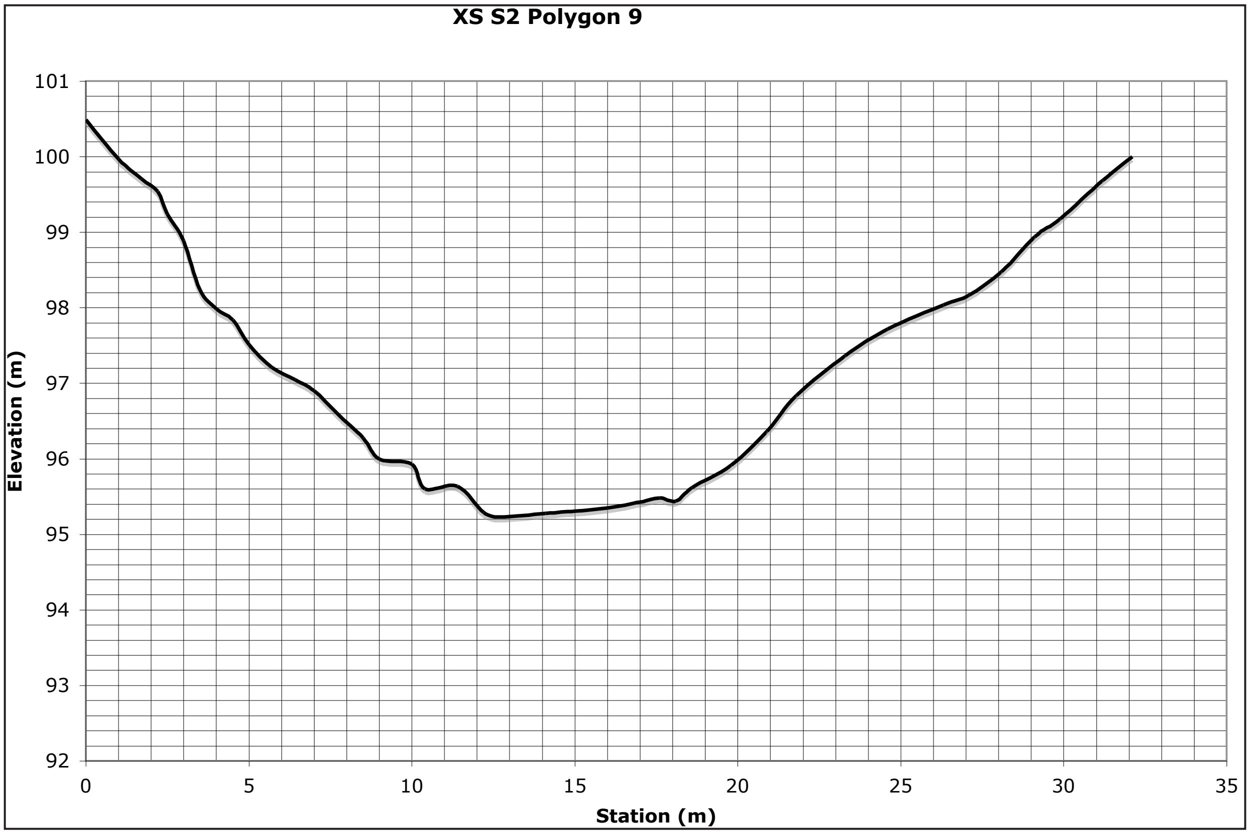
Wilcock, P. 1997. Entrainment, Displacement and Transport of Tracer Gravels. Earth Surface Processes and Landforms, Vol 22, 1125-1138

