



FINAL Napa River Basin Limiting Factors Analysis

EXECUTIVE SUMMARY

Prepared for

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Preface

The San Francisco Bay Water Quality Control Board (Regional Board) regulates water quality throughout the Bay Area, including the Napa River watershed, to protect the beneficial uses of water for the use and enjoyment of the people of the state. Beneficial uses include water supply, recreation, navigation, and the preservation and enhancement of fish, wildlife, and other aquatic species. Based on evidence of widespread erosion and concerns regarding adverse impacts to fisheries habitat, the Regional Board listed the Napa River and its tributaries in 1990 as impaired by sediment under Section 303(d) of the federal Clean Water Act. As such, the Regional Board is legally required to prepare a total maximum daily load (TMDL). TMDL is a national program mandated by the Clean Water Act to identify pollution problems, determine pollution sources, and develop plans to restore the health of polluted bodies of water.

The California State Coastal Conservancy (Coastal Conservancy), a non-regulatory agency, was created by the state legislature in 1976 to work with agencies, nonprofits, and landowners to preserve, restore, and enhance natural resources along the coast for the use and enjoyment of the people of the state. Its legislative mandate was expanded in 1997 to include the nine-county San Francisco Bay Area. It is actively involved in restoration and planning projects in the Napa River watershed, including enhancement of the lower Napa River floodplain and restoration of approximately 10,000 acres (4000 ha) of former commercial salt ponds. The Coastal Conservancy has a strong interest in funding projects in the Napa River watershed to restore and enhance natural habitats and processes, and thus has helped fund this study, which includes recommendations for restoration activities.

To serve the public trust, and to fulfill the responsibilities of our agencies, the Regional Board and Coastal Conservancy funded a two-year study of stream and riparian habitat conditions in the Napa River watershed. The study, conducted by the University of California in collaboration with Stillwater Sciences, evaluated factors limiting populations of three species of rare or threatened native fish and aquatic wildlife in the Napa River watershed and was designed to help the Regional Board refine the TMDL problem statement and facilitate the Coastal Conservancy's restoration planning and project implementation.

The study, which represents Phase I of a planned two-phase study, had three primary objectives:

1. To help inform the Regional Board's sediment TMDL process;
2. To improve our understanding of current conditions in the Napa River system, develop and refine hypotheses regarding impacts on salmonids and freshwater shrimp populations by sediment and other factors, and develop recommendations for additional (Phase II) studies to define cause-and-effect relationships between human land use activities in the watershed and their impacts on water quality and beneficial uses; and
3. To make recommendations regarding planning and implementation of restoration actions to protect and restore aquatic ecosystem functions and beneficial uses in the Napa River watershed. These recommendations are based on and commensurate with our current state of knowledge. We anticipate formulating more detailed recommendations once key uncertainties have been resolved during Phase II.

This Executive Summary and the full Technical Report will be posted on the Regional Board website at <http://www.swrcb.ca.gov/~rwqcb2> (under "Available Documents") and on the Coastal Conservancy website at <http://www.coastalconservancy.ca.gov> (under "News" and "Projects and Programs").

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Acknowledgements

We would like to thank the Regional Water Quality Control Board and Coastal Conservancy for providing the primary sources of funding for this study. We are also grateful for funding provided by the Napa RCD as part of a separate study that allowed us to conduct additional surveys in some of the northern tributaries and helped improve our general understanding of tributary conditions.

We express special thanks to Michael Napolitano (Regional Water Quality Control Board) and Ann Buell (Coastal Conservancy) both of whom contributed to the success of this project in many ways, including many hours reviewing and helping us improve the Executive Summary and Technical Report. Paul Jones (U.S. Environmental Protection Agency) provided input throughout the project. Leslie Ferguson (Regional Water Quality Control Board and UC Davis) was the person primarily responsible for getting the project started, and she provided important technical input throughout this study. Martin Trso, R.G., contributed greatly to the geomorphic field surveys and analyses, and provided much useful input on the report. We thank Sayaka Araki (UC Berkeley) for her steadfast efforts in the field, and with many hours of data analysis and graphics editing. We had a number of productive discussions with Laurel Collins about Napa and Bay Area streams and geomorphic assessment.

Access

We are grateful to all of the private landowners who took an interest in this study and were kind enough to grant us permission to make channel observations and measurements on their property. Obtaining permissions for access would not have been possible without the help a large number of individuals and several organizations. We offer special thanks to the Conservation Committee, Directors, and staff of the Napa County Farm Bureau; the members of the Carneros, Dry, Huichica, and Sulfur Creeks tributary stewardship groups; the staff and Board of Directors of Napa County RCD; the staff of the Land Trust of Napa County; staff and members of the Napa Valley Vintners Association and Napa Valley Grape Growers Association; staff of the Both Napa Valley State Park and Las Posadas State Forest, and members of the Friends of the Napa River.

Technical Input

Numerous individuals provided us with existing data and provided critical input to our ideas and studies designs during the project. In particular, we'd like to thank Matt O'Connor of O'Connor Environmental); Robin Grosinger, Lester McKee, Sarah Newland, and others at the San Francisco Estuary Institute; Derrick Acomb, Bob Coey, John Emig, Mike Rugg, Gail Seymour, Bob Snyder, and Larry Week at California Department of Fish and Game; Phil Blake, Jonathon Koehler, Jennifer O'Leary, Dave Steiner, and Bob Zlomke at Napa RCD; David Graves (Carneros Creek Stewardship); Charles Dewberry and Chris Malan for providing data from the Friends of the Napa River steelhead and macroinvertebrate surveys; Volker Eisele and Tom Gamble of the Napa County Farm Bureau; and Mignon Everett, Trish Hornisher, Pat Kowta, John Lander, Patrick Lowe, Bob Peterson, Jeff Redding, John Stewart, and Charlie Wilson at various Napa County agencies.

Public Comment

We also thank all individuals and organizations that provided comments during the public review period and at the public meeting on June 10, 2002 in Yountville, Napa County.

I. SCOPE AND OBJECTIVES

This report evaluates the current habitat conditions found in the Napa River and its tributaries using an iterative process of hypothesis development and testing to identify the factors that are most likely limiting populations of key aquatic species of concern. This two-year study, conducted by Stillwater Sciences and the University of California at Berkeley, was jointly funded by the San Francisco Bay Water Quality Control Board (Regional Board) and the California State Coastal Conservancy (Coastal Conservancy) as part of their efforts to gather the necessary information to guide the protection and restoration of beneficial uses and aquatic ecosystem functions in the Napa River basin.

We report herein on the first phase of a planned two-phase research program, focused on a watershed-wide¹ assessment of current conditions in the Napa River and its tributaries, and analysis of the factors that are most likely limiting the populations of three aquatic species chosen for focused study: Chinook salmon (*Oncorhynchus tshawytscha*), steelhead (*O. mykiss*) (also known as steelhead trout), and California freshwater shrimp (*Syncaris pacifica*)². The study also includes a limited effort to reconstruct historical conditions using available information to document changes that have occurred in stream habitat conditions, particularly those most likely to affect the three analysis species. This limited historical analysis was intended to improve our understanding of current conditions, the nature and degree of water quality impairment by sediment and other factors, and generate hypotheses for future study during the planned second phase of our research program. We have recommended that a more detailed historical analysis be conducted during Phase II to help establish causal linkages between any observed impairment and processes operating at the watershed scale.

The results of the Phase I studies described herein are meant to serve three primary objectives:

1. To help inform the Regional Board's sediment TMDL process (the Napa River is listed as being impaired by sediment, requiring the Regional Board to implement the TMDL process as mandated under the Clean Water Act);
2. To improve our understanding of current conditions in the Napa River system, develop and refine hypotheses related to impairment of salmonids and freshwater shrimp populations by sediment and other factors, and develop recommendations for additional studies to define cause-and-effect relationships between human land use activities in the watershed and their impacts on water quality and beneficial uses; and
3. To make recommendations regarding planning and implementation of restoration actions to protect and restore aquatic ecosystem functions and beneficial uses in the Napa River watershed. These recommendations are based on and commensurate with our current state of knowledge. We anticipate formulating more detailed recommendations once key uncertainties have been resolved during Phase II.

II. APPROACH

The purpose of using an iterative process of hypothesis development, testing, and refinement is to provide the most adaptive and effective mechanism possible for restoration planning and implementation in the Napa River basin. This approach may be viewed as a model for longer-

¹ This study was designed to provide a reliable assessment of current conditions from a watershed-wide perspective. Available resources were not sufficient, however, to support the more intensive sampling program that would be required to give a reliable and comprehensive assessment of current conditions for individual tributaries.

² It should be noted that the water quality portion of our analysis was focused on sediment and temperature as potential limiting factors. Other water quality parameters, such as nutrients, pathogens, or chemical contaminants may affect the analysis species or other beneficial uses, but were outside the scope of this study.

term adaptive management by stakeholders, who will prioritize, monitor, and refine watershed restoration actions over time.

The Phase I Limiting Factors Assessment was a five-step process:

Step 1. Assemble and Review Available Information. We assembled and reviewed relevant existing information, and interviewed local experts to characterize the general physical and biological attributes of the Napa River and its tributaries, and identify key issues of concern. This step included development of various Geographic Information System (GIS) layers that reflected watershed conditions in a map-based format and allowed us to stratify the watershed and channel network to aid in hypothesis development and study site selection. Chapter 2 (Approach) in the main report provides a more comprehensive description of the approach used to generate initial hypotheses about physical and biological conditions and guide types and locations of field studies.

Step 2. Develop Initial Hypotheses and Work Plan for Focused Studies. Building on the watershed characterization and other information developed in Step 1, we selected three at-risk species for more in-depth study and began developing hypotheses regarding current habitat conditions and potential limiting factors for the analysis species (specific hypotheses are presented in Section IV). We then conducted rapid reconnaissance of the watershed to begin refining hypotheses and identify priorities for focused studies. Two of the analysis species, steelhead and Chinook salmon, are widely hypothesized to have exhibited marked declines within the Napa River watershed from historical conditions. Less is known about the third analysis species, California freshwater shrimp, but it too has likely undergone a substantial decline in distribution and abundance from historical conditions. In addition to representing at-risk species, the three analysis species serve as indicators of general habitat needs of native cold-water fish species in the mainstem (Chinook salmon, and to a lesser extent, steelhead) and tributaries (steelhead), and other aquatic organisms in the mainstem and lower-gradient reaches of tributaries on the valley floor (California freshwater shrimp). Available information, scope, and budget constrained us from including consideration of additional analysis species.

Step 3. Conduct Focused Studies. We conducted focused studies to begin testing the most likely hypotheses. We also assessed the uncertainty associated with the results of the focused studies. Focused studies included field measurement of general habitat conditions for Chinook salmon, steelhead, and freshwater shrimp, water temperature, turbidity, pool filling, spawning gravel permeability, bed mobility, potential barriers to fish passage, and summer baseflow persistence, as well as a study to determine summer growth rates of juvenile steelhead. When appropriate, we used the GIS map layers to develop stratified random sampling designs for selecting field sites. Access limitations, however, frequently prevented us from fully implementing our desired sampling designs. Other focused studies involved more detailed analysis of existing information, such as review of historical and recent aerial photographs of the mainstem Napa River to document changes in channel habitats and review of fish survey data to document current fish community composition and identify likely changes from historical conditions. The results of focused studies led, in some cases, to development of new hypotheses and additional field studies.

Step 4. Conduct Limiting Factors Analysis. This step involved review and synthesis of available data from the focused studies and other sources to evaluate the factors most likely to be limiting populations of the three analysis species under current conditions. This analysis helped provide the context for rejecting, accepting, or refining hypotheses based on the results of the

focused studies, and improved our understanding of key uncertainties that might affect our ability to manage and restore aquatic ecosystems in the watershed.

Step 5. Develop Recommendations. Based on information currently available and information and hypotheses developed during Phase I studies, we identified restoration actions and priorities, and developed recommendations for future studies to establish cause-and-effect relationships between limiting factors and human land use activities (proposed Phase II studies, see Appendix C of the Technical Report).

