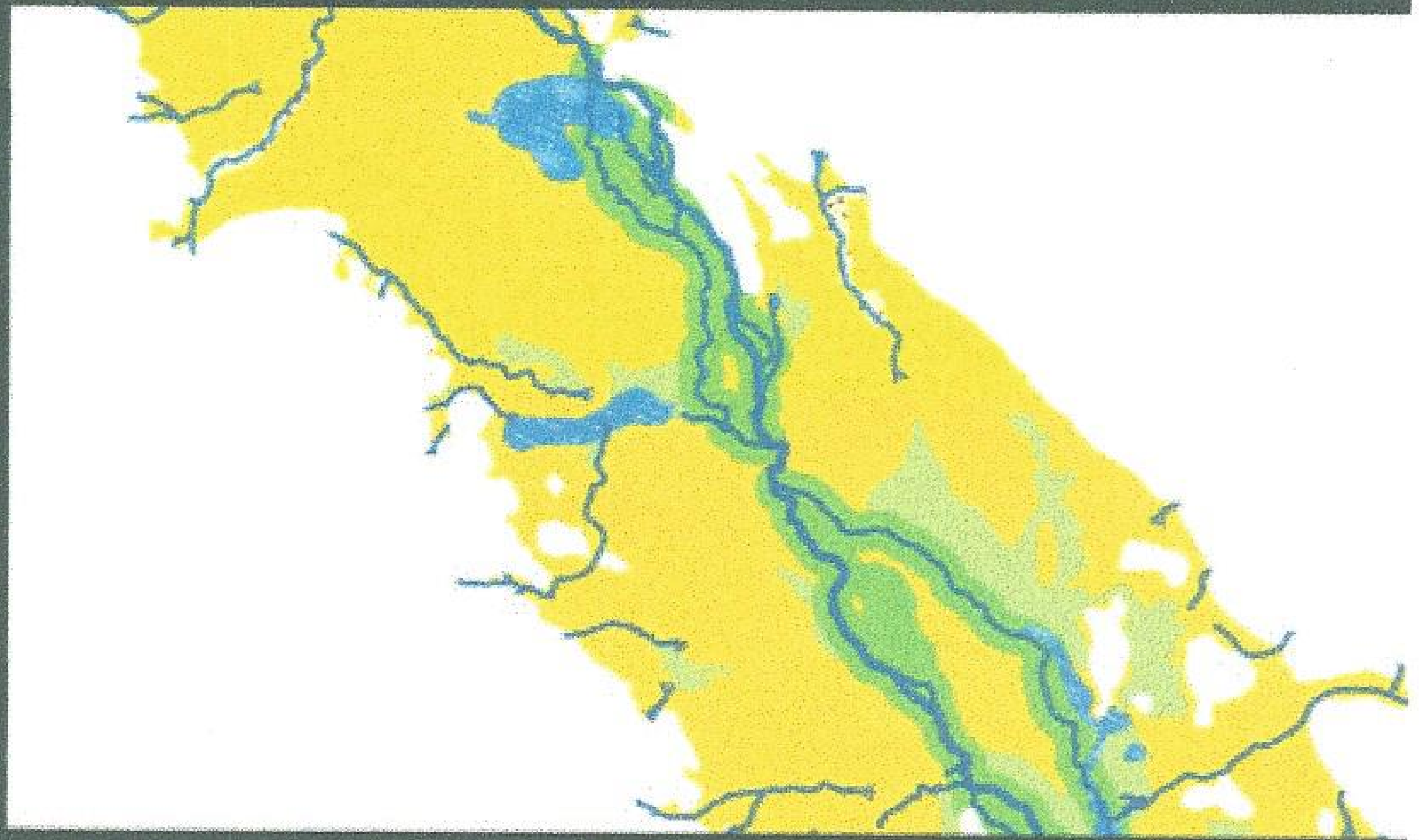
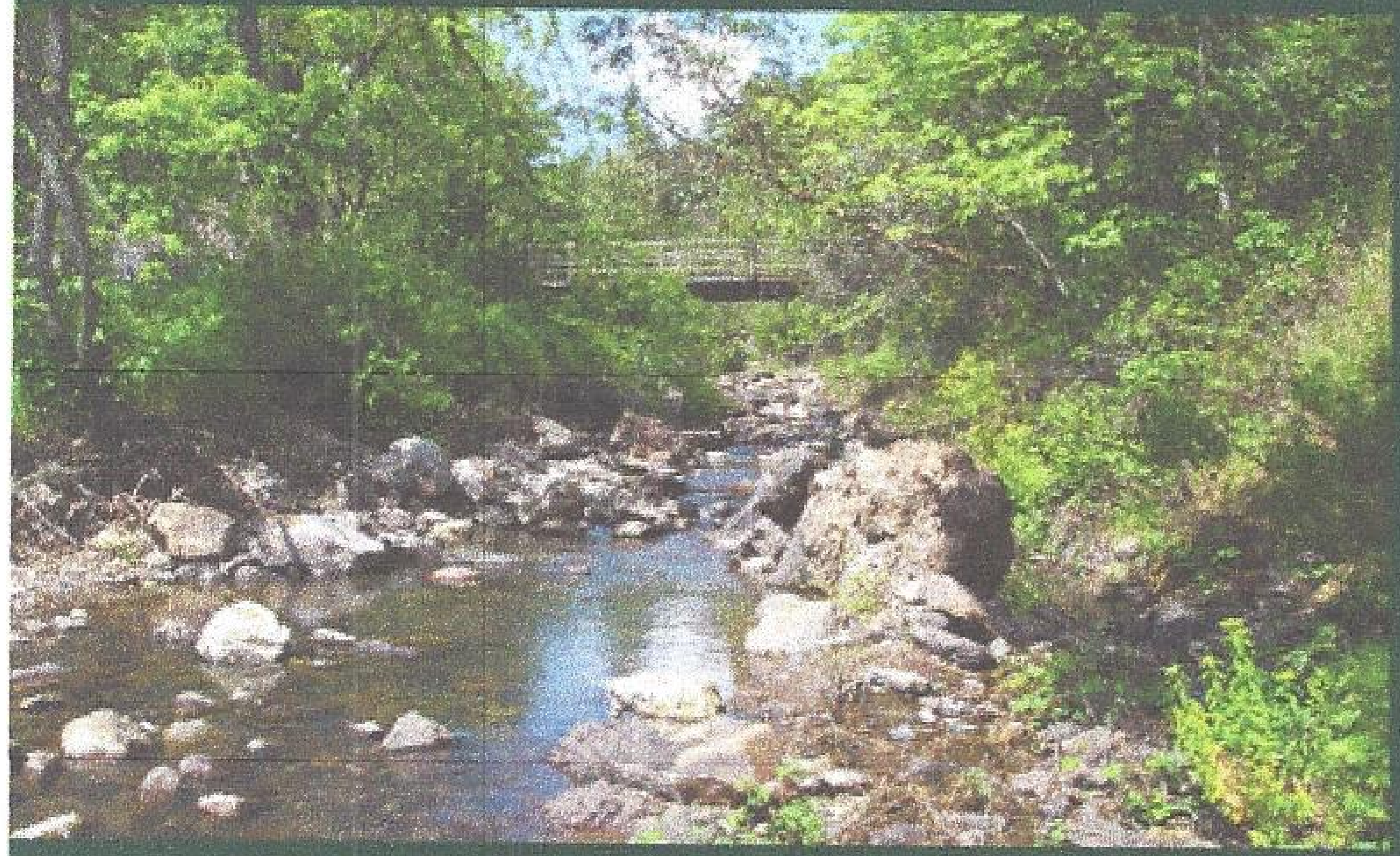
Napa River Watershed Profile:
Past and Present Characteristics with Implications for Future Management of the Changing Napa River Valley





