Final Report

Redwood Creek Watershed Assessment

Prepared for:
Golden Gate National Recreation Area
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San Francisco, CA 94123-1307

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August 2011

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Cover:
Robin L. Changler’s Salmon Returning to Redwood Creek
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ACRONYMS

AMP	Adaptive Management Plan
BMI	benthic macro-invertebrates
CCC	Criterion Continuous Concentrations
CDFG	California Department of Fish and Game
CMC	Criterion Maximum Concentrations
CNPS	California Native Plant Society
CTMP	Comprehensive Transportation Management Plan
CTR	California Toxics Rule
CWA	Clean Water Act
DFC	desired future condition
DPS	distinct population segment
EIR	Environmental impact report
EIS	environmental impact statement
ENSO	El Niño Southern Oscillation
EPT	percent of environmentally sensitive orders
FMP	Fire Management Plan
GGNRA	Golden Gate National Recreation Area
Gpd	gallons per day
LWD	large woody debris
MBCSD	Muir Beach Community Services District
mg/L	milligrams per liter
MMWD	Marin Municipal Water District
MPN	most probable number
MSL	mean sea level
NPS	National Park Service
PAHs	polycyclic aromatic hydrocarbons
PDO	Pacific Decadal Oscillation
RM	river mile
RWQCBs	Regional Water Quality Control Boards
SFAN	San Francisco Bay Area Network
SFBRWQCB	San Francisco Bay Regional Water Quality Control Board
SOD	Sudden Oak Death
SBWD	Stinson Beach Water District
SWAMP	Surface Water Ambient Monitoring Program
SWRCB	State Water Resources Control Board
TSS	total suspended solids
ug/L	micrograms per liter
USFWS	U.S. Fish and Wildlife Service
USGS	U.S. Geological Survey
WNV	West Nile Virus
WY	Water Year
YOY	young-of-the-year

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EXECUTIVE SUMMARY

Introduction

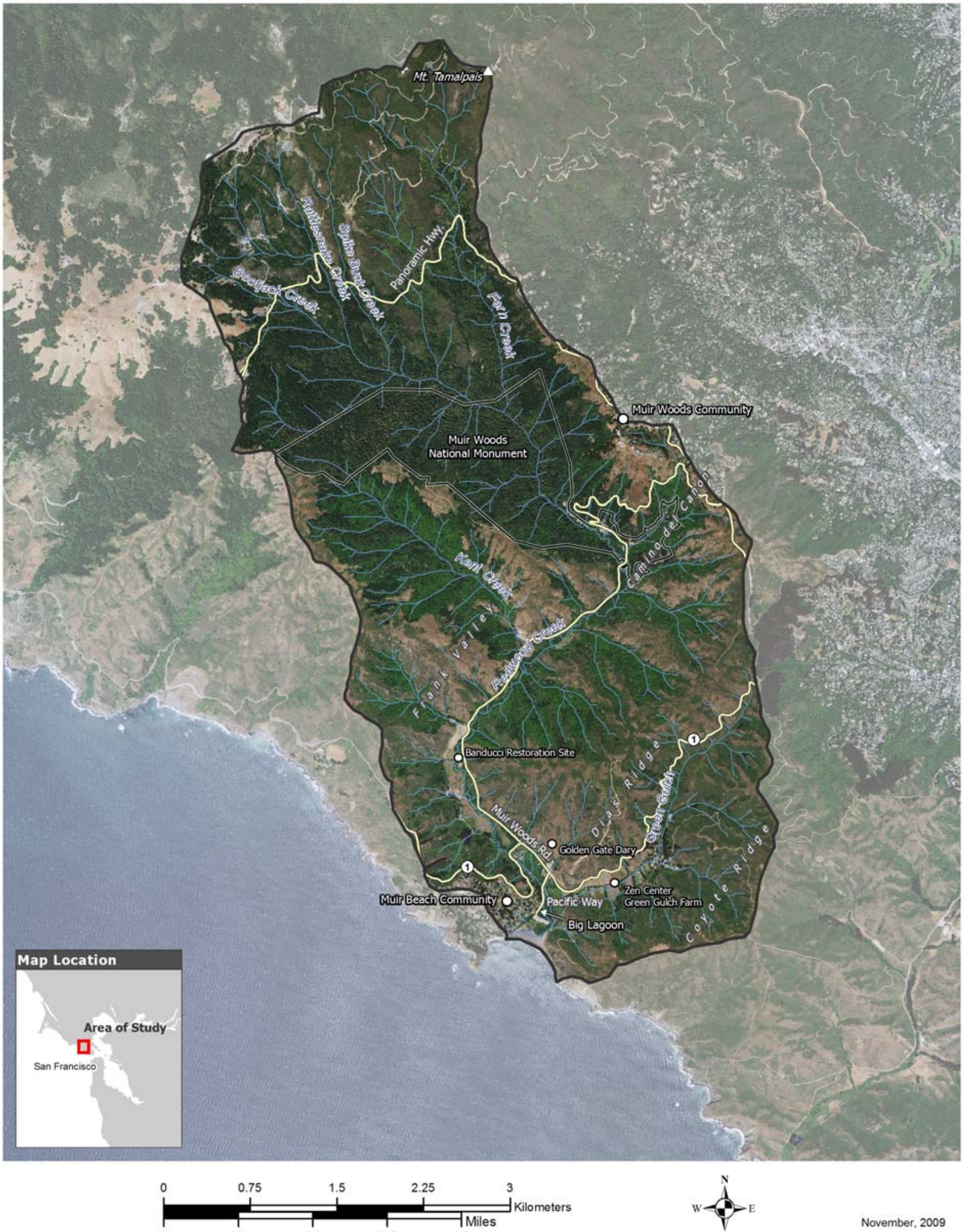
The remarkable natural resources of the Redwood Creek watershed have been recognized and valued for over a century. This roughly 9 square mile (mi^2) watershed, located in Marin County and less than an hour drive from downtown San Francisco, hosts the iconic ancient redwoods grove at Muir Woods National Monument, which is nestled between slopes of Mount Tamalpais and Muir Beach (Figure ES-1). The watershed is an extremely popular sightseeing and recreational destination, receiving over 2.5 million visitors annually. Four federally listed animal species (coho salmon, steelhead, red-legged frog, and northern spotted owl), and several rare plants occupy the diverse habitats within the watershed. Roughly 95 percent of the land in Redwood Creek watershed is publically owned, thereby offering a unique opportunity to provide a highly visible example of effective natural resources management, public outreach and education (NPS 2004, CDPR 2002).