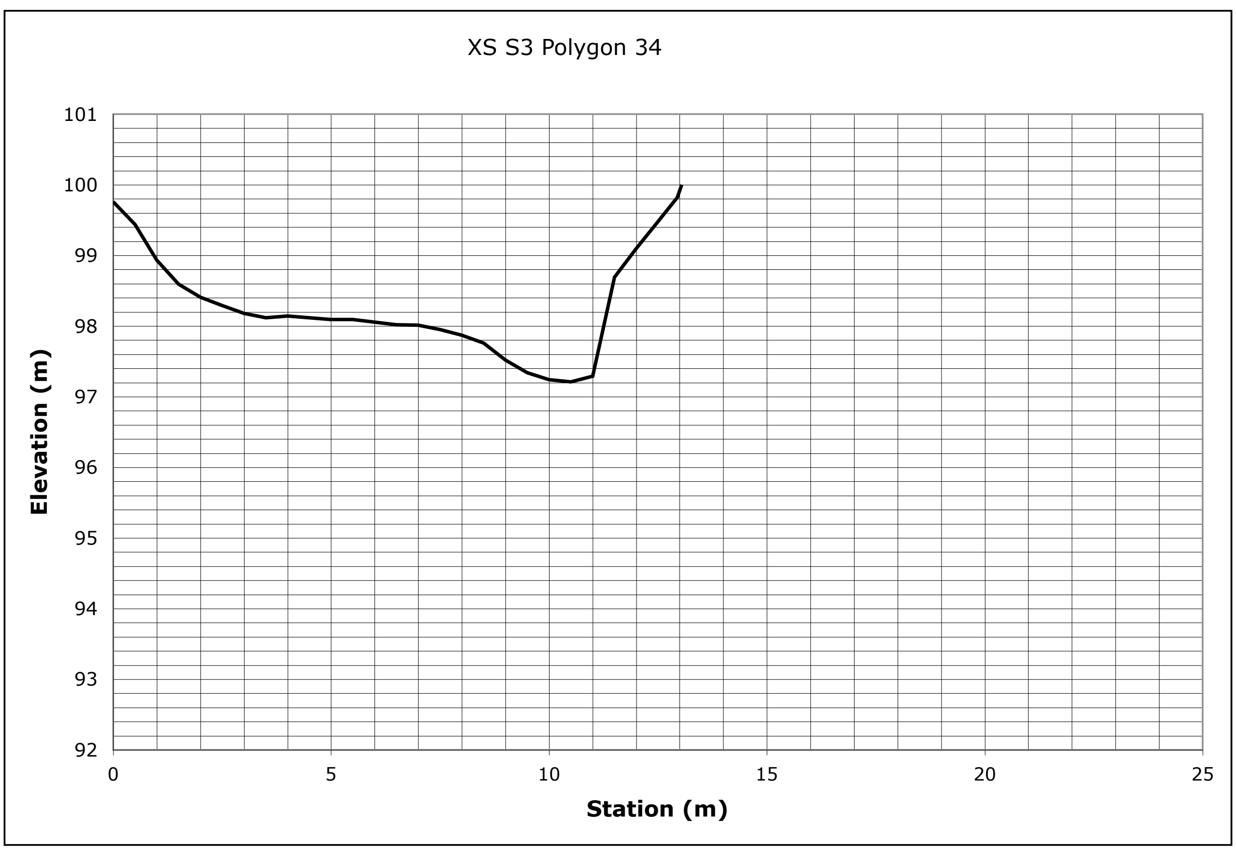
Wolman, M. G., 1954. A Method of Sampling Coarse River-Bed Material. Transactions of the American Geophysical Union 35(6):951–956.