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Overview

Ecological health and economic health are intimately interconnected in the Napa River Watershed. Napa Valley is the most recognized area within the best-known wine growing region in the United States. It yields wines that are enjoyed around the world. The community trades on the beauty and healthy life style that is emblematic of Napa Valley. The good health of the river ecosystem is essential to maintain this valuable reputation. The fish and wildlife that are endemic to the river ecosystem are primary aspects of its health. The habitat conditions for salmon and steelhead are especially important because they indicate not only the health of the river in the valley but also the health of its connection to tributaries and to San Francisco Bay.

Natural rivers adjust in width, depth, plan form, and slope to changes in sediment and water inputs. If the inputs are consistent enough in the long term, the ongoing natural processes of erosion and deposition within the river will stabilize its form. The stable form of a natural river usually includes pools and riffles, active bars and floodplains, meanders and straight reaches, and other elements that are predictably distributed along the river course. Seasonal and annual variability around the long term average inputs of water and sediment contribute to variations in river form that in turn increase the diversity of habitats for native plants and animals. Under natural conditions, rivers that are not confined by hillsides or canyon walls tend to migrate laterally. Napa Valley was formed over many thousands of years by the back-and-forth migration of the river.

The health of the Napa River ecosystem has significantly declined due to unnatural imbalances between inputs of water and sediment. In the Napa River watershed, a series of major land use changes beginning with Euro-American settlement increased the inputs of water relative to the inputs of coarse sediment, causing the river to erode its bed, abandon its floodplains, and become laden with fine sediment. Some reaches were artificially straightened and others were armored or revetted to prevent erosion of their banks. As a result of these land uses, the river system has become greatly simplified in physical form and unable to support healthy communities of aquatic and riparian plants and animals, including salmon and steelhead (Napolitano et al., 2009).

The Napa River is listed as impaired under Section 303(d) of the US Clean Water Act due to pathogens (RWQCB 2008), nutrients (RWQCB 2003), and excessive sedimentation (RWQCB 2007). The sediment problem is arguably most important because it significantly impacts the overall form and ecological complexity of the river ecosystem (Stillwater Sciences and W.E. Dietrich 2002), and because its solution is likely to involve adjustments in land and water management throughout the watershed (Pacific Watershed Associates 2003a,b,c; RWQCB 2007). A broad diagnosis of river health is warranted to outline possible solutions to the systemic imbalance between inputs of water and sediment that portends chronic river erosion and habitat loss.

This report recognizes that improvements in the health of the river ecosystem must also assure adequate flood control and water supplies. Studies of domestic and agricultural demands for water have recently been conducted (NCFWCD 2005, 2050 Napa Valley Water Resources Study). Almost none of the water used by agriculture in the Napa River Watershed is imported. Agriculture depends on precipitation that generates runoff and recharges groundwater aquifers within the watershed. Water shortages may become more widespread for agriculture outside of the groundwater-deficient areas due to its heavy reliance of the indigenous water supplies (2050 Napa Valley Water Resources Study). Agricultural growth, in combination with climate change, is likely to strain water supply further (Cooley et al., 2009, Lee et al., 2009, Lobell and Field 2009). Studies of flooding in Napa Valley and how to control it have also been conducted. A naturalistic approach to flood control is being implemented in parts of the river system and is likely to improve its health http://www.countyofnapa.org/pages/departmentcontent.aspx?id=4294971816.

This report builds on these studies with a broad recommendation for the agricultural community to decrease water consumption through conservative irrigation and frost control practices, water re-use, conjunctive water use, and a variety of ways of increasing the overall reflect some of the conceptualized landscape differences mentioned above, based on the detailed analysis of historical conditions conducted. The reconstructed hydrograph is specific to these conceptualized conditions and should not be extended to other conceptualizations. The hydrological model should be updated as the conceptual understanding of pre-settlement conditions evolves.

It is difficult to assess the accuracy of the resulting reconstructed hydrograph, and it is certainly unreasonable to expect that it captures the day-to-day variability of the historical system. It is, however, reasonable to expect that the model generates the overall shape of the historical average annual hydrograph, and the general shapes of its components. Thus, for the purpose of historical hydrograph reconstruction, a reasonable calibration of the hydrological model is one that captures the observed hydrograph variability on the scale of weeks to months. Note that the model tends to overestimate peak flows. As explained below, this means that the model conservatively estimates how much the average annual hydrograph has changed (see System Response and Current Configuration section, Modern Hydrograph discussion).

Model Results

To generate the historical average annual hydrograph, the rainfall and evaporation data used to simulate the actual average annual hydrograph were applied to the historical watershed conditions as described above. In essence, the model simulates the average annual hydrograph that would have occurred for the period 1987 to 2006 if the historical watershed existed during that period.

The model output is striking but not surprising (FIGURE 10). The very gradual slopes of the rising and falling limbs suggest that the historical watershed tended to absorb and retain rainfall, releasing it slowly to the river. The broad crest of the hydrograph suggests that the channel was very complex, with abundant active floodplains, complex riparian plant communities, and in-channel debris jams that spread and slowed the storm flows. The model results also suggest that the historical watershed sustained perennial base flow, at least in the lower reaches of the river. It seems likely that wintertime recharge of the valley's aquifers through the alluvial fans and wetlands on the valley floor maintained high water tables that discharged gradually to the river throughout the summertime. These interpretations are consistent with our detailed reconstruction of the historical landscape.