Purpose and Need

In 2002, public agencies in the Redwood Creek watershed joined with stakeholders and the public to define the Desired Future Conditions (DFCs) of the watershed through what became known as the 'Vision Process'. The purpose of this process was to create a document based on consensus outlining common goals for managing the watershed. Thirty-three DFCs were identified that relate to four aspects of the watershed: Natural Resources, Cultural Resources, Resident Community, and Visitor Experience. Ten DFCs were described for natural resources, of which two may be considered guiding principles for natural resources management in the watershed:

1) The watershed is managed as an intact, continuous, and linked system from the ridge tops to the ocean, with all parts contributing to the health of the whole; and
2) Ecosystem management in the watershed is founded on the restoration and protection of natural processes and disturbance regimes, such as fire and flooding.

Within the framework of these DFCs, this Watershed Assessment provides a common knowledge base regarding natural resource conditions and management in the watershed, identifies key challenges in our understanding and management of natural resources, and outlines approaches for addressing these issues. Chapter 2, *Watershed Characterization*, synthesizes information on existing natural resource conditions. Chapter 3, *Human Uses and Values*, describes current and historical human uses of the watershed and how they are or could be affecting natural resources. These two chapters provide an information base for addressing critical management issues and filling important knowledge gaps regarding natural resources and processes in the watershed. In Chapter 4, *Issues and Indicators*, the information provided in the two previous chapters is applied to indentify: (1) key issues for watershed management within the framework outlined by the DFCs, (2) where natural resources and processes are most affected by agency management, and (3) actions that are likely to improve watershed health. Chapter 5, *Priority Actions and Studie*s, provides work plans for implementing select actions and studies that were identified through the development of this Watershed Assessment.



November, 2009

Sources: National Park Service (GGNRA), Marin Municipal Water District; NAIP 2009 Imagery, ESRI 2008 Basedata

Stillwater Sciences

Figure ES-1. Redwood Creek Watershed and Regional Setting
(Stillwater Sciences 2004)

Overall, this document is meant to serve as a common technical reference point for jurisdictions and stakeholders to provide specific guidance regarding agreed-on priority issues and potential actions to address those issues, and most importantly to facilitate joint and/or coordinated efforts to improve the health and collective management of the Redwood Creek watershed. In the process of addressing the critical priority issues in the watershed it is understood that sources of stress and disturbance, stakeholder concerns, and approaches to management will change through time. As such, this "living" document will be updated as necessary to reflect changes in natural resource conditions and management paradigms.

Public land owners, agencies, and numerous other stakeholders that have contributed to development of this first edition of the Redwood Creek Watershed Assessment include:

- Golden Gate National Recreation Area, a unit of the National Park Service (includes Muir Woods National Monument).
- Marin Municipal Water District
- California Department of Parks and Recreation (Mt. Tamalpais State Park)
- Marin County (Departments of Public Works and Community Planning)
- San Francisco Bay Regional Water Quality Control Board
- National Marine and Fisheries Service
- Muir Beach Community Services District
- Muir Woods Park (residential community)
- Green Gulch Farm Zen Center
- Ocean Riders
- Marin Conservation League
- Sierra Club, Marin Chapter

Current versions of this document, as well as information regarding on-going management actions, research, and public meetings, can be accessed at the Golden Gate National Recreation Area web site:

http://parkplanning.nps.gov/parkHome.cfm?parkID=303

Goals and Objectives

The overarching goal of the Redwood Creek Watershed Assessment is to support on-going, informed and coordinated natural resources management in the watershed. The primary objectives of the Redwood Creek Watershed Assessment are to:

1) Assemble, evaluate, and summarize existing data and knowledge related to natural resources and natural resources management in the watershed;
2) Identify and describe aspects of natural resources management and knowledge in the watershed that are incomplete or in need of additional information;
3) Work with fellow agencies and stakeholders to determine priority studies and actions that will significantly improve our understanding and/or conditions in the watershed;

4) Lay the foundation for improving management and understanding of natural resources in the watershed; and
5) Support integrated management and information sharing by fostering on-going communication among agencies and stakeholders in the watershed.