III. BACKGROUND

A. Analysis Species and Aquatic Biodiversity

The Napa River drains a 426 mi² (1,103 km²) watershed that discharges into San Pablo Bay (Figure ES-1)³. The Napa River basin is estimated to have historically supported a spawning run of 6,000–8,000 steelhead, and as many as 2,000–4,000 coho salmon (*O. kisutch*) (USFWS 1968). By the late 1960s, coho salmon were extirpated from the watershed, and the steelhead run had declined to 1,200–1,900 adults (Anderson 1969). At present, the steelhead run is believed to be less than a few hundred adults (J. Emig and M. Rugg, CDFG, pers. comm., 2000). Much less information is available to determine historical status of Chinook salmon, although examination of Napa River habitat and hydrology and oral history interviews conducted by the Sonoma Ecology Center in the Sonoma Creek watershed (which has similar form and hydrology) suggest the Napa River may have supported a large run of Chinook salmon as recently as the 1940s (Sonoma Ecology Center 2002). California freshwater shrimp, which are known to occur in the Napa River and a few of its tributaries, are federally listed as endangered and currently restricted to only a few watersheds in the North Bay, and coastal watersheds in Marin and Sonoma counties. Although abundance and distribution of several fish and aquatic wildlife species are thought to be substantially diminished, the Napa River basin continues to support a diverse and almost entirely intact community of sixteen native fish species, including steelhead, fall-run Chinook salmon, Pacific and river lamprey (*Lampetra tridentata*, *L. ayresi*), hardhead (*Mylopharodon conocephalus*), hitch (*Lavinia exilicauda*), tule perch (*Hysterothorax traski*), and Sacramento splittail (*Pogonichthys macrolepidotus*) (Leidy 1997). Such native fish diversity is unsurpassed in Central Valley and Sierra streams, and matched only in a small number of Bay Area streams, suggesting that the Napa River should be a priority watershed for native fish and aquatic wildlife conservation (Leidy 2000). A review of survey data from a variety of sources (CDFG, Napa County RCD and USEPA/ SFEI), dating as far back as the 1950s, indicated that salmonids currently appear in surveys less frequently than they did historically. This literature review also indicated that the system appears to be supporting a number of warm-water exotic species, including some important predators of juvenile salmonids such as smallmouth and largemouth bass and striped bass.

B. Land Use History

By the 1840s, the primary land uses in the Napa River watershed were agricultural activities, including timber production, grazing, and field crops. Vineyards were first developed in the 1860s, and up until 1960 the valley floor was used primarily for a combination of orchards, field

³ Our study focused primarily on that portion of the watershed that lies upstream from the City of Napa since the estuary and lower reaches of the Napa River have already been well studied as part of ongoing flood control and river restoration efforts.

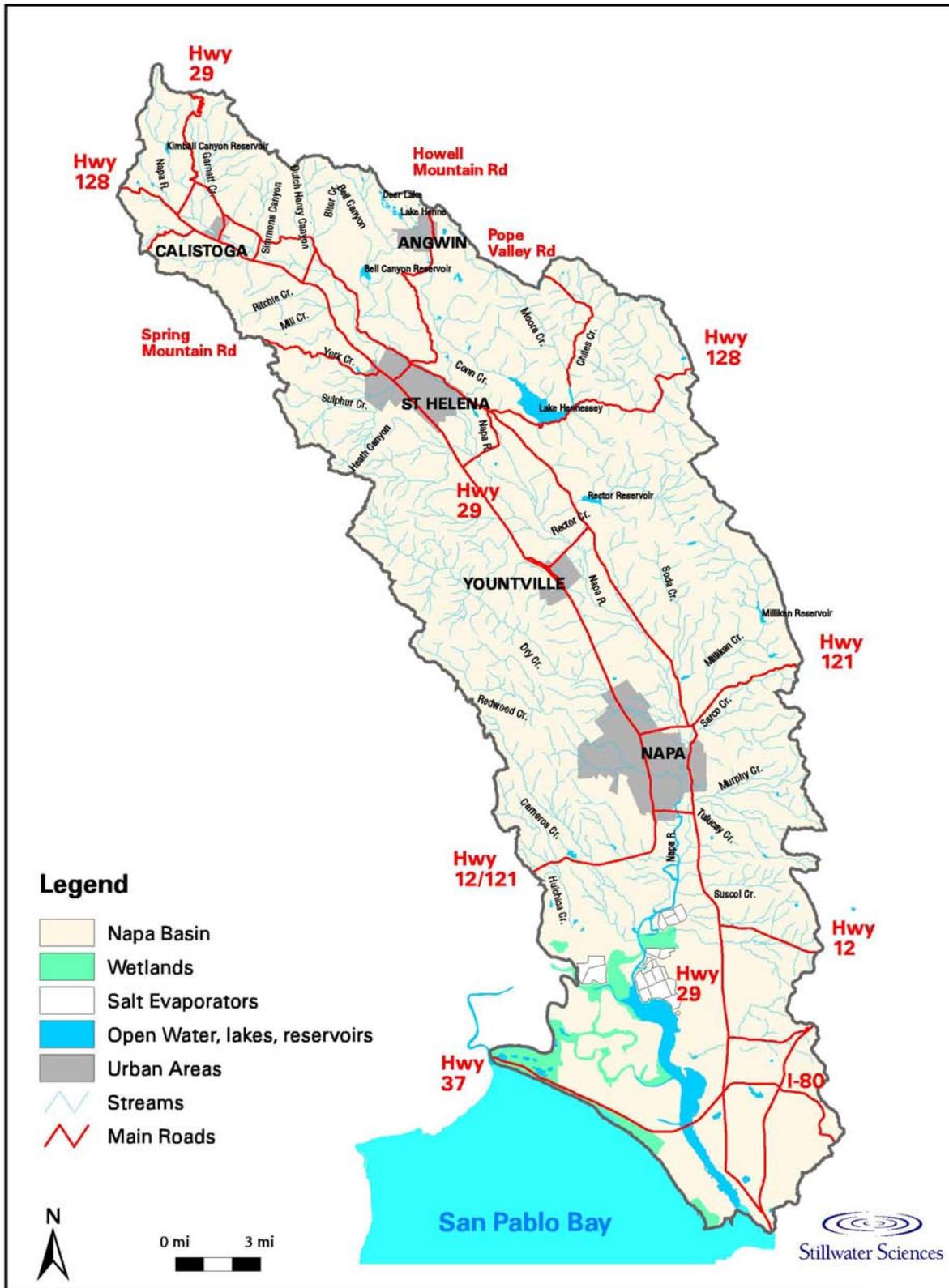


Figure ES-1. The Napa River watershed. The study area of the limiting factors analysis focused primarily on the Napa River and its tributaries upstream of the City of Napa.

crops, and vineyards, with localized urban development in the cities of Napa, Yountville, St. Helena, and Calistoga. The area under grape production in the Napa River watershed rapidly increased from approximately 15 mi² (39 km²) in 1970 to 49 mi² (130 km²) in 1996 (about 25 percent of which occur on hillsides, and the remainder on the valley floor and alluvial fans) (Napa County RCD 1997). Timber was intensively harvested in certain parts of the watershed until the 1950s. Groundwater pumping rates peaked between 1910 and 1950 and gradually decreased until frost pumping once again increased groundwater extraction. However there was relatively little frost pumping between 1973 and 2000 (D. Graves, pers. comm., 2002). Approximately 34 mi² (88 km²) of the watershed are currently developed for urban uses, including areas that are managed for water supply, resorts (spas and golf courses), rural residential housing, and rangeland. Regulation of approximately 17 percent of the watershed area occurred when three major dams (Conn, Bell, and Rector dams) were built within a short time period (1946 to 1959). Direct in-channel alterations include river-bottom dredging on the mainstem Napa River from its mouth to about 15 river miles upstream to improve navigation, intensive removal of large woody debris (LWD) and channel clearing, and levee building in the 1960s and 1990s for flood control (WET, Inc. 1990). These land cover changes, in-channel activities, and water use practices have altered the physical processes that shape the quality, abundance, and connectivity of habitat for salmonids and other native fish and wildlife species.

IV. RESULTS

Based on initial reconnaissance surveys of the Napa River and its tributaries conducted for this study, along with more in-depth surveys in selected reaches and review of published literature and other existing information, we developed a number of hypotheses and general conceptual models of historical (or reference) conditions and current conditions in the mainstem and tributaries. These general conceptual models are summarized below.

We then used these conceptual models, available information, and knowledge of the life history and habitat requirements of the three analysis species to generate hypotheses about key factors limiting populations of these species in the Napa River watershed. Focused studies were then conducted to explore these key factors, including testing hypotheses related to the importance of:

- Sediment related factors (turbidity, pool filling, gravel permeability, and bed mobility);
- Water temperature;
- Fish passage barriers;
- Patterns of dry season surface flow;
- Distribution and abundance of potential freshwater shrimp habitat; and
- Juvenile steelhead growth rates.

General changes in the physical habitat in the mainstem and tributaries of the Napa River are presented below in Section IV.A. The results of these other focused studies are summarized in Sections IV.B through IV.G.

A. Changes in Physical Habitat

Changes in the Mainstem Napa River Physical Habitat

Aerial photographs taken in the 1940s show the mainstem Napa River valley fully developed into agriculture. At this time, the mainstem Napa River, above the city of Napa was a low gradient, gravel-bedded stream exhibiting bar-pool morphology, with point bars, mid-channel or island

bars and multiple channels in the unconfined reaches. These reaches were bordered by floodplains that appeared to be inundated annually with well-established vegetation. There were well-developed wetlands located in the transitional areas between alluvial fans and the valley floor, and on the floodplains. In confined reaches, the Napa River was a single-thread channel with the extent of the active floodplain generally constrained by coarse-textured, erosion resistant tributary alluvial fans.

In contrast to the 1940s, the 1998 aerial photographs show a greatly simplified river-floodplain system. Review of channel cross-section records, published reports, and recent field observations indicate that the river has incised about 4–6 ft or more on average from the mouth of the river to a point upstream of Calistoga in the last several decades, and field survey observations of features such as actively eroding bed indicate that the channel is currently in the process of active incision upstream of Calistoga. Figure ES-2 illustrates some of the changes that occurred between 1940 and 1998 in one reach (additional examples are provided in the Technical Report). The abandonment of the floodplain and the present-day channel entrenchment are most likely due to anthropogenic causes, such as draining and diking of the valley floor, groundwater pumping (both causing watershed-wide and local lowering of the groundwater level), mainstem channel straightening, mainstem bank stabilization, levee construction, dredging (downstream of the City of Napa), gravel bar skimming, loss of bedload supply due to dam construction, and large woody debris (LWD) removal on the mainstem.

These types of alterations to the mainstem appear to have generally occurred throughout the valley floor, from Calistoga downstream to the City of Napa. Our aerial photograph interpretations are supported by observations from the reconnaissance surveys (survey sites shown in Figure ES-2), data from previously published studies, and our surveys of current habitat conditions conducted on eight mainstem reaches (approximately 10 miles [16 km]) (Figure ES-3). These alterations to the mainstem have affected the quality and abundance of suitable aquatic and riparian habitat for native species. The natural bar-pool morphology, with its alternating sequence of pools and riffles, has been converted into a series of long, run-pools (i.e., long pools that are shallow relative to their length) separated by very small bars in many reaches. These long run-pools create lentic (lake-like) habitat for non-native predatory fish, increasing the exposure of native salmonids to predation during rearing and outmigration.

Fine sediment deposition has caused some pool filling in the long run-pool habitats and further reduced the quality of remaining salmonid spawning habitat (due to covering and infiltration of fines). Increases in channel bed mobilization may have resulted in increased frequency or intensity of scour of salmon redds (see Bed Mobility results below). Floodplain abandonment has resulted in the loss of side channel, backwater, and slough habitats. Throughout most of its length, the mainstem Napa River now has only a narrow band of riparian vegetation.