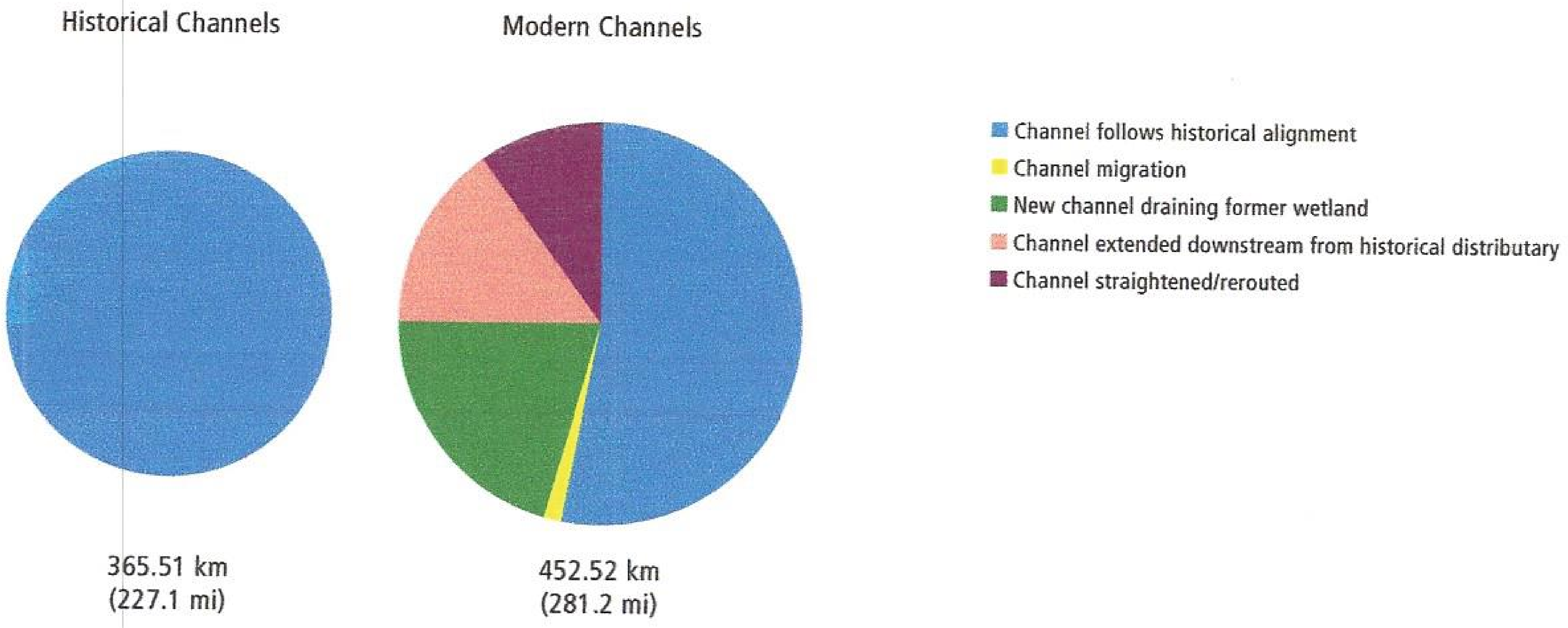
Groundwater

Groundwater data are not abundantly available for the Napa River Watershed. The major groundwater basins have been identified as mapped in FIGURE 11. General conditions for the 20th century have been summarized based on data available from the California Department of Water Resources (California Dept. of Water Resources 1995). These data suggest that historical groundwater levels approached the ground surface for most of the valley during the wet season, and dropped less than 2m below the surface during the dry season (FIGURE 17).

Under historical conditions, the relatively narrow valley was bounded by substantial tributary watershed with moderate amounts of precipitation. These watersheds had a high capacity for groundwater recharge. In many cases, the tributaries terminated on permeable alluvial fans that served as recharge areas and do so to this day in areas where they have not been converted to impervious surfaces. In addition, the river had access to broad floodplains that also served to recharge the shallow aquifers of the valley floor adjacent to the river. As a result, groundwater probably remained high enough to sustain cool base flows through much of the valley. Historical textual evidence supports this interpretation. (Grossinger 2012)

"Napa River itself is not an important direct contributor to groundwater and acts rather as a drain of the alluvial fill" (Bryan 1932). This and other previous groundwater studies for Napa Valley have consistently concluded that more water flowed from the ground into the river than from the river into the ground (e.g., Bryan 1932, Faye 1973). The construction of dams and