Watershed Characterization

Redwood Creek originates in steep headwaters on the southwestern slopes of Mt. Tamalpais, a 2,571 ft peak in the south central Marin County, north of San Francisco, California (Figure 1). The creek flows through Mt. Tamalpais State Park, forming Redwood Creek Canyon before passing through the heart of Muir Woods National Monument. At the downstream end of the Monument, Redwood Creek Canyon gives way to Frank Valley, where the creek and its tributaries have incised into a relatively broad alluvial floodplain. After winding through Frank Valley and flowing through the Big Lagoon area further downstream, Redwood Creek empties into the Pacific Ocean at Muir Beach. The total drainage area of Redwood Creek at its mouth is 8.8 mi^2. Named tributaries in the headwaters include Bootjack, Rattlesnake, Spike Buck, and Fern creeks. Kent Canyon Creek, another major tributary (drainage area = 1.0 mi^2), joins Redwood Creek in Frank Valley (Figure ES-1). Green Gulch Creek drains the southeastern 1.1 mi^2 of the watershed, contributing to the mainstem in the Big Lagoon area.

Redwood-Douglas-fir forest covers over one-third of the Redwood Creek watershed. The redwoods occupying the canyon floor of Muir Woods National Monument are the only remaining old growth redwood forest in the Mt. Tamalpais area. Some redwood trees in Muir Woods are as much as 1,000 years old. Special-status animal species that have been detected in redwood-Douglas-fir habitat include northern spotted owl (federally threatened), olive-sided flycatcher (state Species of Special Concern), and two bat species (western red bat and Townsend’s big-eared bat, both state Species of Special Concern). Other important terrestrial and wetland habitats in the watershed include mixed hardwood forest, chaparral (including serpentine chaparral), riparian woodland, grasslands, various coastal communities, and emergent and forested wetlands. Overall, the watershed is known to harbor at least 20 native aquatic vertebrate species, including nine native fishes, nine native amphibians, and two native aquatic reptiles (one turtle and at least one species of garter snake). Two non-native fish species and one non-native turtle have also been identified in the watershed. Three of the native aquatic vertebrate species (coho salmon, steelhead, and California red-legged frog) are listed under the federal Endangered Species Act.

Processes that maintain the native vegetation communities in the watershed have been impacted through Euro-American settlement. Grazing in the 19th and early-to-mid 20th centuries affected grassland species composition, and logging during the same periods affected forest age structure and to some degree, species composition. Euro-American settlement also brought about a shift from frequent, low-intensity wildfires in grassland, shrubland, and forest systems to infrequent and spatially limited fires under a policy of fire suppression in the mid- through late-20th century. Possible effects associated with this change in the fire regime include expansion of shrub and tree cover into existing grassland habitat (an estimated 64 percent decrease in grassland acreage in the watershed has occurred, relative to use under Native American settlement), increased density of mid-canopy trees, and increases in the forest fuel load. The introduction of Sudden Oak Death in the mid-1990s has also impacted the structure and composition of Muir Woods and the redwood forest in Kent Canyon through the large-scale reduction in tan oak cover, formerly a dominant mid-canopy species in these forests. The effects of this change in forest species composition on wildlife and gap-succession dynamics are unknown. It is likely that the current die-off of tan oak has substantially increased the fuel load (including ladder fuels) within Muir Woods; however this has not been quantified or evaluated for its effects on the potential for catastrophic wildfire.

Beyond changes to native species, a steady succession of non-native invasive plant species have made their way to the Redwood Creek watershed over the years, including eucalyptus, cape ivy, pampas and jubata grass, French broom and Scotch broom, periwinkle, panic veldt grass, capeweed, and Himalayan blackberry. Studies have demonstrated that these non-native invasive plant species can have massive impact on native wildlife and in simplifying native plant communities. Substantial progress has been made in reducing the extent and controlling the spread of some of these species, and all three of the public agencies with large land ownership in the watershed have active non-native plant management programs with some degree of cost and data sharing. Pest animal species, such as cow birds, corvids, turkey, Chukar partridge, and the barred owl are also suspected or known to be impacting native animal and plant populations in the watershed.

Although the watershed supports numerous native ecosystems and species, many are in some stage of recovery from historical impacts associated with Euro-American settlement. For example, the sediment balance in streams was profoundly altered during the late 19th and mid-20th centuries. The removal of native trees through logging and conversion of perennial native grasslands to annual European grasslands increased tributary sediment inputs at the same time that increases in grazing and impermeable surface area from roads and trails within the watershed led to increased peak runoff. These changes promoted incision of the mainstem along Frank Valley, subsequently disconnecting the mainstem channel from its floodplain and increasing sediment delivery downstream to Big Lagoon. In the mid-20th century, levee construction, channel straightening, and removal of riparian vegetation and large in-stream woody debris exacerbated these changes in channel processes and morphology. Recovery from these alterations has been underway for at least the past 20 yrs through improved upland vegetation management, improved road and trail design and management, reintroduction of large wood into the stream channel, removal of bank hardening structures, and restoration efforts at Big Lagoon and Frank Valley. However, the mainstem channel remains disconnected from its historical floodplain along much of its length.