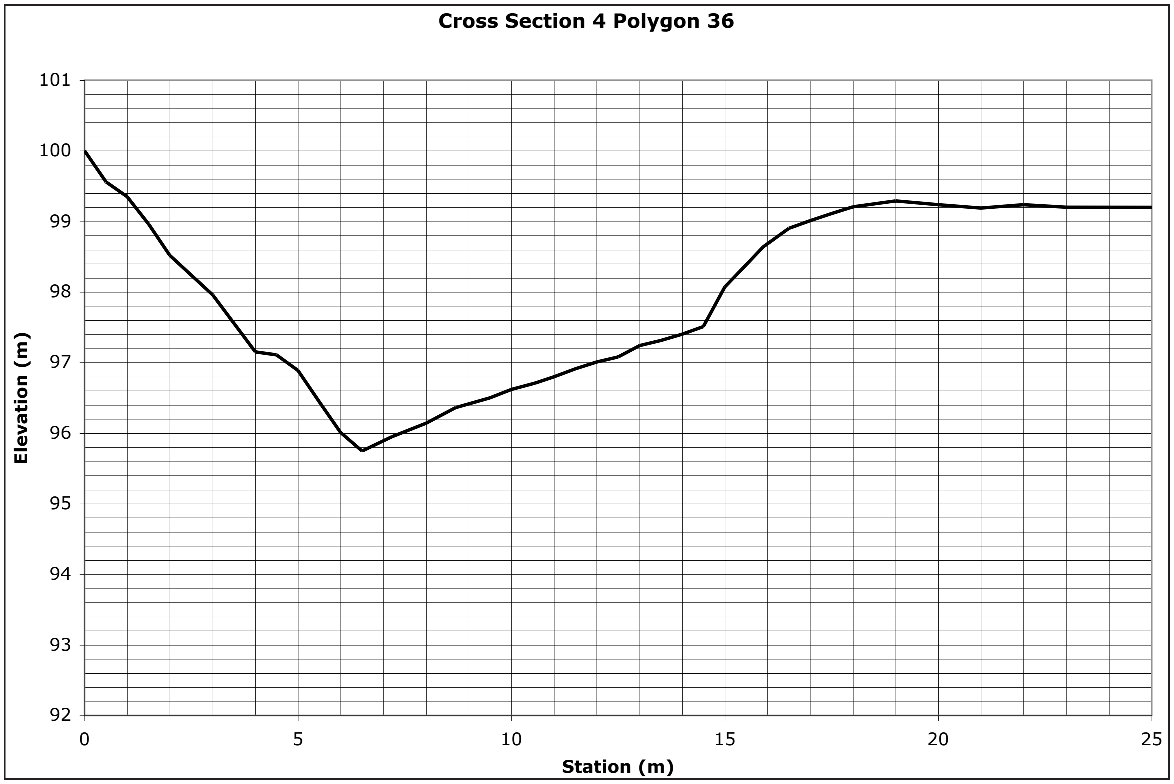
Appendix A | Cross Sections Summer 2009

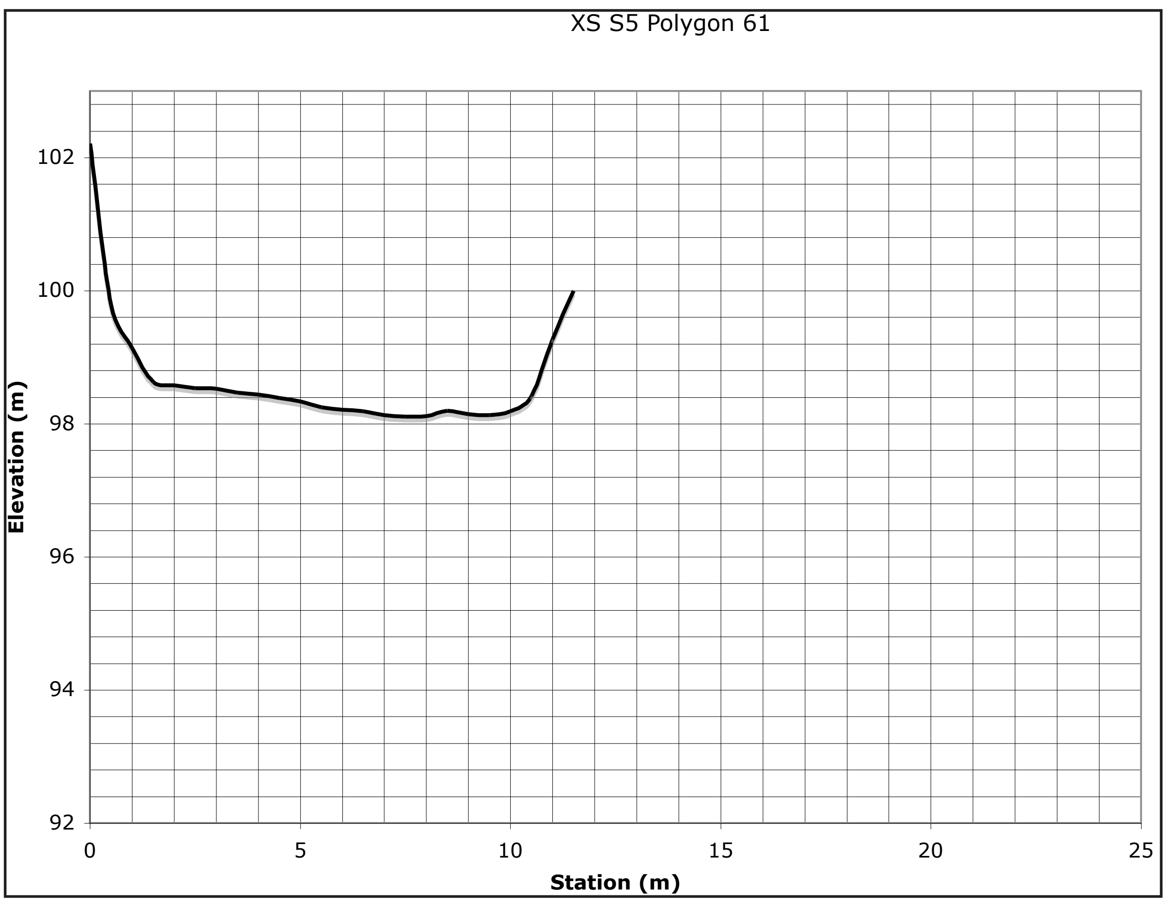
The following nine cross sections were surveyed in July, 2009. They are distributed approximately by property (almost two per property), and were chosen to be representative of the varying geometries of the creek channel. The right and left bank pins are monumented with rebar and GPS coordinates are recorded. Long profiles and pebble counts are available on request. I started at the most downstream end with cross section 1; cross section 9 is the most upstream location.