FIGURE 16. Historical changes in the channel network within Napa Valley. Total channel length has increased 24% resulting in more channel-per-unit area of the valley (greater channel density) and greater overall hydrological connectivity and drainage efficiency.



a runoff coefficient for any type of land cover. (See for example, National Land Cover Institute, http://landcover.usgs.gov/index.php) Pavement and roofs in urban areas tend to have very high coefficients because they are impenetrable and drain directly to ditches, storm drains, or natural channels. Unpaved urban areas are less impervious. Runoff coefficients vary for agricultural lands depending on management practices and topography. Management practices designed to improve the penetrability of agricultural lands or their ability to retain water can reduce runoff for a broad range of land steepness. But, in general, runoff tends to increase with topographic slope for any land cover type. It also increases when natural lands with dense vegetation and intact soils are converted to agriculture or urban land uses (Brabec et al., 2002, Allan 2004). Urban landscapes of the Bay Area have runoff coefficients of about 35%, while industrial areas and transportation corridors areas have coefficients of 70%, whereas more natural open space areas and forested lands have coefficients of about 10% (BASMAA 1996).

Much of the Napa River watershed consists of land covers that are not regarded as very impervious. The urban areas are not large compared to the watershed as a whole. Any reservoir that is overflowing is considered impervious, but the larger reservoirs do not often overflow, and all the smaller reservoirs together only represent a small fraction of the total areas of the watershed. Paved and compacted dirt roads comprise a larger portion of the watershed, and are a significant source of runoff because they are relatively impenetrable and usually drain directly into ditches or natural channels. Vineyards include a variety of roadways that can effectively increase the total area of roadways per unit area of land (i.e., road density). For example, the vineyards in the Carneros Creek watershed have increased the total area of roadways by about 130% (PWA 2003) compared to the days when the Carneros was primarily used for grazing cattle.

Groundwater

Except for the distinct Milliken-Tulocay-Sarco aquifer and the Carneros area, the Napa Valley aquifers are generally unconfined and have not experienced significant long-term declines (California Dept. of Water Resources 1995, NCFWCD 2005). In the 1930s, when almost all crops were dry-farmed, winter groundwater

Fine Sediment

For this report, fine sediment includes particles that are less than or equal to sand-sized (2 mm) including all of the sediment that is typically transported in suspension (suspended load usually consists of sediment ≤0.25 mm). The overall input of fine sediment to the river in the valley has increased in part because of a reduction in course sediment inputs (see section on Coarse Sediment immediately above), and because there has been an increase in the input of fine sediment. Information about the sources of fine sediment is summarized below.

The Napa River Sediment TMDL and Habitat Enhancement Plan (Napolitano et al., 2009) suggests that land use practices associated with viticulture, grazing, roads, and urbanization are major sources of fine sediment in the Napa River Watershed. Vineyards comprise most of the landcover in the valley and are becoming more extensive on hillsides in numerous tributary watersheds. Vineyards can yield fine sediment due to erosion of exposed soil in rows and vineyard avenues, disturbed soil, and small, artificial drainage channels that tend to erode. Although many BMPs are being implemented to conserve soil, such as settling basins, standpipes in reservoirs, and cover crops, the increased runoff, especially from rainfall, is not as well conserved. Fine sediment from disturbed soils and eroding ditches moves more efficiently through the ditches and other artificial channels to the river.

Re-planting practices may in some cases greatly increase the amount of disturbed soil and the risk of it becoming a source of fine sediment. Vines are replaced for three main reasons: they can become too old to produce adequate amounts of grapes; they can become too diseased to be successfully treated; or they can be exchanged for different grape varietals. Planting is usually done in the spring but can continue into summer. Some amount of replanting happens in the Napa River watershed every year. Rapid and large scale replanting occurred throughout the Napa Valley during the late 1800s and again in the 1990s to combat phylloxera infestations. The initial planting of a vineyard is usually regulated to prevent harmful discharges of sediment and other materials into aquatic habitats (Ziblatt 2001). Replanting is generally less regulated, but has the potential to yield significant amounts of fine sediment to the river. The relative importance of replanting as a sediment source is not known.

Fine sediment from grazing is primarily due to hillslope effects, including soil compaction, reduction of vegetation cover, and conversion of the plant community to species that are less able to intercept and take up water. These effects tend to increase surface erosion due to raindrop impacts, and to increase runoff. The increased runoff can cause gullying and headward erosion of small channels, which can weaken side slopes and trigger landslides. Surface erosion from grazing has historically been a problem, but it has been reduced by improved range management plus a conversion of range lands to non-grazed open space or vineyards. However, historical dirt roads, gullies, and cattle trails that have captured surface runoff have become effective components of the drainage network that provide abundant fine sediment and help transport it downstream.