Stress on the aquatic ecosystem due to these historical changes remains as the system slowly recovers, and is compounded by other changes, including ground channel water pumping in Frank Valley, changes in regional weather patterns, and anthropogenic nutrient loading to the lower reaches which reduces instream dissolved oxygen concentrations. Some part or a combination of all these factors could be affecting the health and recovery of coho salmon and steelhead populations in the watershed. Fish populations generally respond to conditions on a much shorter time scale than do geomorphic processes, and while simply removing the human cause of disturbance can allow natural geomorphic process rates and morphology to recover in decades to centuries, anadromous salmonids could be extirpated from the basin within that time frame. Therefore, restoration actions are required that actively address sediment dynamics, fluvial geomorphology, riparian functions and the quality and quantity of summer baseflows, as they relate to the needs of aquatic habitat in the short (1 to 5 yrs) term. These are further discussed in Chapter 4, *Issues and Indicators for Redwood Creek Watershed*.

Human Use and Values

Most of the Redwood Creek watershed is owned by the California Department of Parks and Recreation (Mt. Tamalpais State Park), the National Parks Service (including Golden Gate National Recreation Area and Muir Woods National Monument), and the Marin Municipal Water District (MMWD), which own and manage 52 percent, 26 percent, and 17 percent of the watershed, respectively (Figure ES-2). The remaining 5 percent of the watershed includes roads (managed by the California Department of Transportation, Marin County, and local service districts), Muir Beach Community Services District property, and private properties in the communities of Muir Beach, Muir Woods Park, and Green Gulch Farm Zen Center.

Human residential development within the watershed occurs principally in three locations: (1) Muir Beach Community, located near the mouth of Redwood Creek; (2) Green Gulch Farm Zen Center – located a short distance up a side-valley from Muir Beach; and (3) Muir Woods Park Community, located high in the watershed along the Panoramic Highway. A small number of additional residences for park staff are located on NPS and State Park lands and a few residences remain in a small community on NPS lands at Camino del Canon.

Several important issues with relevance to watershed planning are associated with human habitation within the watershed, including: the siting, leakage and failures of septic systems, water use, runoff and soil erosion, congestion on area roads, and introduction of non-native plants and animals. All houses within the watershed, excepting those in Muir Woods National Monument, currently operate on septic systems, and problems with overloaded or poorly sited septic fields are noted within community plans. Further development, including redevelopment to larger residences, is expected to exacerbate these problems. Similarly, increasing development, home sizes, paving of roads and driveways, and removal of native vegetation are also expected to increase water runoff and the potential for soil erosion and water pollution. Water quality monitoring conducted by NPS has occasionally found Redwood Creek bacteria levels to exceed state standards for human contact and elevated nitrogen levels. Problems with traffic congestion, particularly park visitors and people travelling through on Highway 1, are also exacerbated by full-time residents within the watershed due to the area’s narrow and winding road system.

The water needs for all residents and agricultural uses is accommodated through diversion and extraction from surface or subsurface water resources within the watershed. In particular, groundwater extraction affecting Redwood Creek is a significant issue as low summer flows have been identified as the primary limiting factor for the endangered coho salmon (Smith 2001). As described in Section 2.4.8 *Flow Diversions*, water is diverted from Redwood Creek and its tributaries (by direct diversion and by groundwater pumping) by the Muir Beach and Green Gulch communities, but also by the Marin Municipal Water District and Mt. Tamalpais State Park (Muir Woods receives water from outside the watershed).

The diverse mountain, valley, and coastal resource settings of the Redwood Creek watershed provide an attractive resource base for numerous recreational and educational activities. Most visitors access the watershed by vehicle or bus from San Francisco via Highway 101 through Marin City to Highway 1 (Shoreline Highway), Panoramic Highway and Muir Woods Road. Increasing traffic congestion on these