Changes in Physical Habitat in Tributaries

Tributaries of the Napa River are generally steep, coarse gravel- or cobble-bedded streams with small or non-existent floodplains, few deep pools suitable for steelhead rearing, and limited spawning gravel. We hypothesize that historically, prior to European-American settlement, the wooded tributaries would have had relatively frequent log jams that created deep pools, and locally reduced the flow velocity, inducing deposition of spawning size gravel in patches. Based on the field evidence and other records, there were likely abundant redwood and mixed evergreen forests within the Napa River watershed, providing long-lasting woody debris to stream channels. Clearing of woody debris has altered the morphology and local hydraulics of many tributary streams. Removal of woody debris, construction of extensive streamside road networks,

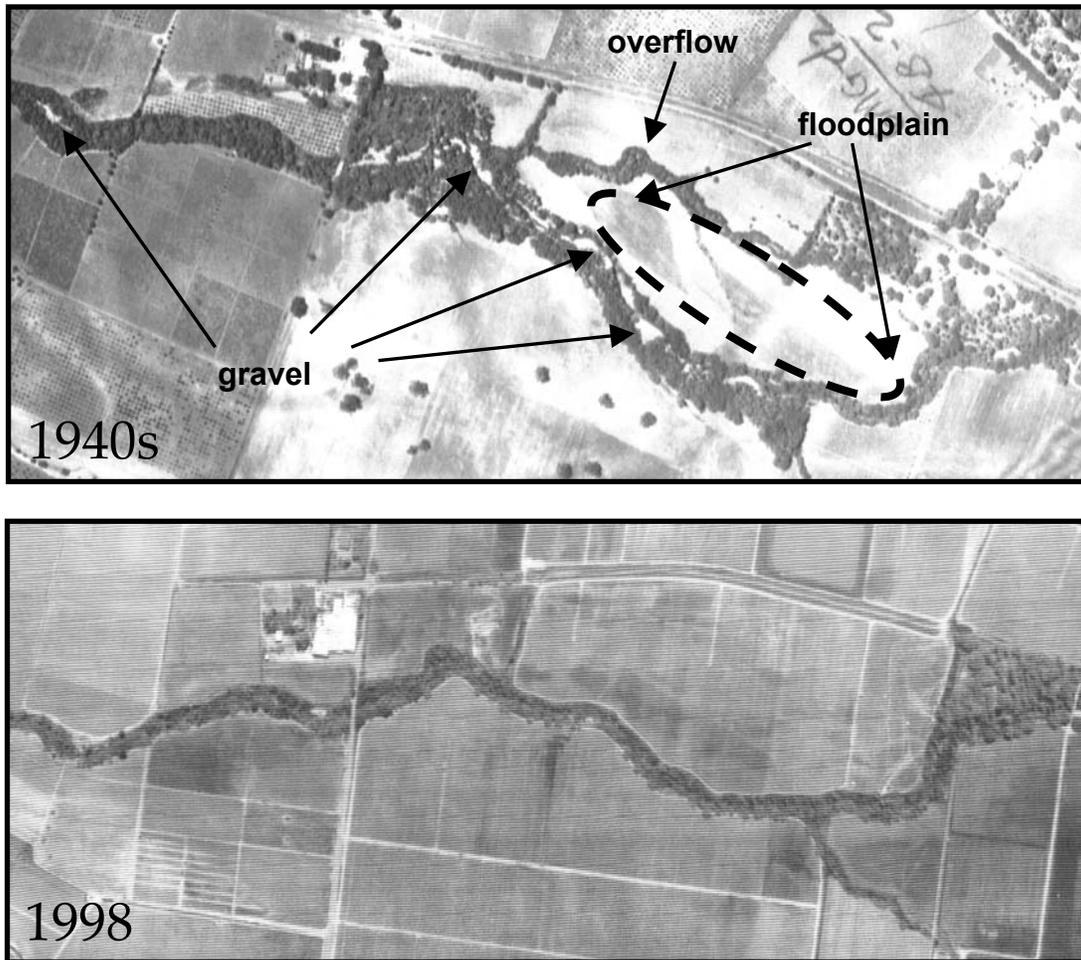


Figure ES-2. Comparison of early 1940s and 1998 aerial photographs of the mainstem Napa River, north of Ritchie Creek. In the 1940s, the channel was characteristic of a wandering stream. For the most part it had a single-thread channel with low sinuosity, but it also had reaches with mid-channel bars and islands. The channel in the reach shown above was still connected to a relatively large active floodplain with a well-defined overflow channel, which provided backwater rearing habitat for chinook salmon and steelhead.

The 1998 aerial photograph depicts a simplified channel where the channel has narrowed and has apparently abandoned its floodplain (note the lack of evidence of the previous overflow channel). These changes are most likely due to a combination of channel incision, levee construction, dam construction upstream and resulting loss of coarse sediment input, and LWD removal.

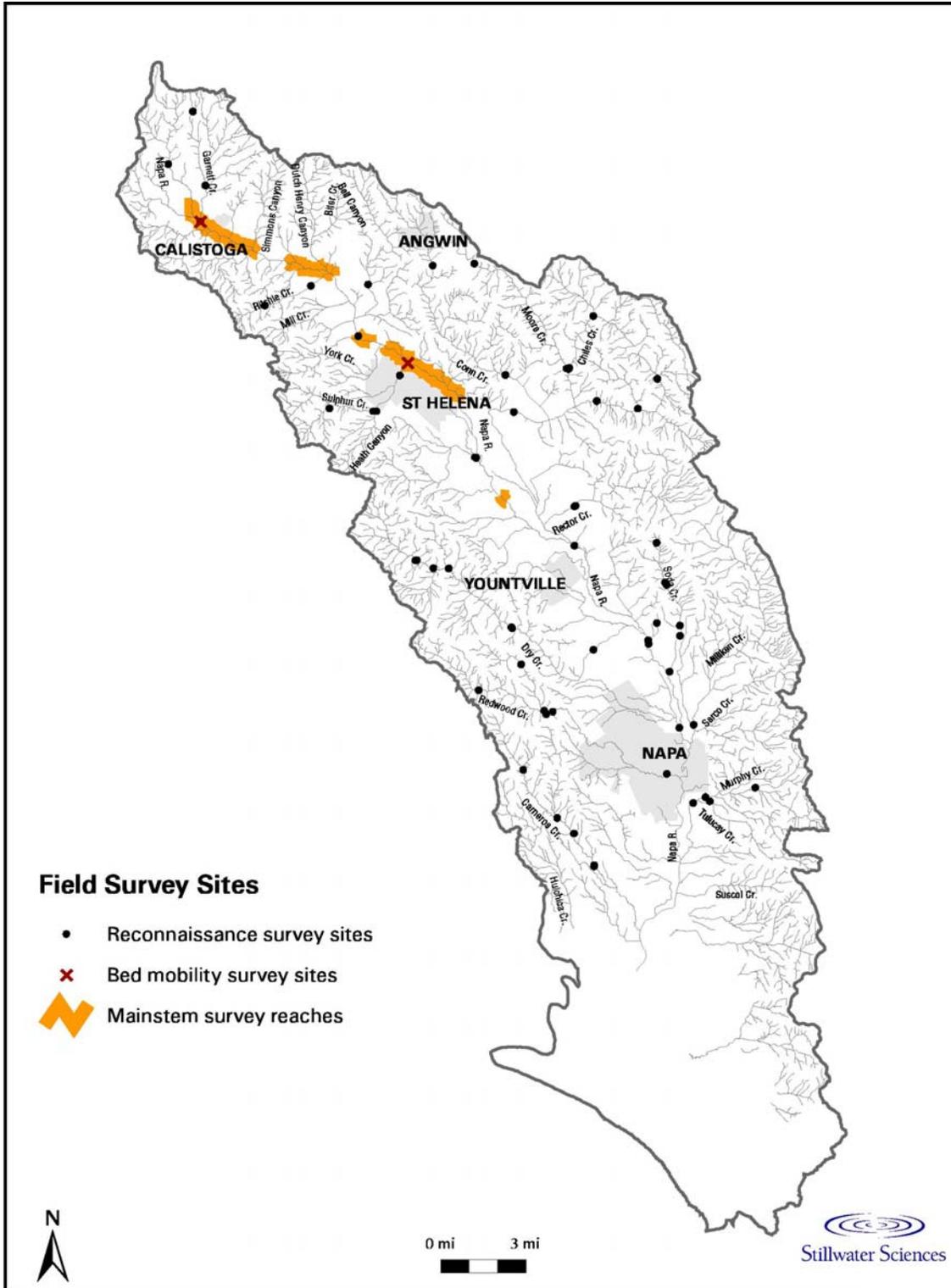


Figure ES-3. Reconnaissance, mainstem surveys, and bed mobility survey sites in the Napa River watershed. Reconnaissance survey sites were visited during August 2000 to help characterize current conditions and develop hypotheses for Phase I of this study. Mainstem surveys, conducted in October 2000, and the bed mobility surveys, conducted in 2001, involved more intensive data collection efforts to test or refine particular hypotheses.

construction of dams, and other land use practices appear to have resulted in a simplified channel morphology (including reduction in the size and frequency of spawning gravel patches), locally higher flow velocities, some channel incision, a loss of deep pools, and perhaps some local coarsening of the channel bed. The reduction in LWD loading has likely increased the mobility of spawning gravels and reduced the diversity of in-channel habitats in Napa River tributaries. Additionally, loss of LWD has likely reduced cover for juvenile steelhead rearing in tributaries. A channel lacking sufficient deep-water refugia would likely increase exposure of fish to higher temperatures and greater predation pressure by terrestrial predators such as birds, snakes, and mammals.

Many tributaries, particularly those on the west side of the watershed, cross extensive alluvial fans that extend into the mainstem valley. These alluvial fan surfaces have been highly altered by historical and current land use practices (including grazing, vineyards, urbanization, and groundwater pumping), which may have led to channel incision and widening (causing increased sediment production and supply to the mainstem), LWD clearing (exacerbating channel bank instability), and general channel simplification (including abandonment of floodplains on large fans). Larger tributaries, such as Dry, Conn, and Soda creeks, show signs of recent incision and have graded to the incised current level of the mainstem Napa River. In some cases, smaller tributaries cutting across the valley floor have not fully adjusted to the lowered level of the mainstem and are elevated at their confluence with the mainstem, forming potential barriers to upstream fish migration.

Several large dams were built between 1924 and 1959 on major eastside tributaries (Conn, Rector, Milliken, and Bell dams) and the northern headwaters of the Napa River (Kimball Dam). In addition, many smaller dams can be found throughout the watershed. Many of these dams intercept coarse sediment supply and thereby reduce delivery to downstream reaches, which can cause bed coarsening and channel incision (although incision may be limited by bedrock and bed coarsening).

B. Sediment-related Factors

Turbidity

The impact of turbidity on salmonids and other aquatic species is a major concern in watersheds where land use activities have increased fine and/or total sediment supply to channels. Effects of increased turbidity on fish and other aquatic organisms, including reduced feeding efficiency and disrupted territorial behavior, can occur at relatively low turbidity levels. These changes have the potential to impact the population dynamics of affected species primarily by reducing growth rates.

The Napa Valley is heavily developed for agricultural and residential land uses. Hillslope erosion has been identified as a clear concern of many stakeholders in the watershed. Based on initial information review and field reconnaissance surveys conducted in summer 2000, we hypothesized that feeding opportunities for juvenile steelhead during the rainy season (particularly in the late fall and early spring when temperatures are not too cold to inhibit feeding and growth) have been reduced by elevated turbidity levels. Reduced growth may affect subsequent survival (see juvenile summer growth study description below for discussion of possible mechanisms). If prolonged high turbidity occurred only after infrequent flood events (e.g., flood events with a recurrence interval of 5 years or greater), then high turbidity would probably not have a significant impact on steelhead production in the Napa River watershed. We hypothesized that to be deleterious, prolonged high turbidity would have to occur after relatively

common storms. To assess whether turbidity levels at commonly occurring flows could be sufficiently elevated (i.e., at levels above a threshold of 20 NTUs [nephelometric turbidity units, a common measure of turbidity], a conservative estimate of the turbidity threshold at which prey capture efficiency by steelhead would become impacted), we measured turbidity under winter baseflow conditions immediately following four storms in 2001 and one larger storm in 2002, to see if these storms could increase turbidity enough to cause a chronic reduction in steelhead feeding efficiency. During water year 2001, we conducted turbidity monitoring at a total of 24 sites (Figure ES-4); 19 sites were sampled to fully characterize the recessional limb of 4 different storms, and the remaining 5 sites were sampled for fewer storms. Turbidity was re-measured at 22 of the 24 original sites in a limited sampling effort to capture conditions after a larger storm event during water year 2002, which was much wetter than 2001.

Our results indicate that feeding opportunities were probably not lost for more than one or two days following even the largest storms (based on the 20 NTU estimate). Therefore, turbidity probably did not pose a significant limitation to feeding by steelhead during the period studied (Figure ES-5). No sediment source analysis was done, hence we do not know if potential significant sources of fine sediment and clays (dirt roads, freshly ploughed agricultural fields, etc.) were exposed during the period of measurement. Within the narrow time frame of this study, no turbidity effects were found, despite our examination of 17 tributaries and 7 sites on the mainstem Napa River. This suggests that there is not a permanently elevated chronic source of sediment causing deleterious turbidity levels. However, our results reflect conditions during only two water years and may not have captured the effects of episodic or rare phenomena such as periods with higher rates of land conversion or road construction or infrequently occurring natural events, such as landslides or extremely large storms.