The road network, including both paved roads and unpaved roads (e.g., vineyard roads and alleys, residential roads, ranch roads, and active and inactive timber roads) deserves special consideration. They contribute fine sediment via direct erosion of the roadbed surface and inboard ditches. Surface erosion of the roadbed, caused by wind erosion, or formation of rills and gullies on the surface is widely observed in the Napa River watershed. The runoff from roads is also important. Since roads are either impervious (paved) or highly compacted, they tend to generate large volumes of runoff. This runoff can cause erosion of the inboard ditches that convey the runoff, and erosion of hillsides and channels into which the runoff is directed. The Napa River Sediment TMDL and Habitat Enhancement Plan (Napolitano et al., 2009) includes an estimate that 50% of the total road system in the Napa River Watershed is connected hydrologically to the channel network that drains to the river. Bridges and culverts can also be sources of sediment. If they are undersized or become blocked with sediment or debris, the backflow can cause bank erosion.

Storm drains are artificial drainage systems for urban environments and other areas with abundant impervious land cover. They convey runoff from paved roofs, sidewalks, parking lots, and roads, including highways and freeways. Runoff from these areas tends to have large suspended loads of fine and ultrafine sediments and other pollutants (Guy 1972, Leopold 1968, Barrett et al., 1995, Adachi and Tainosho 2005). Prior to the 1930s, storm drains were usually combined with sewage collection systems. Runoff from major rainstorms can exceed the capacity of such combined systems, causing overflows. Modern storm drains are separate from sewerage. All the municipal and industrial storm drains in Napa Valley are now separate from sewerage and drain to the Napa River (Napa County Stormwater Pollution Prevention Program FAQs http://www.countyofnapa.org/Pages/DepartmentContent.aspx?id=4294969023). The agricultural sub-surface drains used to dewater the root zone of vineyards and to manage hillside runoff also function as storm drains. Their overall extent is unknown, but they might be more extensive then the municipal and industrial storm drains. Many of them incorporate soil conservation BMPs that help filter and entrap their sediment loads before they get to the river. According to the Napa River Sediment TMDL and Habitat Enhancement Plan (Napolitano et al., 2009), the sediment loads from storm drains are much smaller than the loads from other sources in the Napa River watershed.

During recent decades, most of the fine sediment load in the Napa River has probably resulted from erosion of the bed and banks of the river and its major tributaries. Furthermore, channel incision is a local source of fine sediment that directly reduces habitat quality for salmonids and other wildlife by significantly simplifying the overall physical complexity of the river ecosystem.

River erosion is discussed more thoroughly in the following section on Channel Form. Simply stated, historical and ongoing reductions in coarse sediment inputs, plus the overall increase in runoff and peak annual flows (see following section on Flow) have caused the river and most of its tributaries to erode their beds and banks. These adjustments proceed upstream in a process called headward erosion. It can progress all the way upstream through the channel network, unless it intercepts a dam, bedrock, or other obstruction. In the uppermost reaches of the channel network, increased runoff can cause headward erosion that proceeds upslope from the channel head, thus elongating the channel network. Hillside gullies are a manifestation of this kind of headward erosion. As the channel beds degrade and erode headward, the channel banks become unstable and more susceptible to failure. In the upper reaches of the channel network, where the channels drain steep hillsides, degradation and headward erosion can trigger landslides. The river in the valley has undergone multiple periods of chronic incision with net degradation since the time of Euro-American contact (see following Timeline of land use effects). Some reaches are still incising.

The Napa River Sediment TMDL and Habitat Enhancement Plan (Napolitano et al., 2009), reports that the total average rate of sediment input to the channel network below the major dams is about 159,000 tonnes per year. This is estimated to be about twice the historical rate. The modern rate is attributed to roadway-related processes (55,000 tonnes/yr), surface erosion in vineyards and range lands (37,000 tonnes/yr), gullies and landslides (30,000 tonnes per year), and channel incision plus bank erosion (37,000 tonnes/yr). The estimates for channel erosion (channel incision and bank erosion) noted in this report are conservative, based on the review of historical evidence (see following section on Channel Form). The proportions of fine and coarse sediment inputs due to channel erosion depend largely on the nature of the sediment sources. The proportion of fines is likely to be greater where channels pass through areas of friable sedimentary bedrock, the toes of alluvial fans, or the valley floor. The valley is described as consisting of poorly consolidated and non-cohesive gravels, sands, silts, and clays (Knudsen et al., 2000). The areas of historical wetlands along the valley floor are likely to consist of very fine silts and clays. Bank and bed erosion in these areas can deliver large quantities of fine sediment directly to the channel network.