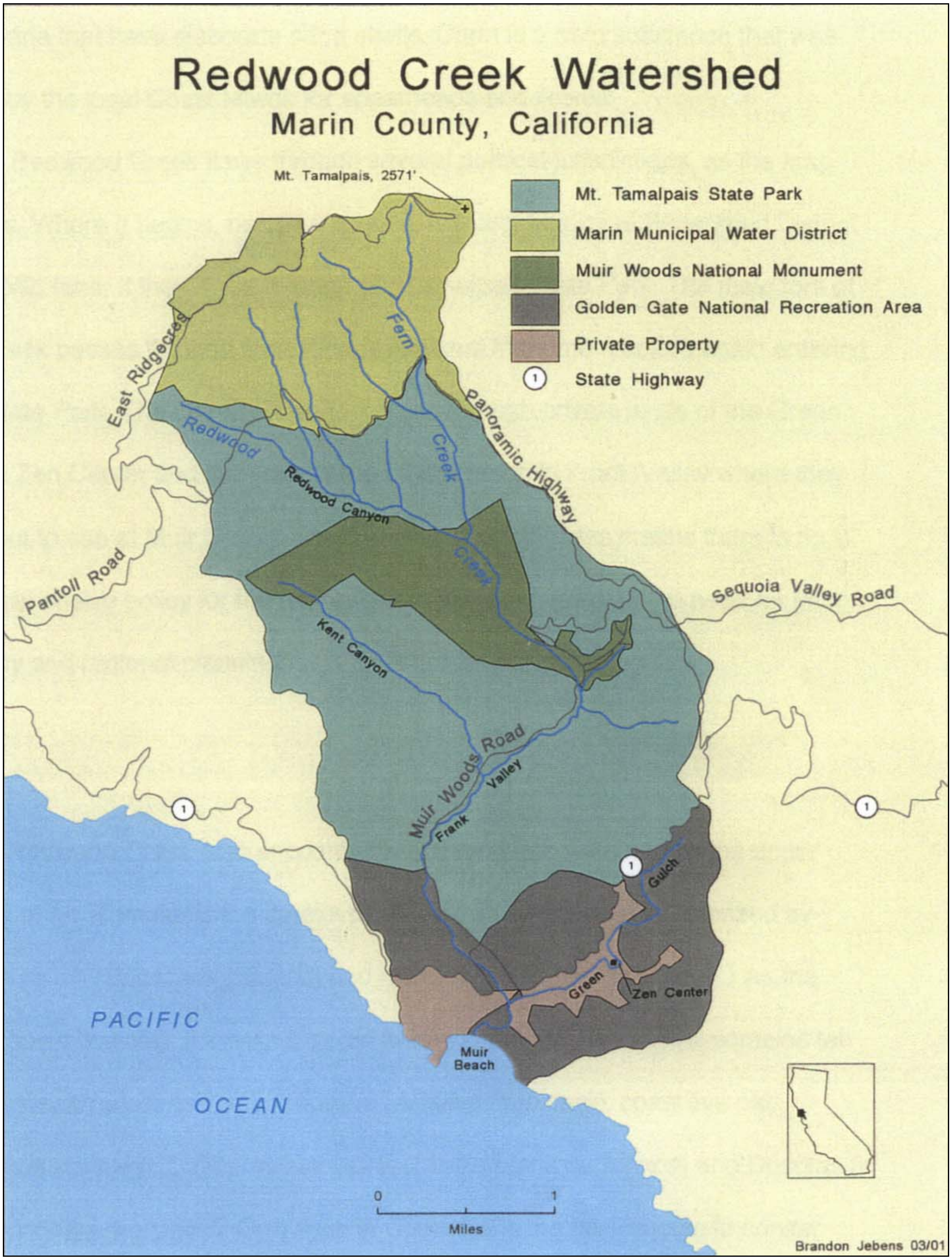


Figure ES-2. Land Ownership in the Redwood Creek watershed
(Jebens 2001)

two-lane roads and limited parking within the watershed are prompting a shift to greater reliance on buses for moving visitors. Visitation is largely day-use as few options exist to accommodate overnight stays within the watershed.

Increasing numbers of visitors to protected natural environments such as the Redwood Creek watershed inevitably contribute negative effects to natural and cultural resources that can also degrade the quality of visitor experiences. For example, erosion from heavy trail use can contribute to sedimentation and turbidity in streams, create rutted trails that are aesthetically displeasing, make travel difficult or unsafe, and degrade the quality of visitor experiences. Similarly, increasing numbers of visitors, particularly at popular attraction sites, can lead to visitor crowding and conflict that also diminish visitor satisfaction. Such concerns are a common and a recurring challenge for land management agencies such as the NPS. "Providing opportunities for public enjoyment is an important part of the Service's mission; but recreational activities and other uses may be allowed in parks only to the extent they can take place without causing impairment of a park's resources, values, or purposes" (NPS 2006a). This statement, from the NPS *Management Policies*, recognizes the legitimacy of providing opportunities for public enjoyment of parks. However, the *Management Policies* also acknowledge that some resource degradation is an inevitable consequence of visitation and directs managers to "ensure that any adverse impacts are the minimum necessary, unavoidable, cannot be further mitigated, and do not constitute impairment or derogation of park resources and values" (NPS 2006a).

The NPS has developed the Visitor Experience and Resource Protection framework to guide carrying capacity decisions needed to protect park natural and cultural resources while maintaining the quality of the visitor experiences (NPS 1997, Manning 2001). Based on management objectives that prescribe desired resource and social conditions for an area, measurable indicators and standards of quality are selected that reflect desired conditions. Standards of quality define the minimum acceptable conditions. These "limits" define the critical boundary line between acceptable and unacceptable conditions, establishing a measurable reference point against which future conditions can be compared through periodic monitoring. When conditions for resource or social indicators exceed standards, the carrying capacity has been exceeded and corrective management actions are needed. Such actions may involve or trigger a range of management actions including visitor education, regulation, site management, or use limits.

Issues and Indicators

Building upon information synthesized through the watershed characterization, this assessment identified key natural resource-related issues for watershed management. Issues were identified as those that threatened or had degraded key natural resources and/or processes based a technical assessment of existing conditions, and confirmation through communications with land owners, managers and other stakeholders. These issues were described within a common framework of desired conditions for the watershed (Vick 2003). In total, thirty-three issues were identified as priorities for the watershed. The priority issues are listed in Table ES-1, organized by DFC.

Table ES-1. Redwood Creek Watershed Priority Natural Rescue Issues.