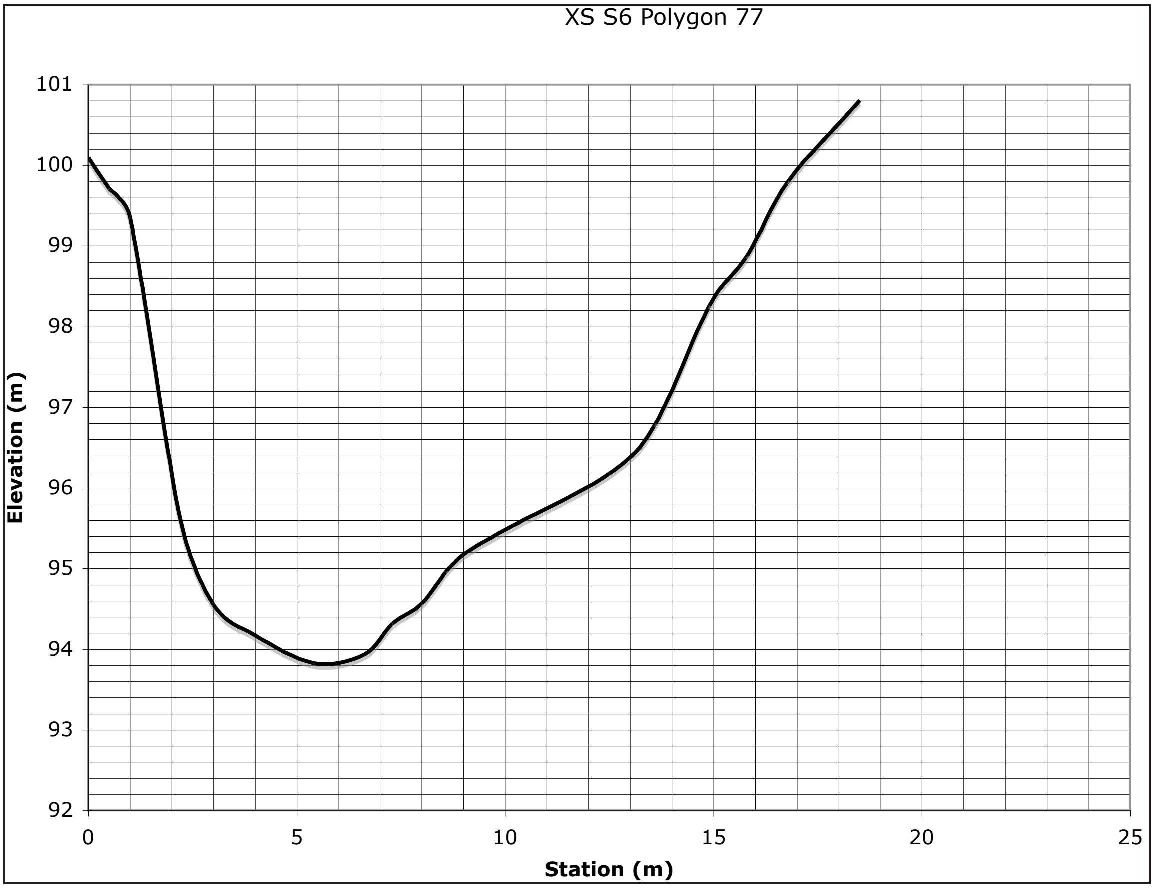


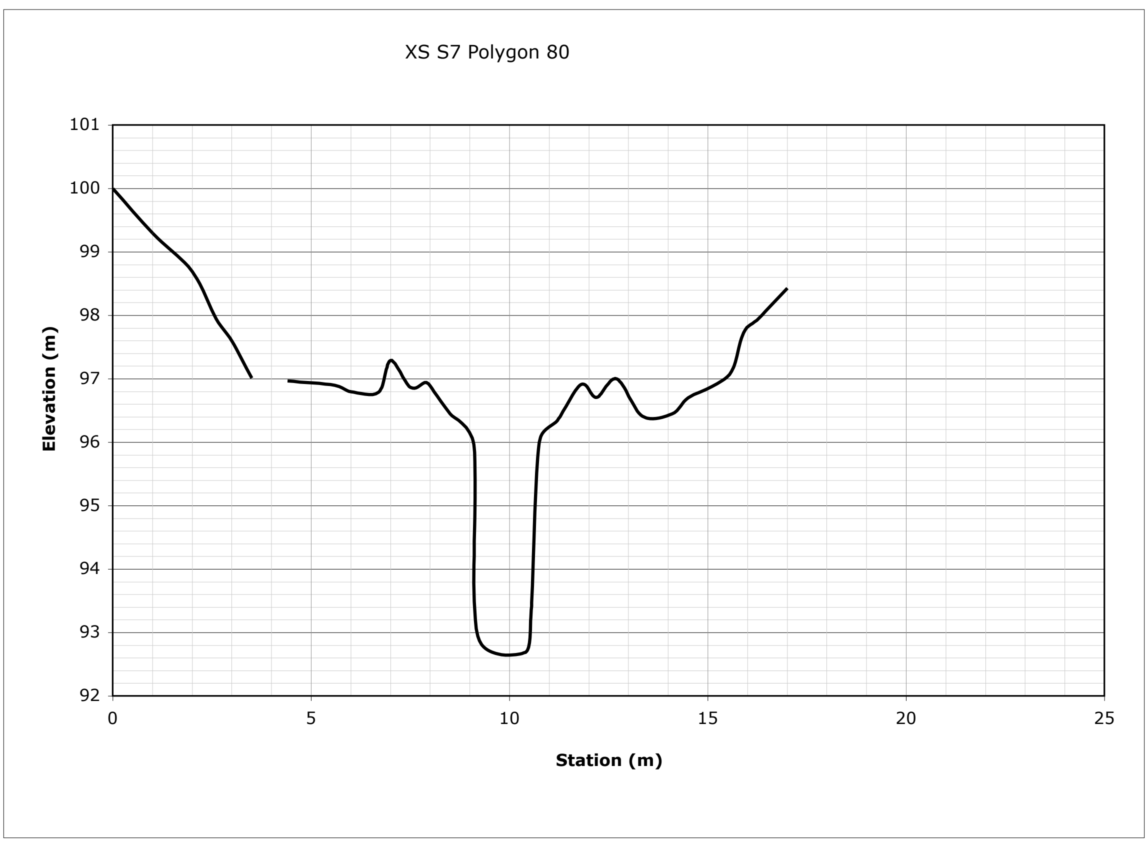

XS S2 Polygon 9
Elevation (m)
Station (m)
101
100
99
98
97
96
95
94
93
92
0
5
10
15
20
25
30
35