Pool Filling

If the fine bed-material load (sand and fine gravels) is high relative to transport capacity of a channel, large deposits of fine bed material (predominantly sand and very fine gravels) may accumulate in pools. Reduction in pool volume caused by fine sediment deposition is biologically important because it has the potential to reduce the amount of juvenile rearing habitat for salmonids and other native fish and aquatic wildlife. Reductions in pool depth, in addition to reducing the total quantity of juvenile rearing habitat, may also adversely affect thermal and velocity refugia that are often associated with deep pools, as well as reduce areas used for cover to avoid predators.

Reconnaissance surveys of tributaries throughout the Napa River watershed did not find substantial evidence of pool filling by fine sediment. Extensive anecdotal evidence of fine sediment loading exists, however, and we tested the hypothesis that pool filling by elevated fine sediment loading caused by recent changes in land use activities is not a pervasive problem in the Napa River watershed. The V^* index is a standard measure of pool filling with fine sediment that provides a means of assessing morphologic response to fine sediment delivery. We used a modified V^* approach to develop a rapid assessment index of pool filling.

We surveyed pool filling during 2001–2002 at 29 reaches in 18 tributaries to the Napa River (Figure ES-4). Our results indicated a median watershed-wide level of pool filling of only 2 percent and confirmed the initial reconnaissance observations that pool filling was not high in the Napa River watershed: 25 of the 29 reaches had index values of <10 percent (21 were less than 5 percent), probably well within the expected range of natural variability. One reach on Dry Creek had a value between 10 and 20 percent, and only three reaches (two on Carneros Creek and one on Sulphur Creek) had values >20 percent. Further study is needed to establish if the few high

Figure ES-4. Field survey sites where temperature, permeability, pool filling, and turbidity were measured in the Napa River watershed. Temperature sites were generally monitored continuously from August 2000 through November 2001. Turbidity monitoring was conducted immediately following selected storm events in 2001 and 2002. Gravel permeability and pool filling surveys were conducted in 2001 and 2002.

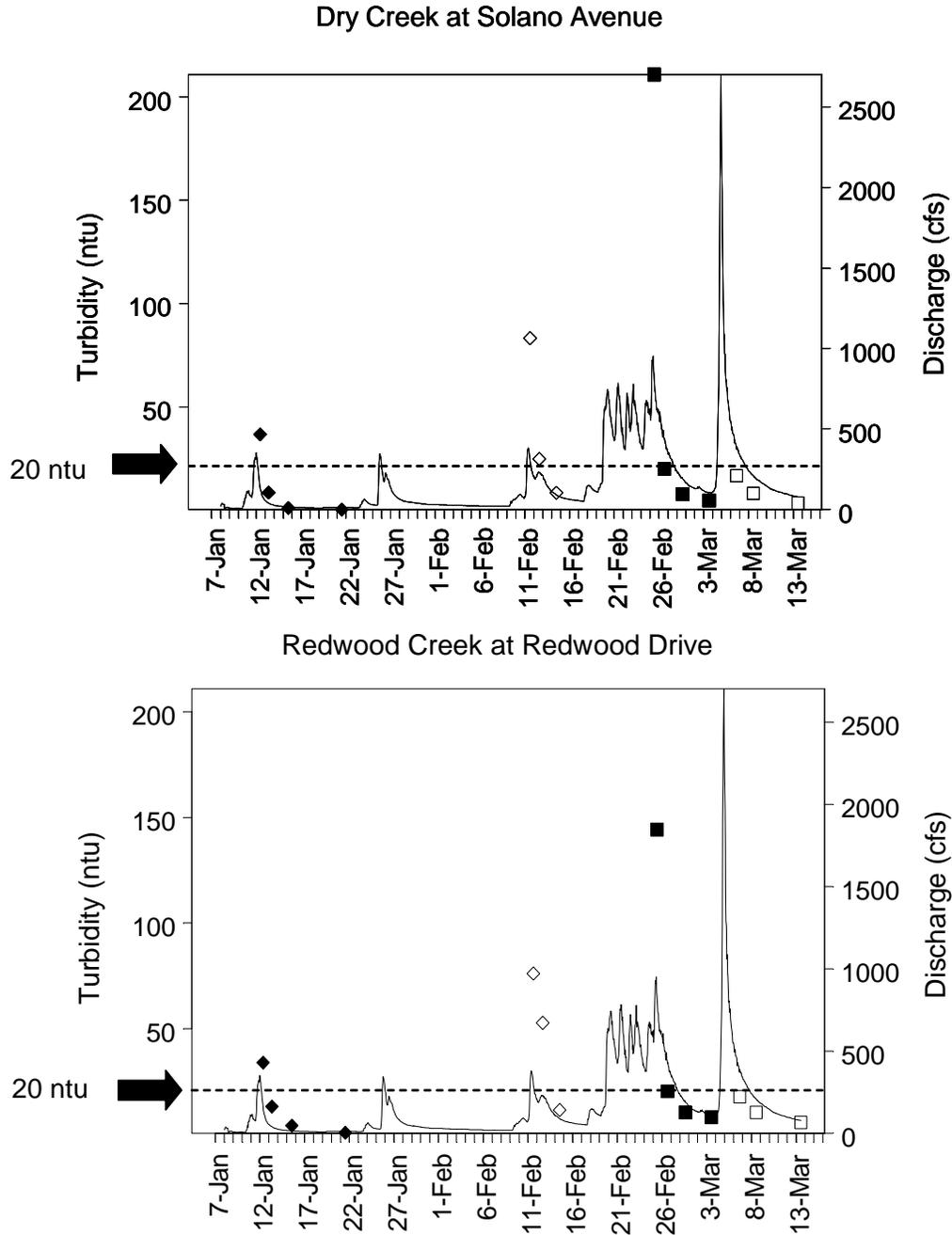


Figure ES-5. Turbidity monitoring results for two locations in the Napa River watershed. Turbidity was sampled in a total of eighteen tributaries during the days immediately following significant storm events. The results of this effort, illustrated for two representative tributaries above, indicate that, while turbidities increased markedly during peak storm runoff, they quickly fell to low levels within one to two days (the open and closed symbols represent sampling sessions following particular storms). The conservative threshold for an adverse turbidity impact to successful feeding of 20 NTU (shown by large arrows) indicated that no feeding opportunities would have been lost during baseflow conditions and that elevated chronic turbidity is not likely to be a key limiting factor to steelhead growth during the rainy season. Note that discharge (the solid line) shown in the figure is from the St. Helena gauge on the mainstem and is shown as a proxy for peak flow timing on the tributaries, which were not gauged.

pool-filling values indicate a significant pattern of local habitat degradation and determine whether they may be due either to natural or anthropogenic sediment sources located upstream of the survey sites.

Gravel Permeability

The key factor determining survival of salmonids during egg incubation through fry emergence is the presence of sufficient flow of cool, clean water through the spawning gravels to ensure delivery of dissolved oxygen and elimination of metabolic wastes. When a high percentage of fine sediment is deposited in or on the streambed, gravel permeability (or flow rate of water through the gravels) can be reduced by a substantial amount. Reduction of gravel permeability results in progressively less oxygen and greater concentrations of metabolic wastes around incubating eggs and alevins (newly hatched fish larvae or sac-fry) as they develop within the streambed in the pore spaces between gravels, resulting in higher mortality. Permeability is a useful descriptor of spawning gravel quality that (1) is known to directly affect salmonid survival during egg incubation through fry emergence, and (2) is affected directly by fine sediment deposition. Measured permeability rates can be converted into an index of predicted mortality rates for salmonid egg incubation through emergence using relationships established from field observations and experiments (Taggart 1976, McCuddin 1977).

Initial observations made during field reconnaissance during summer 2000 suggested that the amount of fine sediments present at potential spawning sites was typically low. Considering the potential importance of spawning gravel quality as a limiting factor, and conditions observed at reconnaissance sites, we tested the hypothesis that gravel permeability was not impaired by fine sediment in Napa River tributaries. We measured permeability at 28 reaches in 17 tributaries during field surveys conducted in 2001-2002 (Figure ES-4). Measured permeability values at 28 potential spawning sites for steelhead in Napa River tributaries were lower than those typically found in steelhead streams considered “good” quality (Taggart 1976, McCuddin 1977): the median predicted mortality index value was 55 percent, with 3 of 28 sites having mortality index values greater than 75 percent and no sites having mortality index values lower than 25 percent. Permeability measured at three potential Chinook/steelhead spawning sites on the mainstem was comparable to the results for the tributaries, with mortality index values of 33, 54, and 57 percent. We concluded that our original hypothesis, that streambed permeability at potential spawning sites was typically sufficient to support high egg survival, is incorrect, and that fine sediment loading may be a widespread problem in the Napa River basin. Further study is needed to establish the causes of the high fine sediment loading to stream channels. However, existing data on fish distribution and abundance (including snorkel surveys conducted throughout most of the watershed in 2001 by Friends of the Napa River and data we collected during summer 2001 in Dry and Ritchie creeks) indicate that a number of Napa River tributaries appear to be relatively well-seeded with juvenile steelhead. Empirical and theoretical evidence suggests that spawning gravel quality and quantity are rarely the primary factors limiting population levels of species such as steelhead and resident trout because a relatively limited amount of successful spawning is capable of seeding large amounts of rearing habitat (Elliot 1984). However, production of fry is still a general concern because extremely low quantity or quality of spawning gravels may be important contributing factors to salmonid population dynamics. The relative importance of reduced permeability as compared to factors, such as the availability of rearing habitat for juveniles, is discussed in the context of a limiting factors analysis below (Section V).

Bed Mobility

Movement of spawning gravels at high flows can cause redd scour, resulting in displacement and

mortality of eggs. Land management practices have the potential to influence the frequency of mobilization of the channel bed. For example, construction of roads along major tributaries can significantly increase peak flows in small channels and increase the frequency of bed mobilizing flows. Furthermore, the construction of levees or artificially reinforced banks tend to confine and increase the depth of high flows, increasing shear forces acting on particles in the channel bed. Downstream of dams, bed mobility may be greatly reduced. This in turn may lead to changes in aquatic invertebrate species composition and abundance and an overall reduction of food available to fish. It may also lead to an accumulation of fine sediment in the streambed. During reconnaissance and extensive surveys conducted in summer and fall of 2000, we saw extensive bars and riffles of finer, and presumably readily mobilized, sediment in the mainstem Napa River. As a result, we hypothesized that gravels in the mainstem that are potentially suitable for spawning tend to be mobile under relatively frequent flows (i.e., flows with a recurrence interval of less than 1 year), leading to a high likelihood that salmonid redds created in any given year would experience mechanical scour, likely resulting in high mortality of eggs and larvae. As opposed to the mainstem, observations in the tributaries showed that the channel bed was typically much more coarse (gravel to cobble sized particles predominate), and therefore we did not predict increased bed mobility in the tributaries.

Quantitative analysis of bed mobility and linkage to spawning failure on the mainstem Napa would be part of the Phase II study. Given the relatively fine size of gravel and its apparent mobility (looks deposits, poor sorting, and extensive exposure of bedrock due to removal), we anticipate that bed mobility may be an important factors on the Napa River mainstem.

C. Temperature

While it is important to consider water temperature as a potential limiting factor for any salmonid population, it is a particularly relevant parameter for understanding constraints on steelhead because steelhead rear as juveniles in freshwater for one or more years. Steelhead may experience several summer seasons while rearing, during which they may be subject to warm water temperatures and the resulting thermal stresses. In addition, water temperatures during the rest of the year determine, in part, whether juvenile steelhead can experience significant growth outside of the summer. Growth during the fall or spring, for example, may be of particular importance to steelhead populations in the southern portion of their range (including the Napa River watershed). Changes in environmental temperatures have profound direct impacts on fish because, as cold-blooded organisms, fish are unable to internally regulate their body temperature. In addition, because steelhead are quite sensitive to increases in temperature, any additional factors that might increase physiological stress on steelhead such as disease, food limitations, elevated turbidity, or increased competition between species, have the potential to worsen the impact of elevated temperatures.