<table>
<tr><td colspan="2">DFC for hydraulic and geomorphic function:
<i>Restoration and protection of a full range of natural geomorphic and hydraulic functions in Redwood Creek from its headwaters to the Pacific Ocean support complex instream and floodplain structure that, in turn, supports a diverse community of native aquatic and riparian-dependent species</i></td></tr>
<tr><td>Issue 1</td><td>Gather sufficient information on stream flow for lower Redwood Creek to assess water use/availability, habitat conditions/effects, and flood control needs</td></tr>
<tr><td>Issue 2</td><td>Reconnect Frank Valley floodplain to Redwood Creek mainstem</td></tr>
<tr><td>Issue 3</td><td>Establish baseline and perform on-going monitoring of channel geomorphic structure for Redwood Creek watershed</td></tr>
<tr><td colspan="2">DFC for erosion effects on fish habitat:
<i>Human-caused erosion on watershed lands does not impact fish and aquatic habitat.</i></td></tr>
<tr><td>Issue 4</td><td>Quantify and reduce high potential sediment yields resulting from human actions in tributaries, including Camino del Canon</td></tr>
<tr><td>Issue 5</td><td>Quantify and reduce excessive sediment yields due to mainstem and tributary incision in Frank Valley impact water quality, fish habitat, and flood conveyance</td></tr>
<tr><td colspan="2">DFC for infrastructure:
<i>Infrastructure and its maintenance are appropriate to the anticipated use and public safety, while minimizing impacts on natural resource and cultural resources.</i></td></tr>
<tr><td>Issue 6</td><td>Reduce flood hazard during high flow events along Pacific Way</td></tr>
<tr><td>Issue 7</td><td>Increase flood capacity in existing culverts</td></tr>
<tr><td>Issue 8</td><td>Remove constraints on natural processes by existing structures and parking lots</td></tr>
<tr><td colspan="2">DFC for water flow and quality in relation to aquatic ecosystem health:
<i>Aquatic ecosystem health is not impaired by water diversion or water quality degradation.</i></td></tr>
<tr><td>Issue 9</td><td>Minimize effects of water withdrawal on fish populations</td></tr>
<tr><td>Issue 10</td><td>Reduce vulnerability of lower Redwood Creek to additional water diversions</td></tr>
<tr><td>Issue 11</td><td>Characterize and minimize negative water quality effects from stormwater runoff from parking lots and roads</td></tr>
<tr><td>Issue 12</td><td>Quantify dissolved metal levels throughout the watershed</td></tr>
<tr><td>Issue 13</td><td>Identify sources and reduce bacterial contamination of lower Redwood Creek and Muir Beach</td></tr>
<tr><td>Issue 14</td><td>Identify sources and reduce nutrient enrichment of lower Redwood Creek</td></tr>
<tr><td colspan="2">DFC for native plant community health:
<i>Native plant communities are healthy and comprise a mosaic of diverse cover types, including native grasslands, chaparral, riparian woodland, hardwood and redwood forests, and wetlands.</i></td></tr>
<tr><td>Issue 15</td><td>Allow for regeneration and natural disturbance regimes in Muir Woods and other redwood forests in watershed</td></tr>
<tr><td>Issue 16</td><td>Determine baseline structure and composition of the redwood forest in Muir Woods</td></tr>
<tr><td>Issue 17</td><td>Characterize and minimize Sudden Oak Death effects on plant community composition and structure</td></tr>
<tr><td>Issue 18</td><td>Slow or reverse conversion of native grasslands to shrub-dominated plant communities</td></tr>
</table>

Issue 19	Characterize extent of and threats to native serpentine and dune communities and species
DFC for non-native species effects and native habitat: *Invasion by and the adverse effects of non-native plant and animal species on the ecosystem are reduced or reversed, and imperiled habitats are restored.*	
Issue 20	Limit introduction and spread of invasive plant species through systematic monitoring and public outreach
Issue 21	Improve invasive non-native plant species control and eradication
Issue 22	Minimize impacts of non-native animals and native “pest” species on native species
DFC regarding the protection of special-status animals and plants *Special-status and locally rare plant and animal species are protected and, where appropriate, their populations are expanded.*	
Issue 23	Increase amount of winter refugia for rearing coho salmon and steelhead
Issue 24	Survey and increase if necessary suitable habitat for listed terrestrial invertebrate species
Issue 25	Increase California red-legged frog breeding areas and consider reintroduction of foothill yellow-legged frog in watershed
Issue 26	Characterize and address potential long-term negative threats to local northern spotted owl population, including the recent invasion of barred owls in the watershed
Issue 27	Estimate disturbance of native bat populations in the watershed and reduce disturbance if necessary
Issue 28	Assess potential for marbled murrelet habitat in watershed and if supported, manage lands for marbled murrelet habitat
DFC regarding native wildlife populations and habitat *Native wildlife populations are visible and diverse, and key habitats and habitat linkages (i.e., corridors) are protected and restored.*	
Issue 29	Reduce wildlife habitat fragmentation associated with roads and development
Issue 30	Halt declines in wetland bird species due to the loss of suitable habitat
Issue 31	Halt decline of local native song bird populations due to nest predation and brood parasitism by introduced, non-native birds
Issue 32	Minimize effects of human-caused sound, light, and activity disturbances on wildlife
Issue 33	Perform comprehensive study on coho salmon and steelhead populations

Relevant attainment “indicators” of the natural resource-related Desired Future Conditions associated with implementation of management measures are further described in this Watershed Assessment.