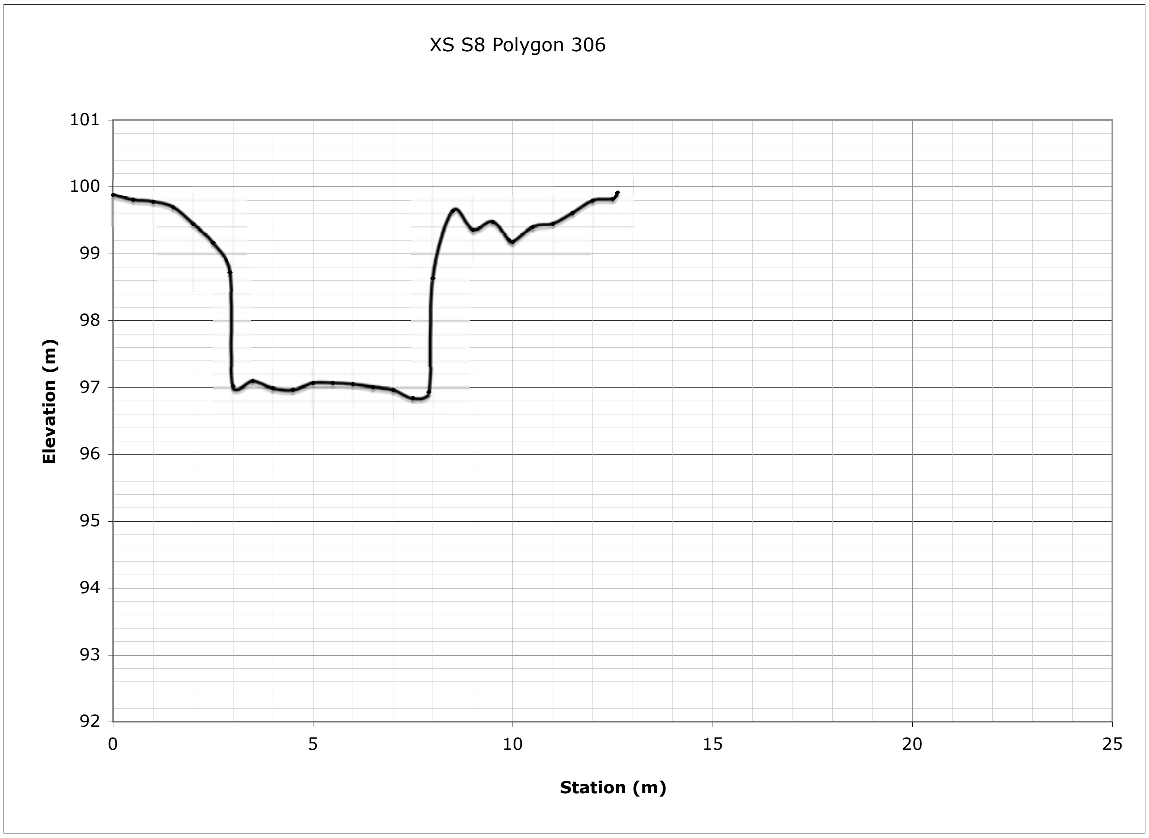

XS S3 Polygon 34
Elevation (m)
Station (m)
101
100
99
98
97
96
95
94
93
92
0
5
10
15
20
25