The amount of direct solar radiation reaching the water surface is a primary factor affecting water temperature. Management activities that include removal of riparian vegetation that shades the stream surface can lead to increased solar radiation hitting the water surface, causing warmer water temperatures. In addition, alterations of channel geomorphology that lead to increases in the width-to-depth ratio of the channel result in increased surface area per unit flow volume, and thus a greater total heat load to the stream channel. The Napa River mainstem, however, has been incising and is highly entrenched, which has most likely led to a reduction in the width-to-depth ratio at high flows. Groundwater inputs to the stream system typically have a cooling effect, at least during the summer months, and may be of particular importance in providing local pockets of cold water areas (thermal refugia) within a generally warmer stream network. Land uses and management actions (such as withdrawals or reduced percolation of rainfall) that directly or

indirectly reduce groundwater inputs into the stream channel during summer months can therefore affect the thermal environment experienced by salmonids and other aquatic organisms.

The Mediterranean climate of the Napa River watershed has probably often created conditions in the summer where water temperatures are relatively high compared with other steelhead streams in the Pacific Northwest. It is therefore likely that resident Napa River watershed steelhead populations are reasonably well-adapted to these conditions. However, the naturally low summer flows also result in the system being particularly susceptible to impacts that further exacerbate naturally high water temperatures, including anthropogenic reduction of riparian shading, direct pumping of groundwater, or indirect land use effects causing reductions in the quantity of groundwater inputs to the system.

Considering evidence of low flows, riparian clearing, and channel modification, we hypothesized that water temperatures in the Napa River watershed may be elevated compared with historical conditions and high enough to cause chronic negative physiological effects on salmonids. While we did not test whether temperature was elevated relative to historical reference conditions (which is proposed for Phase II), we did characterize existing temperature patterns in the Napa River watershed using continuous recording thermographs (set to record temperature at 15-minute intervals) that were deployed at 22 sites on 13 tributaries throughout the watershed, as well as at 6 sites on the mainstem Napa River (Figure ES-4). These thermographs were deployed in early August 2000, checked in November 2000 and then left in place through November 2001, when we were able to recover 24 of the 28 thermographs.

We found that summer water temperatures were typically warm, but not generally high enough to be acutely lethal to steelhead (Figure ES-6). Data for the two monitoring sites shown in Figure ES-6 are largely representative of patterns in the watershed as a whole, where the tributaries have general summer daily average temperatures that range from 59–68°F (15–20°C) and winter temperatures that fluctuate between 41–50°F (5–10°C). Daily average temperatures in mainstem reaches generally range from about 43–54°F (6–12°C) to about 63–77°F (17–25°C) during the summer, with a trend toward progressively warmer temperatures downstream. In both the tributaries and the mainstem, the summer pattern occurred in May–September and the winter temperature pattern was evident in November–March.

Temperature patterns in the tributaries indicate that, while temperatures generally did not reach acute lethal levels, potentially stressful temperatures approaching 68°F (20°C) were common during the summer. Temperatures at this level are sufficient to elevate metabolism and potentially affect growth efficiency of juvenile salmonids during the summer months. Data from the Napa River mainstem site presented in Figure ES-6 are representative of other mainstem sites from Calistoga to the estuary. Mainstem temperatures tended to increase progressively downstream and were generally high enough to favor exotic warm-water fauna over salmonids and to preclude the possibility of successful summer rearing by salmonids in the mainstem. Water temperature may interact with other factors, such as food supply, to create conditions that may limit fish populations (see the Juvenile Steelhead Summer Growth Study section below).

D. Potential Fish Passage Barriers

Barriers to fish movement can cause significant adverse impacts to fish populations within a watershed by impinging on the ability of anadromous fish to leave and return to the system and by restricting the movement of rearing juveniles and resident adults within the system. The impact of barriers should ultimately be analyzed with respect to the quantity and quality of

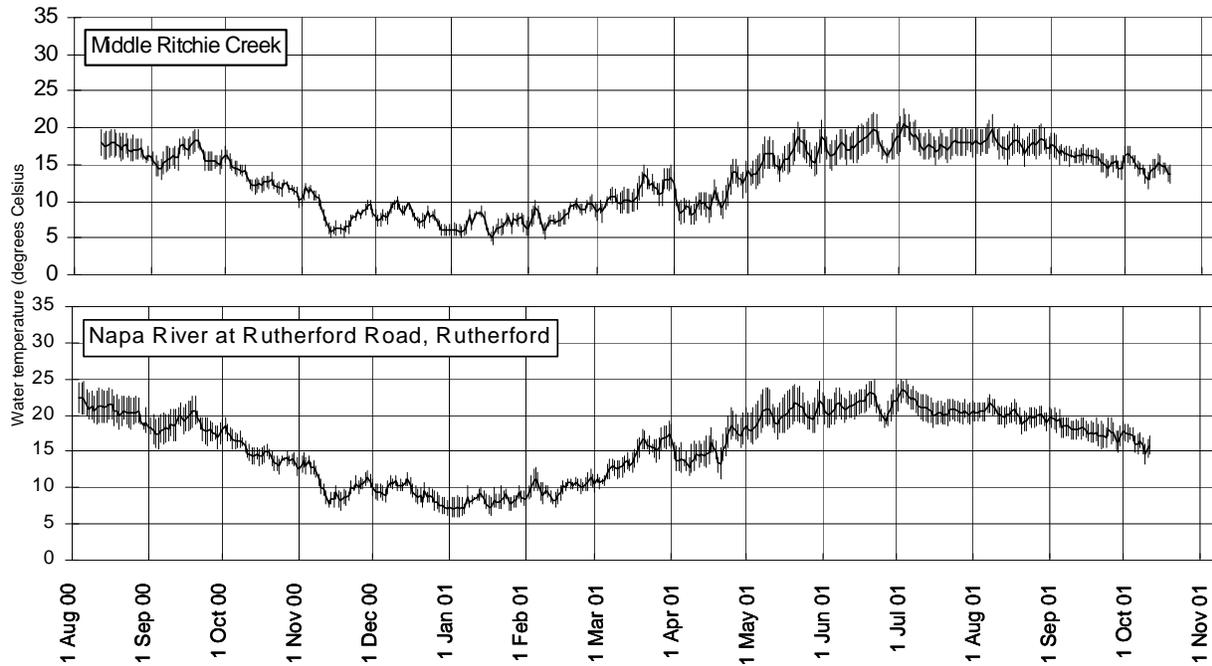


Figure ES-6. Temperature monitoring data for two locations in the Napa River watershed. Thermographs were deployed in well-mixed, shaded pools, generally upstream of public crossings. Example data of the results of this monitoring effort are shown for a canyon reach of Ritchie Creek where steelhead rearing occurred and the mainstem Napa River near Rutherford Road. The dark line indicates daily mean temperatures while the vertical bars indicate the range of temperatures recorded each day.

upstream habitat that is being permanently blocked, along with examination of any partial or temporary barriers to fish movement within the channel network throughout the freshwater phase of the life cycle. By disrupting habitat connectivity, even a small number of barriers can have a disproportionately large impact on a population by obstructing access to large amounts of habitat.

We interviewed a number of local fisheries experts and conducted extensive stream surveys over ten miles of the mainstem Napa River between Yountville and Calistoga (Figure ES-2). We did not discover, and were not made aware of, any significant impediments on the mainstem of the Napa River to upstream spawning migration by Chinook salmon and/or steelhead. Therefore, we focused our analysis of potential barriers on Napa River tributaries.

Historically, about 300 miles (480 km) of the 1,300 miles (2,100 km) of stream channels within the Napa River basin were likely accessible and suitable for spawning and rearing of steelhead in most years (USFWS 1968). Between 1946 and 1959, three large dams on Conn, Bell Canyon, and Rector creeks were constructed, reducing historically available habitat by approximately 17 percent.

In order to identify additional potential barriers to fish passage, we reviewed data collected by CDFG dating from the 1950s to present, reviewed recent surveys by the Napa County RCD in a number of northern tributaries, and analyzed USGS topographic maps (1:24,000 scale). We identified 69 in-channel structures that are suspected to be impediments and/or complete barriers to migration of steelhead on Napa River tributaries (Figure ES-7), although some of the potential impediments/barriers identified in the CDFG surveys may not still exist. USGS maps show numerous lakes or reservoirs (over 220), most not included in the CDFG or Napa County RCD surveys, that overlap with mapped location of tributary channels, suggesting that the actual number of barriers could be much greater than 69. In addition, GIS analysis using USGS data indicates there are over 400 sites where roads cross streams in the watershed, at least a few of which are expected to be impediments or barriers to fish passage. We propose to analyze barriers in relation to suitable habitat during Phase II. If many of the suspected barriers actually impede or block migrations, barriers likely exert an important control on population of steelhead within the watershed.

E. Patterns of Dry Season Surface Flow

As a result of the Mediterranean climate, numerous streams in the Central California region typically become discontinuously wetted or completely dry during the summer or fall. Streams in this region may be extremely vulnerable to adverse effects from even small flow alterations during late spring, summer, and fall low-flow periods. Groundwater pumping, small dams and flow diversions all may reduce baseflow. Larger dams may increase baseflow or reduce this flow depending on how their flows are managed. Channel incision will draw the water table down and agricultural drains will reduce recharge to the groundwater system, while summer irrigation (when using water from distant sources) may increase baseflow. Increased baseflow in urban areas may occur due to watering of gardens and lawns.

Increased incidence of dry channels may adversely impact free movement by juvenile salmonids and smolts during the spring and summer. Aside from loss of habitat connectivity, surface dewatering also results in direct loss of habitat for aquatic species. No factor is as fundamental to the health of a stream system as flow. Flow not only ensures maintenance of aquatic conditions, it also serves to connect habitat types, allowing organisms to track resources between habitats. Without sufficient flows, juvenile steelhead and other coldwater species may experience low growth, weight loss, or mortality. Reduced flows or dry reaches may also impede migration,

Note: This map is intended to provide an indication of the magnitude of potential fish passage problems at the basin scale. Further study is needed to confirm whether specific locations currently have structures impeding or blocking fish passage.

Figure ES-7. Potential barriers and impediments to fish passage in the Napa River watershed. The locations of dams or other barriers were obtained from review of CDFG and RCD habitat surveys and from information provided by the Department of Safety of Dams. Locations of roads crossing streams and in-channel impoundments were obtained from GIS data provided by the USGS.

increase predation and competition for increasingly scarce food and habitat, or affect territorial behavior and aggression among members of the same species.

Many long-time observers of stream conditions in the Napa River watershed believe there has been a substantial reduction in dry season low flow over the past 40 years, possibly due to groundwater pumping, in stream reaches important to steelhead, California freshwater shrimp, and other native aquatic species (USFWS 1968, F. Kerr, pers. comm., 2000, J. Emig and M. Rugg, CDFG, pers. comm., 2001). Reconnaissance surveys during the summer of 2000 indicated that riffles, and frequently all of the associated in-channel aquatic habitat, were commonly dry in parts of most tributaries, particularly in alluvial fan areas. However, the WET report (1990) shows that low flows have increased on the mainstem Napa. They suggest that this is due to the influence or reservoir releases. As part of Phase II it would be essential to establish what controls the low flows on the mainstem Napa.

Because we observed many dry reaches during field surveys conducted in the watershed in summer 2000, we hypothesized that completely dry reaches, or reaches with no flow over riffles, are pervasive. To characterize the pattern of surface flows in the watershed and develop a baseline understanding of the extent of channel drying in the watershed, we conducted an extensive survey of stream channels in late October to early November 2001, just prior to the onset of winter rains. Flow status of each survey reach was qualitatively assigned to one of four "flow states." These were: (1) "Dry" where the channel was completely dry or where the only water present was clearly associated with an artificial in-channel structure, such as a bridge, that caused subsurface flow to come to the surface, (2) "Semi-wet" where pools were wet and riffles were dry, thus fragmenting in-channel habitat types, (3) "Stagnant" where all habitat units were wet, but there was no noticeable flow between units, thus partially fragmenting in-channel habitat, and (4) "Flowing" where habitat units were covered with noticeable flowing water between units.

Of 148 sites surveyed during 2001, only about 30 percent of reaches were fully wetted across all of the habitat units and had noticeable flow (Figure ES-8). Some portion of the alluvial fan reaches of all tributaries was completely or partially dry by the end of the summer, which was likely the case historically. Tributaries such as Sulphur and Napa creeks, which flow through urban areas, tended to have more flow in the alluvial fan reaches. In general, most streams that were dry started flowing again in the vicinity of the mainstem Napa River, probably as a result of shallower groundwater near the mainstem. We concluded that dry reaches likely reduce the connectivity between habitat units as well as the absolute amount of habitat available to juvenile steelhead in the tributaries. Also, dry reaches within the channel probably interfere with salmonid migration patterns from late spring through early fall.