Prioritization of Issues

Because addressing all 33 issues at once would be challenging, priority issues were identified through applying a three-tiered criteria ranking system. The “tier one” criteria were based on the first two “guiding principle” DFCs: (1) the watershed is managed as an intact, continuous and linked system from the ridge tops to the ocean; and (2) management of the watershed is founded on the restoration and protection of natural processes and disturbance regimes, such as fire and flooding. The “tier two” criteria aimed at assessing the degree to which addressing one issue would enhance the natural resources of the Redwood Creek watershed compared to what may be achieved by addressing other issues. All 33 priority issues were scored again, according to a third tier of criteria based on pragmatic concerns such as funding sources, costs, technical feasibility, and community support. The ranking of the 33 issues is further described in Section 4, and presented in Appendices G through J.

Numerous of the 33 priority issues were highlighted as critically important through application of the initial two tiers of the ranking system, including the following:

- Limit introduction and spread of invasive plant species through systematic monitoring and public outreach
- Reduce nutrient enrichment of lower Redwood Creek
- Halt declines in wetland and riparian bird species by restoring suitable habitat.
- Improve invasive non-native plant species control and eradication
- Characterize Sudden Oak Death effects on plant community composition and structure.
- Characterize extent of and threats to native serpentine communities and species
- Comprehensive study on Coho salmon and steelhead populations
- Quantify excessive sediment yields due to mainstem and tributary incision in Frank Valley impact water quality, fish habitat, and flood conveyance
- Increase amount of winter refugia for rearing coho salmon and steelhead.
- Increase California red-legged frog breeding areas in watershed
- Allow for regeneration and natural disturbance regimes in Muir Woods and other Redwood forests in watershed

In particular, seven priority issues were identified that would benefit most from further definition, and were expanded upon in this assessment. These seven issues include four management actions and three research studies. A fifth priority management action, public outreach and participation, was identified during public outreach workshops conducted as part of Watershed Assessment development process. These 5 priority management action and 3 research studies are as follows:

PRIORITY ACTIONS

- **Minimize effects of water withdrawal on fish populations**: The largest water withdrawals from mainstem Redwood Creek supply the Muir Beach Community. The Muir Beach Community Service District operates a well on the Redwood Creek floodplain near the Banducci Property. Pumping during the summer months reduces flows in Redwood Creek; in dry years pumping can affect the continuity of pools, which creates adverse conditions for salmonids. Several alternatives have been identified to address this issue. An assessment and cross-comparison of the costs and feasibility of these alternatives, as well as research into funding opportunities, is needed in order to define the next steps towards reducing impacts of water withdrawals on fish populations. One potential solution for this issue would be developing additional water storage for the Muir Beach Community that would reduce the need for pumping in dry years.

- **Remove infrastructure constraints on fluvial processes:** Transportation infrastructure (e.g., roads, bridges, and parking areas), utilities, and engineered channel infrastructure (e.g., bank protection and levees) alter natural processes along the Redwood Creek corridor. Processes and affected by infrastructure include channel hydraulics, sedimentation and erosion, floodplain functions, and terrestrial habitat connectivity. Many infrastructure constraints have been clearly identified and area targeted for removal or modification. Additional studies, designs and funding are needed continue to the process of removing or modifying infrastructure that adversely affects natural fluvial processes. An example of addressing this issue would be replacing the Pacific Way Bridge with a wider span to allow for channel migration.

- **Address road conditions along the lower Muir Woods Road corridor and associated effects on ecosystem functions.** Lower Muir Woods Road parallels Redwood Creek between the visitor's center at Muir Woods National Monument and Highway 1.Through this extent, the valley bottom is narrowly to moderately confined and the road is situated directly adjacent to the banks of the Redwood Creek in some locations. At several of these locations, the road is damaged or potentially threatened by a combination of problems related to road surface drainage, tributary drainage, and channel bank erosion. An updated road assessment and specific management plan is needed for lower Muir Woods Road in order to address the range of current problems related to vehicular and pedestrian traffic needs, road surface and tributary drainage, erosion, and associated ecosystem effects.

- **Restore floodplain connectivity in Frank Valley**: Lower Redwood Creek has become disconnected from its former floodplains by channel relocation and realignment, floodplain modifications (e.g., land leveling and levee construction), and disequilibrium in fluvial processes. Restoration actions that would improve hydrologic and geomorphic function have been identified in the reach from Mt. Tamalpais State Park to the Highway 1 Bridge (referred to as Lower Frank Valley) and in the reach from Highway 1 to Muir Beach. A first phase of restoration work was completed in the Middle Reach in 2003 by NPS and the Parks Conservancy. A second phase of restoration that includes over 2,500 linear feet of channel is under consideration by NPS and the Parks Conservancy (NPS 2007, Kamman Hydrology & Engineering 2006). Less emphasis has been placed on evaluating the feasibility of restoring channel and floodplain functions in the reaches of Redwood Creek upstream of the Banducci site; an assessment of restoration feasibility is needed for this reach.

- **Coordinated Public Outreach and Participation:** Multiple public workshops were conducted during the development of this Watershed Assessment. The most common input received from the public was a desire to be informed of watershed actions and involved in watershed management. As such, the watershed stakeholder group has identified public outreach and participation as a priority action. Ways to implement this action would be to hold regular public briefings on the watershed management activities or to utilize volunteers to assist with implementation of management actions.