The excess fine sediment in the river is affected by the historical reduction in active floodplain areas, as well as the absolute increase in fine sediment inputs and the decrease in coarse sediment inputs. Prior to its degradation, the river was bounded by broad vegetated floodplains, across which floodwaters would spread and slow, depositing much of their suspended load. The degraded channel in the valley has abandoned most of its historical floodplains, and replacement floodplains have yet to evolve.

River Flow

The historical version of the average annual hydrograph that was simulated for Napa River at Napa City (see section above on Historical Conditions) is remarkably different than the modern version hydrograph (FIGURE 19). The historical version is much broader and flatter. This is probably due to the overall retentive nature of the extensive historical watershed relative to current conditions. As explained above, historical changes in land cover have significantly increased runoff, reduced the number of groundwater recharge areas (especially alluvial fans and wetlands), while concurrently causing the river to abandon its historical floodplains and greatly increasing the overall efficiency of the channel network. Despite the increase in surface water storage (large and small reservoirs), there is more runoff and it reaches the river faster, especially after reservoir capacity has been reached and additional storms result in discharges over the spillway. Early in the wet season and during droughts, the unfilled reservoirs attenuate downstream peak flows by withholding runoff. But, once they have reached their capacity, they release essentially the same volumes of water that they receive, minus evaporation (which is minor during storms). These land use changes explain the steeper rising and falling limbs of the current hydrograph, its higher and sharper peaks, and the overall increase in flow volume. Reduced infiltration, artificial sub-surface drainage, and a lower groundwater recession rate no longer allow for extended summer base flow.

It should be noted that the model used to simulate the average annual hydrograph probably overestimates the peak flows because it does not account for flows spreading onto floodplains. This means that, with regard to peak flows, the actual difference between the historical and current hydrographs are probably greater than portrayed here. It should also be pointed out that although the peak flows were historically lower, the historical river bed was higher, such that the valley floor probably flooded more often. As discussed further in the following section on Management Actions, dedicating more valley land to natural flooding is one way to reduce overall flood hazards while greatly improving the health of the river ecosystem.

The historical watershed was much more retentive, due to the more complex drainage system that minimized runoff and slowed its movement through the river to the Bay. The natural system served as a dynamic physical template for complex mosaics of habitats that supported very diverse plant and animal communities. The current watershed with its artificially efficient drainage network, including rapid groundwater drainage to the river, has short-circuited the historical hydrological processes and compromised the associated ecological functions.

TABLE 3. Current and [estimated] historic land use/land cover for the non-tidal portions of the Napa watershed. Current acreage based on ABAG 2000 reported land use. Although more recent land use data are available, the year 2000 data are included in the ten year rainfall record used for this modeling (1987-2006).

Land Use/Cover	Est. Historic Acreage	Est. Historic %	Current Acreage	Current%	% Change
Urban/Built-up	0	0	11,900	9%	-
Agriculture	0	0	49,200	35%	-
Grassland/Range	24,000	17%	21,400	15%	-11%
Forest	109,600	79%	55,100	40%	-50%
Wetland/Water	5,500	4%	1,400	1%	-75%

System Response Timeline

The general effects of land use on the form of the river in the valley can be separated into five main periods (APPENDIX 6). The period of indigenous management spanned thousands of years, but there is no evidence of any major impacts on natural hydrological processes. No evidence of river diversion or impoundment has been found, although the river undoubtedly adjusted to alterations of runoff caused by the indigenous use of fire to manage vegetation. The remaining four periods have each lasted less than a century, although the current period is, of course, ongoing.

The Mission period begins with the cessation of indigenous management and the advent of Euro-American settlement. It is characterized by the introduction of ranching, and other non-indigenous land use practices. These practices may have had some impact on watershed processes, but this period was relatively brief in Napa Valley.

The Agricultural period begins in the mid 1800's, after the California gold rush. It is characterized by a sudden increase in the extent and intensity of most Euro-American land uses, due to increased settlement in the valley. Ranching gave way to farming, with major shifts in dominant crops from grains to vineyards and orchards. A multitude of small reservoirs were built in the hills surrounding the valley to provide water for local ranches, farms, and vineyards. Significant increases in overall channel density, channel degradation, bankfull width, and peak flow began during this period, as did decreases in dry season base flow.