F. Juvenile Steelhead Growth Rates

Growth by juvenile steelhead as they rear in their freshwater environment may be critical to their success in the marine stage of their life history and, therefore, to the overall viability of the population. In large part, this is because available data indicate the probability of return of spawning adults is strongly related to the size at which they migrate to the ocean. Two principle factors controlling fish growth are the availability of food and the temperature in the fish's environment. Invertebrate drift from riffles is probably the most important food source to juvenile steelhead in most systems.

Food sources may become reduced, however, because of reduced surface flows over riffles, changes in channel geomorphology (such as sedimentation) that reduce available habitat for

Figure ES-8. Discharge measurements taken in late October and early November 2001, prior to the onset of winter rains in the Napa River watershed. All in-channel habitat units were completely dewatered at sites labeled "dry." "Semi-wetted" indicates sites where pools were wet but riffles were dry. "Stagnant" indicates sites in which all habitat units (e.g., pool and riffles) were wet, but there was no noticeable flow. All other sites were wet with detectable flow between units (although actual discharge was only measured at a subset of these sites).

benthic macroinvertebrates, and poor water quality resulting from urban runoff or wastewater discharge that may kill or reduce productivity of primary and secondary consumers. During initial reconnaissance surveys of tributaries conducted in summer 2000, we observed numerous instances of dewatered riffles and isolated pools, the latter with dense aggregations of steelhead. These fish showed behavioral signs of food stress, leading to the supposition that food stress may be limiting growth and overall fitness of salmonids. Our observations led us to hypothesize that low surface flows over riffles, whether natural or caused or exacerbated by human land use impacts, result in low levels of steelhead food resources in many tributaries during the summer months. In addition, we hypothesized that limited food resources, coupled with warm temperatures in the summer, would create conditions in which juvenile steelhead would have difficulty meeting their metabolic needs, resulting in little or no growth during the summer months.

To test this hypothesis we conducted a pilot study in summer of 2001 in eight pools located in two Napa River tributaries, including sites believed to have relatively favorable flow conditions. We measured fish growth, assessed habitat quality, and installed monitoring devices for temperature. We documented very limited or negative growth rates for young-of-the-year steelhead at all sites (Figure ES-9), implying that food resources in the reaches monitored were insufficient in summer 2001 to satisfy metabolic demands. Significant weight loss during the summer may stress fish and lead to subsequently higher mortality during the remaining juvenile rearing period. These findings indicate that reduced prey production and salmonid feeding opportunities due to dry riffles in combination with increased metabolic costs caused by warm temperatures could result in small smolts with poor survival during emigration and be responsible, at least in part, for the reported decline of steelhead in the Napa River watershed.

G. Distribution and Abundance of Freshwater Shrimp Habitat

The historical distribution of California freshwater shrimp (CFWS) is unknown, but the species probably once occurred where suitable habitat was present in most perennial lowland streams in the Marin, Napa, and Sonoma county areas (USFWS 1998). Biologists believe that widespread alteration of lowland perennial streams has probably resulted in significant reductions in the species' range and abundance. This has led to concern over the persistence of the species, particularly in view of its extremely limited geographic distribution.

The details of the ecology and life history of CFWS are not well documented. However, it appears that all life stages from larvae to adults graze on microbial and/or organic detritus. In terms of physical habitat, CFWS require undercut bank habitat in quiet, moderately deep (1–3 ft [0.3–0.9 m]) stream reaches with overhanging riparian vegetation, aquatic vegetation, structurally complex banks, exposed roots, and submerged woody debris or live vegetation (Cox 2000). The presence of submerged organic material is probably important as a source of cover and also as a source of microbial and detrital food production on the surfaces of roots and vegetation that extend into the water. The water quality needs of CFWS are not well understood, but the species appears to be intolerant of brackish water and tolerant of low flows and temperatures as high as 27°C (80°F), at least under laboratory conditions (USFWS 1998).

Review of historical documents and our initial reconnaissance surveys indicate signs of dramatic changes in channel morphology in the Napa River mainstem, which may have altered the abundance or quality of undercut bank habitat for CFWS. Recently, riparian groundcover, and sometimes, canopy vegetation, has been actively cut down by some vineyard managers as a means of controlling the blue-green sharpshooter (*Graphocephala atropunctata*), the vector for

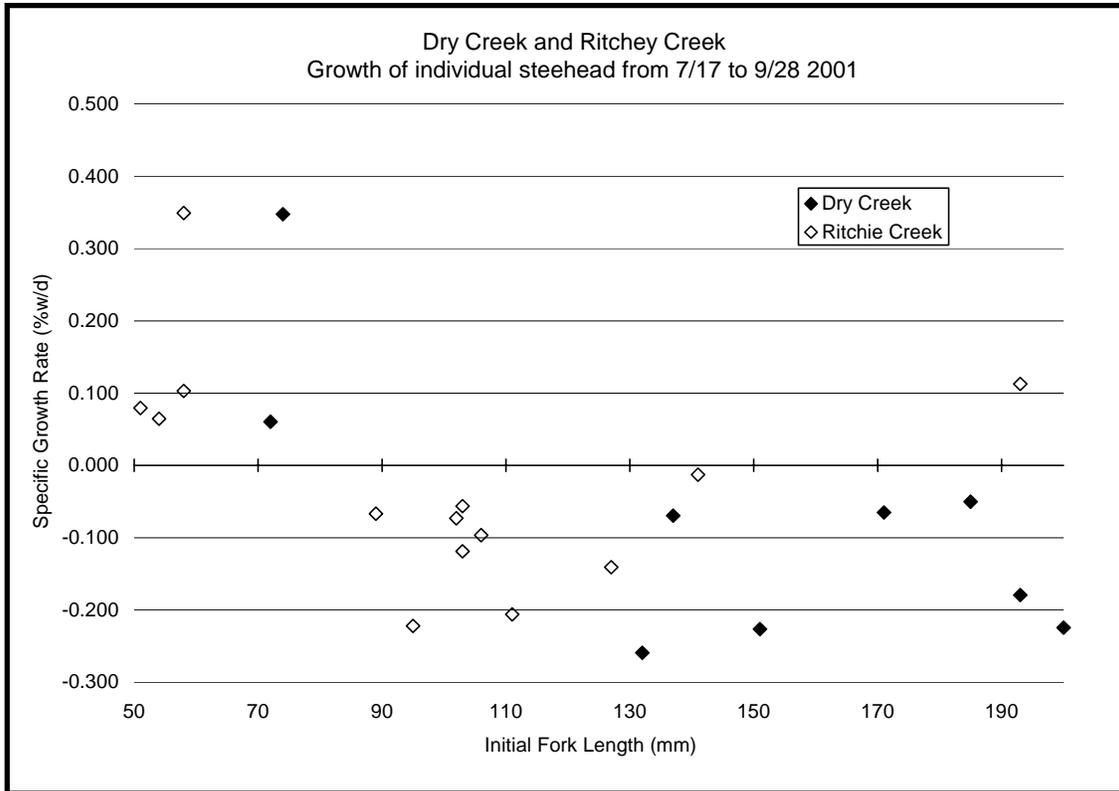


Figure ES-9. Results of juvenile steelhead summer growth pilot study. To explore whether warm temperatures and low food supply to pools from upstream riffles have an impact on summer growth of steelhead, we conducted a pilot study between July and late September 2001 on Ritchie Creek and Dry Creek, on the western side of the Napa River basin. These tributaries were selected to represent different levels of riffle/pool connectivity, with Ritchie Creek having somewhat better connectivity between riffles and pools than Dry Creek. Steelhead juveniles were captured, measured, weighed, and given individual marks, using subcutaneous elasto-polymer injections, early in the summer. At the end of summer, fish were recaptured so that changes in length and weight could be determined.

The results of this pilot study indicate that most steelhead lost a significant amount of weight over the course of the study, with only the smallest fish increasing slightly in weight. This may be because the smaller steelhead could be feeding on smaller prey (invertebrates), prey that would be energetically unprofitable for larger fish (i.e., for larger fish the energetic or metabolic cost of pursuing, capturing, and eating these small prey may be greater than the energy provided by the prey). The data suggest that steelhead may not be gaining sufficient size by the time they migrate out of the basin to the sea, and we have hypothesized that smaller sizes at outmigration may lead to lower levels of returning adult spawners. We recommend that fish growth and potential invertebrate food sources be further explored during Phase II.

Pierce's disease, which attacks grape vines. Poorly conceived vegetation removal adjacent to CFWS habitat could impair the maintenance or recovery of shrimp populations.

In October 2000, we conducted surveys for potential California freshwater shrimp habitat in six reaches of the mainstem channel between St. Helena and Calistoga, covering a total length of 8.4 miles (14 km) (see mainstem survey reaches in Figure ES-3). The purpose of these surveys was to determine the current distribution and abundance of potential CFWS habitat in the mainstem and identify areas with high concentrations of CFWS habitat for further focused studies. We identified a total of 35 sections of undercut bank habitat adjacent with some degree of overhanging vegetation that matched descriptions of suitable habitat for California freshwater shrimp. These sections of undercut bank ranged in length from approximately 6 to 230 ft (2–70 m), with an average length of 37 ft (11 m). These surveys indicated that approximately 3 percent of the channel length (152 ft per mile [28.8 m/km]) in the six reaches surveyed possessed suitable habitat for CFWS. Abundance ranged from a high of 340 ft of appropriate habitat per mile (87 m/km) (distributed among 11 patches in the 0.6-mile (1.0 km) reach between Deer Park Road to Lodi Lane near St. Helena) to a low of 42 feet per mile (8.1 m/km) in 6 patches (distributed along a 1.6-mile [2.6 km] reach extending from Dunawael Lane to Lincoln Avenue, near Calistoga). More information is needed to determine how the current distribution, abundance, and quality of habitat compare with historical conditions. In addition, more information is needed on the ecology and life history of CFWS to determine how the abundance of habitat specifically affects population dynamics.

V. DISCUSSION AND SYNTHESIS OF LIMITING FACTORS

In conducting the limiting factors analysis we attempted to: (1) systematically review the life history requirements of each analysis species, (2) identify the full range of factors that might be operating to limit these populations in the Napa River watershed, (3) screen these potential limiting factors using available information and initial reconnaissance observations on current watershed conditions to develop hypotheses about those factors thought to be of greatest importance in the watershed, and then (4) test and refine hypotheses using the focused studies described above. Because of limitations in our understanding of current conditions and how limiting factors have operated in the watershed, there are various degrees of uncertainty associated with our identification and ranking of key limiting factors for each analysis species. Phase II studies, including a more quantitative population modeling approach to explore the relative importance of potential limiting factors, have been proposed to address what we feel are the most important uncertainties related to restoration and management of aquatic resources in the Napa River watershed (see Section VI, Recommendations).

A. Chinook salmon

The analysis of limiting factors for Chinook salmon production in the mainstem Napa River concludes that human land use activities, many of which were under way in the 1940s (as shown in 1940 aerial photographs), have resulted in clear alterations to the Napa River, leading to a dramatic reduction in the potential of the system to support a viable run of Chinook salmon. Channel surveys and analysis of 1998 aerial photographs indicate alterations to the mainstem that include: (1) channel incision, (2) conversion from a river system with anastomosing zones containing multiple channels with relatively broad floodplains to a confined, single-thread channel, with substantial loss of floodplain area and habitat complexity, (3) conversion from a riffle-pool morphology to a series of long run-pools that provide habitat for exotic predators and, (4) perhaps, fining and increased mobility of the bed.

The Napa River could have supported a large, sustainable population of Chinook salmon under historical conditions. As a result of all the various alterations to the mainstem and its floodplain, the Napa River currently has an extremely limited potential to support a viable population of Chinook salmon. In particular, the dramatic reduction in spawning gravel quantity and quality, coupled with the current high density of exotic predators in the mainstem and loss of off-channel rearing habitat, appear to be the most important limiting factors currently operating in the system. A comparison of historical versus current conditions for the various freshwater life history stages of Chinook salmon is provided in Table ES-1.

Table ES-1. Summary of conceptual models and hypotheses developed during Phase I comparing historical and current conditions in the mainstem Napa River and their potential effects on different life stages of Chinook salmon.