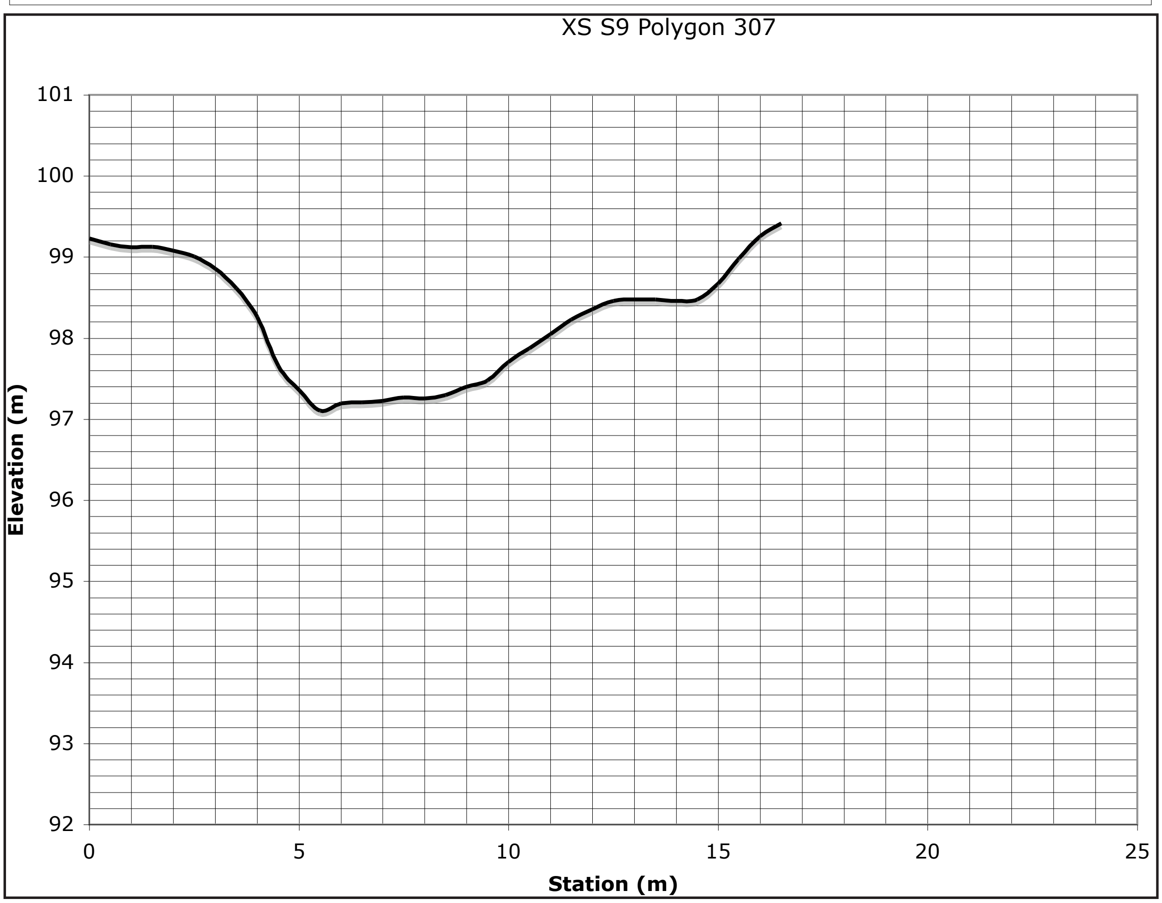

Cross Section 4 Polygon 36
101
100
99
98
97
96
95
94
93
92
Elevation (m)
0
5
10
15
20
25
Station (m)


XS S5 Polygon 61
102
100
98
96
94
92
Elevation (m)
0
5
10
15
20
25
Station (m)


XS S6 Polygon 77
101
100
99
98
97
96
95
94
93
92
Elevation (m)
0
5
10
15
20
25
Station (m)


XS S7 Polygon 80
101
100
99
98
97
96
95
94
93
92
Elevation (m)
0
5
10
15
20
25
Station (m)


XS S8 Polygon 306
101
100
99
98
97
96
95
94
93
92
Elevation (m)
0
5
10
15
20
25
Station (m)


XS S9 Polygon 307
101
100
99
98
97
96
95
94
93
92
Elevation (m)
0
5
10
15
20
25
Station (m)