The urbanization period began after WWII. It is characterized by rapid growth in local urban centers, especially Napa and Calistoga, plus the construction of major dams to meet growing water demands. Both the large dams and urbanization contributed to channel incision by entrapping coarse sediment and increasing urban runoff, respectively. The river became sufficiently entrenched to contain high storm flows that further exacerbated the incision problem. Large woody debris that might have been entrained by flood flows was routinely removed from the river to reduce flood hazards.

The major tributaries and the river were probably still adjusting to urbanization when the current Modern period began, around 1970. This period has been characterized by an expansion and intensification of viticulture designed to meet a rapid increase in the worldwide demand for wine. New irrigation practices, especially drip irrigation, have helped meet this demand. Ditching has continued, reservoirs have been built on the valley floor to meet the increased need for frost control and irrigation, and the practice of sub-surface drainage has been extended throughout most of the valley. Vineyards have been planted on hillsides and fitted with their own storm drain systems. The resulting increases in the rate and volume of runoff have been unprecedented for the watershed. Channel incision and bank erosion have continued, with concomitant increases in the supply of fine sediment, declines in salmonid populations, and reductions in riparian resources. The river ecosystem has become greatly simplified overall, with narrow riparian zones, narrower floodplains, and a lack of in-stream habitat complexity.

Public understanding of the negative environmental impacts of historical land use practices in the Napa Watershed increased markedly during the 1990s. Local agencies translated this understanding into new practices intended to minimize or eliminate the negative impacts. The focus has been on the control of agricultural land erosion through cover crops, retention basins, minimized planting on steep slopes, and other proven practices. One unintended effect of these modern practices has been an increase in runoff without a compensating increase in coarse sediment supply. The next phase in the relationship between channel morphology and land use could emphasize a watershed approach to comprehensive river management.

The following schematics illustrate a broad set of changes in the hydrology, morphology, and sediment regime of the river. Given the scope and purpose of this report, the schematics focus on the effects of agriculture rather than urban land use. They serve as a visual summary of the effects of land use change on river form and function that are discussed in more detail elsewhere in this report.

Over the past two centuries, the Napa River in Napa Valley has undergone significant changes in form and function due to land use. Simply stated, the river in the valley has become overly connected to surface runoff and shallow groundwater, and disconnected from much of its coarse sediment supply. The resulting increase in flow and reduction in coarse sediment load has caused the channel to become deeply entrenched within its valley. Land use has encroached far into the riparian zone, eliminating many of the natural riparian functions. The river has become an efficient conduit for runoff and sediment, with little of its historical ecological value. In short, many of the attributes of a healthy river are greatly diminised.

Landowners and other stakeholders in the Napa River watershed are well-positioned to use these findings to guide recovery of the river's health. Measure A funding may be one avenue for planning and implementing management and restoration projects at the watershed scale that address multiple healthy river attributes. Measure A funds have partially enabled the Rutherford Reach and the Oakville Cross Road to Oak Knoll Avenue restoration projects. Large-scale, coordinated restoration efforts have been initiated that are a great improvement over uncoordinated small-scale projects. These restoration efforts have demonstrated that large-scale projects designed in the watershed context can be implemented, despite some significant institutional challenges. These projects required the involvement of multiple landowners, combined funding from multiple private and public sources, a long-term adaptive management approach, and the support of multiple state and local permitting and implementation agencies. Highly coordinated, truly watershed-scale efforts to improve the Napa River's function can reference lessons learned about collaboration and cooperation from these projects. The technical advisory teams for these projects might find this report relevant for future phases of implementation.

The Napa River community has an engaged set of stakeholders particularly within the winegrower community. Landowner participation in the Fish Friendly Farming program demonstrates a commitment to stewardship of the watershed. Napa Sustainable Winegrowing Group (NSWG) seminars, annual Napa County Watershed Symposia and the WICC are well-established avenues to continue outreach and education using this report and its findings. Steps should be taken to translate the findings from this report into readily understood, actionable products for the Napa River community. Over time, a menu of approaches could be developed for enhancing the river's capacity for pollution filtration, groundwater recharge, flood protection, landscape, native riparian and aquatic species support and, of course, salmonid support.

The need for ongoing research and monitoring will not wane. A better understanding of the relationships between land use and river health will certainly lead to better land use designs and decisions. The scientific understanding will need to be translated into public commitment to restore the ecological health of the Napa River.

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