Life History Stage	Historical Condition	Current Condition
Upstream migration	Upstream migration might have been delayed until first substantial rains (typically in November or December) provided sufficient flow for fish to negotiate bars that created barriers at low flows. The population was probably late fall-run.	Probably similar to historical condition, with fewer bars to negotiate but possibly increased groundwater withdrawals resulting in lower flows (and possibly dry reaches) creating temporary barriers.
Spawning and incubation	Spawning habitat was relatively abundant, and probably of good quality (but actual quality unknown).	Spawning area has been greatly diminished, with higher amounts of fine sediments resulting in presumed decrease in suitable gravel patches. Bed mobility has likely increased, leading to a high scour rate of gravels and increased mortality during the egg incubation stage.
Rearing	Abundant, good quality fry rearing habitat (riffle margins, side channels, sloughs) with abundant food supply likely to have been present in the Napa River. The estuary may have provided important rearing habitat for juvenile Chinook. Some juveniles might have migrated to the estuary for rearing soon after emergence (within 1-2 weeks), while others might have reared in the river until warmer temperatures in late spring or summer triggered migration to the estuary.	Very limited rearing habitat is present in the Napa River (slough, side channel, and riffle margin habitats have decreased substantially). High mortality is likely from exotic predators now found in the dominant long, run-pool habitat. Loss and degradation of estuarine habitat may substantially limit the potential for rearing in the estuary. In addition, downstream migration may be limited or prevented by lack of flow (some reaches of the mainstem go dry).
Outmigration	Unlike many Central Valley rivers draining the Sierra Nevada, the natural hydrograph did not include a snowmelt spring runoff peak that would have facilitated outmigration, but outmigrants had only a relatively short distance to travel to reach the bay (and did not require a long journey through the Delta region). Exotic predators were limited in	It is likely that outmigrants experience high mortality because of the persistence of exotic predators in the long, deep pools now present in the mainstem. There is a possible decrease in spring flows caused by water abstraction (which was probably already low under historical conditions) that might reduce outmigrant success.

Life History Stage	Historical Condition	Current Condition
	abundance or absent. It is possible that warm temperatures occurred during outmigration in some years (such effects would be exacerbated in years when late spawning occurred due to late onset of winter baseflows).	
Summary of Chinook production potential	Overall, the Napa River likely supported a sustainable population of Chinook salmon, with low fall flows and spring temperatures as the most important limiting factors.	Chinook salmon production is currently extremely limited. Spawning gravel quantity and quality, redd scour, reduced riverine and estuarine rearing habitat, and introduced predators are likely key limiting factors. Delayed upstream adult migration caused by low fall flows may also be a key factor limiting production in some years. There is evidence that some, but very limited, successful spawning has occurred in recent years.

B. Steelhead

Based on the types of channels available in the Napa Valley, which are similar to channels in other systems used successfully by steelhead, and historical accounts about the Napa system, it is evident that steelhead probably spawned and reared throughout much of the Napa River system historically, including the mainstem and the major tributaries, particularly the tributaries on the east side that have been dammed for water supply. The alterations to the mainstem have likely affected steelhead in a fashion similar to that described above for Chinook salmon, although the impact on the population should have been proportionately smaller since the mainstem provided only a small portion of the potential steelhead spawning and rearing habitat historically present in the watershed.

Our limiting factors analysis for steelhead has therefore focused primarily on the tributaries. Tributaries to the Napa River are generally steep, coarse-bedded channels with limited pools, except those formed by obstructions (wood, bedrock) or bends. Under current conditions, fine sediment intrusion into spawning gravels is causing low permeability which likely results in relatively low survivorship of steelhead eggs and larvae. Our analysis, however, indicates that a decline in steelhead population levels cannot be attributed to this factor alone. In addition, because Phase I focused on current conditions, we have not established whether the observed levels of fine sediment in spawning gravels are due to natural or anthropogenic causes. The sources of fine sediment and the explanation for its high levels in spawning gravels will be explored in Phase II.

Other alterations to tributaries include numerous dams and road crossings, which serve as barriers or potential impediments to fish passage, reduction in LWD levels, and the likely reduction in flow caused by surface water diversion, groundwater pumping, and various land use activities. Summer water temperatures in the tributaries are generally warm enough to potentially stress juvenile steelhead, although they are not high enough to be acutely lethal. We do not know whether human land use activities have contributed to these warm temperatures, but we can hypothesize that riparian vegetation removal or alteration coupled with surface and groundwater

extraction have likely increased summer water temperatures above historical reference conditions. Testing of this hypothesis has been proposed for Phase II.

Alluvial fans may have provided spawning habitat (although they may naturally have tended to be dry or intermittent seasonally), which, coupled with estuary or lower mainstem rearing, could have led to high steelhead production under historical conditions. Current conditions do not appear favorable for steelhead spawning in the alluvial fan reaches of tributaries or in the mainstem, and the potential for estuary rearing may have been greatly reduced by diking, dredging, or introduction of exotic predators (although we did not evaluate this during Phase I). Testing of this hypothesis has been proposed for Phase II.

To help synthesize the information collected on steelhead habitat conditions, we conducted a population dynamics modeling exercise based on data collected in Ritchie Creek. The modeling results indicate that, under current conditions, the combination of limited spawning gravel quantity and low gravel permeability may be limiting steelhead production to some degree. Furthermore, our results indicate that current conditions are near a threshold, such that any substantial decrease in spawning gravel quantity or permeability would likely lead to a decline in steelhead production. A comparison of conceptual models for the impact of historical versus current conditions on the various freshwater life history stages of steelhead is provided in Table ES-2.

Table ES-2. Summary of conceptual models and hypotheses developed during Phase I comparing the inferred historical condition and current conditions in the mainstem Napa River and their potential effects on different life stages of steelhead.

Life History Stage	Historical Condition	Current Condition
Upstream migration	<p><i>Mainstem.</i> There were no significant barriers or impediments to upstream migration of spawners. Steelhead return later in the season than fall-run Chinook, hence they would have been less likely to be affected by low flows during years when the onset of winter rains occurred later than normal.</p> <p><i>Tributaries.</i> There were relatively few natural barriers present. Large woody debris (LWD) formed deep pools, providing holding habitat for spawners.</p>	<p><i>Mainstem.</i> Probably similar to historical condition.</p> <p><i>Tributaries.</i> As a result of dams, road crossings, and numerous other barriers, there are numerous barriers or impediments to upstream passage by spawners. Eastside tributaries (particularly tributaries to Conn Creek), which were probably historically important for steelhead production in the system, have been blocked by major dams. Reductions in LWD may have resulted in fewer deep pools and reduced holding habitat for spawners.</p>
Spawning and incubation	<p><i>Mainstem.</i> Similar to Chinook salmon, see Table ES-1.</p> <p><i>Tributaries.</i> The steep tributaries of the Napa River would tend to have relatively limited areas of spawning gravel and poorly developed pools. Large woody debris, however, would provide both and we hypothesize that historical levels of LWD probably would have retained sufficient patches of gravel with good hydraulics to allow spawners to fully seed the system. It is not known how</p>	<p><i>Mainstem.</i> Similar to Chinook salmon, see Table ES-1.</p> <p><i>Tributaries.</i> We hypothesize that under current conditions, reduced LWD has decreased the quality and quantity of spawning habitat. The relatively rare patches of spawning habitat that are presently available have probably been degraded by intrusion of fine sediment into spawning gravels, which has reduced permeability and decreased survivorship of steelhead eggs and larvae. Alluvial fans</p>

Life History Stage	Historical Condition	Current Condition
	important alluvial fans were for spawning habitat (see comment below).	have been subject to large-scale incision and alteration, due to urbanization and other development, which may have reduced their value as spawning habitat.
Rearing	<p><i>Mainstem.</i> Similar to Chinook salmon, see Table ES-1.</p> <p><i>Tributaries.</i> Flows were probably lower and temperatures higher than steelhead streams to the north, but the local steelhead race was probably at least partially adapted to cope with these conditions. Flows were probably higher prior to extensive diversions and groundwater pumping, supporting higher production of macroinvertebrates in riffles (higher levels of food for juvenile steelhead).</p> <p>Tributaries to the Napa River were generally steep channels with a coarse bed that provided good over-wintering habitat.</p> <p>Tributaries would have had limited pools except those caused by obstructions (LWD, boulders) or bends. However, well-developed forests around tributaries, particularly on the west side of the watershed, would have provided large amounts of LWD, leading to increased frequency of deeper pools.</p> <p>The Napa River has a large estuary that would have been available for steelhead rearing. More information is needed to determine the role played by the estuary in steelhead life history.</p>	<p><i>Mainstem.</i> Similar to Chinook salmon, see Table ES-1.</p> <p><i>Tributaries.</i> Warm summer temperatures and low food supply (due in part to decreased habitat availability for invertebrate production) appear to severely limit summer growth. We have not assessed the cause of these conditions or whether they differ significantly from historical conditions. Additional studies are needed to test the hypothesis that clearing or alteration of riparian vegetation has increased summer water temperatures above historical or pre-development conditions, and that summer flows are lower due to surface and groundwater extraction, leading to the observed summer growth limitation.</p> <p>As a result, the period in which fish can feed and grow is probably limited to the fall and spring. This hypothesis will be tested with additional growth studies during Phase II.</p> <p>Channels tend to have fewer pools due to reduction in LWD levels, but the amount of over-wintering habitat provided by interstitial spaces in coarse substrates is probably about the same as occurred historically.</p> <p>Turbidity levels during the rainy season do not appear to be limiting juvenile steelhead feeding and growth.</p> <p>The estuary of the Napa River has been dramatically altered by dredging and diking, as well as introduction of exotic species. These activities may have greatly reduced suitability of the estuary for rearing.</p>
Outmigration	<p><i>Mainstem.</i> Similar to Chinook salmon, see Table ES-1.</p> <p><i>Tributaries.</i> Occasional interruption by reaches drying in spring likely occurred under historical conditions.</p>	<p><i>Mainstem.</i> Similar to Chinook salmon, see Table ES-1.</p> <p><i>Tributaries.</i> Outmigration may be interrupted more frequently by early drying of reaches on the alluvial fans due to groundwater pumping and water extraction</p>

Life History Stage	Historical Condition	Current Condition
		for spring frost protection.
Summary of steelhead production potential	Steelhead production would have generally been high. Production would have been limited occasionally during drought years, but the availability of suitable spawning habitat in both tributaries and the mainstem would have spread risks and reduced the odds of substantial year-class failures.	Steelhead production apparently remains sufficient to maintain a population, although at levels probably substantially reduced compared to historical conditions. Summer growth of steelhead in tributaries is apparently strongly limited by warm temperatures coupled with limited food supply, a limitation that may be exacerbated by water extraction. Reduction in frequency of deep pools, caused by LWD removal, may result in reduced carrying capacity of juveniles in the tributaries. Reduction in the abundance of spawning gravel in tributaries, due to LWD removal has almost certainly occurred. Reduction in gravel permeability as a result of increased fine sediments in gravels may also have occurred. Mainstem spawning and rearing potential has been greatly reduced, while outmigration hazards have increased, similar to that described in Table ES-1 for Chinook salmon.

C. California freshwater shrimp

Based on the extensive surveys of the mainstem Napa River conducted during Phase I, potential habitat appears to be relatively common (although an average of only three percent of the mainstem banks provide potential habitat). However, a more quantitative assessment is needed to (1) link freshwater shrimp abundance with habitat quality and quantity, (2) determine the distribution of habitat in the Napa River watershed as a whole, and (3) understand the geomorphic processes responsible for forming and maintaining freshwater shrimp habitat. In particular, the importance of overhanging vegetation should be further explored, particularly to assess impacts of cutting back riparian vegetation to minimize blue-green sharpshooter habitat (the vector for Pierce's disease, which attacks grapevines).

VI. RECOMMENDATIONS

Concern for the short- and long-term health of the Napa River watershed has motivated many individuals, non-profits, and public agencies to either lead, expand, or participate in programs and initiatives focused on protecting, restoring, and enhancing the watershed's beauty, natural resources, agricultural heritage and economic viability. A sampling of the past and current efforts aimed at accomplishing these goals includes: (1) development of Napa County conservation regulations and recent discussions of their modification; (2) establishment of a watershed information center and conservancy; (3) development of a high-resolution vegetation map, high-resolution aerial photography, and topographic mapping (see below) for Napa County; (4) various types of monitoring, including but not limited to steelhead, benthic macroinvertebrates, stream

flow, groundwater, barriers to fish passage; (5) projects enacted by landowners alone or as part of a tributary stewardship group, in some cases with assistance from public agencies such as the Napa County RCD and USDA Natural Resources Conservation Service; (6) research about the historical ecology of the watershed; (7) the work of the Napa Sustainable Winegrowing Group; (8) the proposed Green Certification Program for grape growers and ranchers; and (9) the work of the Watershed Task Force.

A critical component of restoration efforts is to develop a more refined understanding of the cumulative effects of land and water use on in-channel habitat and prioritizing and predicting the cumulative outcome of restoration efforts in the Napa Valley. Such restoration efforts could be dramatically improved by use of a detailed model of the physical topography of the watershed. To this end the Regional Board, University of California, and Stillwater Sciences recently applied for, and were awarded, a CALFED grant to develop high-resolution topographic maps and watershed analysis modeling products for the entire Napa River watershed. This effort will provide much information that could be used in the proposed Phase II studies (see below and Appendix C in the Technical Report for recommended future studies). This high-resolution mapping project is scheduled to be completed by June 2003 and could be used to:

- delineate the complete channel network within the watershed, define stream reach types, and predict habitat structure and potential distributions of native fish and aquatic wildlife species;
- identify shallow landslide hazard areas and other important upslope sources of sediment delivery to channels (road crossings, hillslope hollows, deep-seated landslides, etc.); and
- measure vegetation height and canopy structure to model stream temperature, estimate potential recruitment of large wood to channels, and evaluate habitat quality, quantity, and diversity for riparian and aquatic species.

These tools should also be tremendously useful to land owners, managers, and the Napa County Planning Department for site-specific to watershed-scale evaluation of the ecological benefits of stream setbacks, and in the identification of hillslope areas that may be susceptible to increases in peak flow and mass wasting that could occur as a result of vineyard, rural residential, resort, or other type of development. The watershed mapping and analyses developed from this project will provide residents and land managers with a common frame of reference, and means for exploring the opportunities and constraints of various land and water management decisions. We expect to make the mapping products available as GIS layers (stream channels, landslide hazard areas, etc.) that could be accessed by the public at the County Assessor's Office.

The recommendations for additional studies and restoration actions presented below (many of which we hope to address in more detail during Phase II of our study, see Appendix C in the Technical Report for additional information on the proposed studies) may be facilitated or enhanced through coordination with existing and/or proposed programs, some of which are listed above. For each of the key issues listed below, we have identified important information needs and restoration actions that seem warranted based on currently available information and hypotheses. We expect that local knowledge and experience, conveyed through input from local stakeholders, will enhance and bring specificity to the recommendations provided herein and thus result in some refinement of these recommendations before any restoration actions are implemented. Although some stakeholders expressed an interest in having us rank these recommendations in terms of priorities, we felt it was premature to develop watershed-wide restoration priorities given the current state of our knowledge and scientific uncertainties. The results of future studies, including those currently underway or planned for many tributaries and the Phase II studies we have proposed, should be used to develop a better understanding of

restoration needs and priorities for each major tributary and for the mainstem and Napa River watershed as a whole.

Physical Habitat and Chinook Salmon in the Mainstem Napa River

The mainstem of the Napa River has undergone significant geomorphic transformation, which has converted a system with potentially high salmonid productivity into a system with little potential for salmonid production in the mainstem.

We have identified the following key information needs and studies:

- No further studies to characterize the current state of the mainstem with respect to salmonid spawning have been identified as high priority studies, although further field testing of the redd scour hypothesis and in-depth historical analysis to document pre-European conditions and the extent and timing of channel alternations may be useful.
- The most significant information gaps relate to the effects of mainstem conditions, including exotic predator populations, on outmigrating steelhead smolts. Monitoring of mainstem fish populations, especially of potential salmonid predators, and mortality of outmigrating smolts would be valuable.
- In addition, assessment of historical and current rearing conditions for juvenile Chinook salmon in the estuary could contribute to an improved understanding of salmonid limiting factors in the Napa River watershed and might lead to development of more effective restoration or enhancement strategies.

Given current information, and pending completion of Phase II studies to address the information needs mentioned above, we believe the following actions are warranted:

- Enhancement of Chinook salmon production in the Napa River appears to be of interest to a number of local stakeholders. However, due to the expected high social and economic costs of potential mainstem restoration activities such as riparian and levee setbacks, and gravel augmentation, no immediate actions can be recommended for chinook salmon restoration without substantial further exploration and discussion regarding what is feasible and desirable to stakeholders. The possibility of creating a chinook restoration reach in the lower mainstem, including preliminary development of several alternative strategies, should be considered if there is sufficient stakeholder interest.
- Other recommended mainstem actions are addressed below under California freshwater shrimp habitat.

Physical Habitat Structure in Tributaries

Deep pools in the tributaries are currently rare. In addition, tributaries tend to retain little spawnable gravel. In pre-settlement channels, large woody debris probably created significant deep pool rearing habitat. Information and actions focused on the effects of enhancing large woody debris levels in tributaries appear warranted.

We have identified the following key information needs and studies:

- Stream surveys should be conducted to quantify the amount and existing physical habitat functions of large wood (these surveys could be conducted by stewardship groups). These surveys could be combined with field surveys of barriers and efforts should be made to reconstruct historical LWD loading.
- Examine how land use, geology, LWD, and dam construction impact sediment supply to tributaries and how this affects the quality and quantity of pools and spawning gravels.
- In addition, assessment of historical and current rearing conditions for juvenile steelhead in the estuary could contribute to an improved understanding of salmonid limiting factors in the Napa River watershed and might lead to development of more effective restoration or enhancement strategies.

Given current information, and pending completion of Phase II studies to address the information needs mentioned above, we believe the following actions are warranted:

- Increase retention of spawning gravels and the abundance of pools and cover in tributaries by adding large woody debris. Measures to add large wood to channels should be actively encouraged, carefully planned, and executed (as appropriate) to promote pool formation and gravel retention in tributaries. The effects of these efforts should be carefully monitored. Careful consideration of potential adverse impacts to downstream structures, such as bridges, that might be caused by movement of large woody debris during high flows is needed prior to implementation of any wood enhancement projects.
- Efforts to enhance woody riparian vegetation are also recommended to help provide potential sources for recruitment of in-channel large woody debris in the future (i.e., through natural processes of tree mortality in the riparian zone).

Gravel Permeability and Fine Sediment

Low gravel permeability in the Napa River mainstem and tributaries potentially reduces salmonid fry emergence by 50 percent or more. While the quantitative limiting factors analysis example for Ritchie Creek indicates that the benefits of increasing egg/larval survivorship may be limited, this analysis also demonstrates a potentially drastic negative response of steelhead populations to any further reduction in egg/larval survival compared with current conditions:

We have identified the following key information needs and studies.

- Additional permeability studies should be conducted to better characterize variability within and among tributaries and to provide long-term permeability monitoring to track changes over time.
- Because the system may be near a critical threshold in terms of egg/larval mortality, it is critical the relationship between land use and fine sediment delivery to the channel be characterized as completely as possible. Therefore, a detailed sediment budget should be performed and field studies undertaken to quantify the relationship between different types of land use and the delivery of fine sediment to the channels.

- To improve our understanding of the impact of permeability on the steelhead population in the Napa River watershed, detailed habitat surveys and life history studies are needed to refine and then apply the limiting factors analysis to the whole watershed.

Given current information, and pending completion of Phase II studies to address the information needs mentioned above, we believe the following actions are warranted:

- Opportunities to prevent increased delivery of sediment to channels, and preferably reduce sediment delivery, should be pursued.

Fish Passage Barriers

Our results indicate that there are a large number of known or potential barriers and impediments to fish passage in the Napa River watershed. The scope of our barrier study was limited so uncertainty remains. However, even if only 25 percent of these sites actually serve as barriers limiting access to suitable habitat, the impact on steelhead production in the watershed could be substantial.

We have identified the following key information needs and studies (much of this work should be done in cooperation with local watershed stewardship groups).

- Fully verify and document potential barriers on streams with potentially important salmonid habitat.
- Fully document the extent of suitable habitat and the locations of natural barriers to provide sufficient background for assessing the impact of barriers to help prioritize allocation of resources for barrier removal efforts.

Given current information, and pending completion of Phase II studies to address the information needs mentioned above, we believe the following actions are warranted.

- Considering the potential efficacy of barrier remediation projects, we strongly encourage that barrier remediation projects be emphasized in any strategy to restore the steelhead run. Artificial barriers that block fish access to usable habitat should be identified and removed or made passable, with emphasis given to those barriers obstructing access to large amounts of suitable habitat.

Effects of Temperature, Food, and Flow on Growth of Juvenile Steelhead

Summer growth rates of juvenile steelhead observed during our pilot study were very low, and in most cases negative, supporting our hypothesis that warm summer temperatures and low food supply (caused by low baseflows and very low or discontinuous flow during the dry season over productive riffle habitats) are important factors limiting steelhead production in the Napa River watershed. Levels of rainy season turbidity measured during our studies did not indicate a significant problem for steelhead, but increases in chronic turbidity beyond the 20 NTU threshold during rainy season baseflows (especially during the fall or spring growth seasons that we hypothesize are particularly critical for steelhead growth) could have adverse impacts on steelhead feeding and growth.

We have identified the following key information needs and studies:

- Further fish growth studies should be conducted in a larger sample of tributaries and extended into the spring and fall to confirm whether or not lack of summer growth is a spatially extensive phenomena, and whether low or negative summer growth can be offset by growth during the spring and fall.
- To improve our understanding of the relationship between flows and fish growth, studies should be performed that involve manipulating flows and measuring fish growth. The relative importance of macroinvertebrate and habitat availability versus temperature should be determined to better define the relationship between flows and fish growth.
- Studies to assess historical and current levels of baseflow and hydrograph change should be conducted to determine how much land and water use activities have affected summer baseflow levels. This analysis should include potential effects of both surface and ground water pumping on baseflow.
- Further turbidity work should be conducted to characterize the turbidity response of the system under a broader range of conditions than was observed in Phase I, and to develop plans for long-term monitoring.
- When they become available, the high-resolution topographic maps and other products to be developed under the CALFED grant should be used to perform GIS and digital terrain computer modeling to identify reaches with high current summer temperatures that might benefit from increased stream shading achieved through enhancement of riparian vegetation.

Given current information, and pending completion of Phase II studies to address the information needs mentioned above, we believe the following actions are warranted:

- Reduce water temperatures where feasible by increasing stream shading through enhancement of riparian tree cover.
- Explore opportunities to reduce unnecessary or inefficient water use and thus increase summer baseflow in tributaries to increase macroinvertebrate production. (For example, efforts to provide diverters with flow information, through dial-up flow gages, should be funded and the benefits of sustained minimum flows should be monitored.)
- Ensure that potential sources of turbidity, such as sites of mass wasting and active gullies, are not increased or exacerbated.

Protection of California Freshwater Shrimp Habitat

California freshwater shrimp habitat appears to be relatively well distributed in the Napa River mainstem, at least in the reaches we surveyed. However, we have little knowledge of the current or historical distribution and abundance of this species throughout suitable habitats in the Napa River watershed.

We have identified the following key information needs and studies:

- Further surveys to document the distribution and abundance of undercut bank habitat should be conducted in all low gradient valley-floor streams, especially those known to support California freshwater shrimp (i.e., the Napa River, Garnett and Huichica creeks).
- While undercut banks with overhanging vegetation are clearly associated with California freshwater shrimp populations, the relationship between other aspects of habitat quality and production of California freshwater shrimp should be better developed to make restoration actions more focused and efficient.
- Conduct studies to determine the important geomorphic processes creating and/ or maintaining California freshwater shrimp habitat.

Given current information, and pending completion of Phase II studies to address the information needs mentioned above, we believe the following actions are warranted:

- With our limited knowledge of this species, it is not possible to make detailed recommendations. However, the association of California freshwater shrimp with undercut bank habitat and overhanging vegetation and roots is well documented and protection of this habitat in the mainstem Napa River and tributaries known to support this species (i.e., Garnett and Huichica creeks) should be strongly encouraged. In addition, projects should be promoted that seek to retain or establish riparian vegetation that extends to the water's edge.
- Opportunities to develop riparian setbacks and conservation easements should be encouraged. Given the potential cost of such actions, however, better information on California freshwater shrimp habitat and population density may be required to help determine where conservation or restoration efforts might yield the greatest ecological benefits per unit cost.

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