PRIORITY STUDIES

- **Assessment and monitoring of channel condition**: Cycles of channel instability (e.g., incision, bank erosion, and aggradation) and changes in channel morphology (e.g., pool spacing, bankfull width and depth, floodplain connectivity) have occurred in lower Redwood Creek in response to land use development, channelization, structural modifications, and other management activities. However, limited data are available to assess trends in channel conditions. Repeated observations of channel geometry, bed and bank morphology, sediment storage, and bed material composition in response reaches of Redwood Creek and larger tributaries would (1) provide a measure of channel response to changes in water, sediment, and wood inputs; (2) provide a means of evaluating the effectiveness of restoration activities on fluvial processes, geomorphology, and aquatic habitat conditions; and most importantly (3) inform future resource management and restoration in the watershed. The study to address this issue would establish a long-term program that monitors channel morphology (e.g., cross-sections and profile) at fixed location along Redwood Creek and large tributaries.

- **Assessment of stream gauging needs**: The sporadic record of stream gauging in Redwood Creek leads to numerous uncertainties in the flow record that hinder hydrologic and fluvial geomorphic analyses useful for resource management and restoration in the watershed. Long-term, continuous gauging at a network of stations in the watershed is needed to better understand the hydrologic (e.g., storm hydrograph characteristics, peak flood discharge, baseflow, and flow exceedance) and fluvial geomorphic (e.g., hydraulic geometry and sediment transport rates) responses to changes in watershed inputs, ongoing baselevel change (i.e., incision or aggradation) and to inform restoration and resource management in the watershed. The flow record for Redwood Creek could be improved by (1) establishing a reliable stage–discharge relationship at the existing Highway 1 gauge site, and (2) expanding the network to include additional gauge sites that account for accretion from large tributaries.

- **Status of ancient redwood grove in Muir Woods National Monument as well as adjacent Douglas-fir forests**: Measurements of the structure and composition of the redwood forest and its adjacent Douglas-fir forests in Muir Woods National Monument have not been made for over thirty years (McBride and Jacobs 1978). In this time many new stressors have been introduced and the effects of ongoing stressors on the forest have likely changed. Given the ecological and social importance of Muir Woods as one of the last stands of old growth coastal redwood, renewed efforts to track and understand the health and response of this ecosystem to its conditions is warranted. Establishing baseline forest structure and composition data would be essential for early detection of changes in the rate and distribution of redwood regeneration and recruitment, encroachment of the redwood forest by adjacent Douglas fir stands, effects of Sudden Oak Death on understory composition and structure, effects of new diseases on plant species, and effects of changes in the distribution and character of snags and logs on wildlife species.

Work plans for implementing the top ranked actions and studies are presented in Chapter 5 of this Watershed Assessment.

Conclusions and Recommendations

The intent of this Watershed Assessment is to provide land managers and stakeholders with a framework for implementing actions and studies that will ultimately improve watershed health through integrated watershed management. It is anticipated that the jurisdictions within the watershed will sign a Memorandum of Understanding (MOU) that acknowledges this document as the framework for watershed management. Key watershed stakeholders will meet on a quarterly basis to further advance the priority actions and studies identified in this assessment and to coordinate other management actions within the watershed. Although the key watershed stakeholders have agreed on the current set of priorities, conditions in the watershed will change, and as human needs and opportunities change, this assessment will need to be updated with new knowledge and concerns. The priority studies and actions will also need periodic updates to acknowledge those that have been completed and to define new priorities as they arise. Adaptive management and monitoring plans will be developed to track the performance of priority actions that have been implemented. These plans will also serve as a vehicle for public outreach and participation.

1 INTRODUCTION

The remarkable natural resources of the Redwood Creek watershed have been recognized and valued for over a century. This roughly 9 square mile (mi^2) watershed, located in Marin County and less than an hour drive from downtown San Francisco, hosts the iconic ancient redwoods grove at Muir Woods National Monument, which is nestled between slopes of Mount Tamalpais and Muir Beach (Figure ES-1). The watershed is an extremely popular sightseeing and recreational destination, receiving over 2.5 million visitors annually. Four federally listed animal species (coho salmon, steelhead, red-legged frog, and northern spotted owl), and several rare plants occupy the diverse habitats within the watershed. Roughly 95 percent of the land in Redwood Creek watershed is publically owned, thereby offering a unique opportunity to provide a highly visible example of effective natural resources management, public outreach and education (NPS 2004, CDPR 2002).

1.1 Goals and Objectives

The overarching goal of the Redwood Creek Watershed Assessment is to support ongoing, informed, and coordinated natural resources management in the watershed that respects both human natural resource use as well as the natural processes that sustain those resources. The primary objectives of the Redwood Creek Watershed Assessment are to:

- assemble, evaluate, and summarize existing data and knowledge related to natural resources and natural resources management in the watershed;

- identify and describe aspects of natural resources management and knowledge in the watershed that are incomplete or in need of additional information;

- work with fellow agencies and stakeholders to determine priority studies and actions that will significantly improve our understanding and/or conditions in the watershed;

- lay the foundation for improving management and understanding of natural resources in the watershed; and

- support integrated management and information sharing by fostering ongoing communication among agencies and stakeholders in the watershed.

1.2 The Vision Process

In 2002, public agencies in the Redwood Creek watershed joined with stakeholders and the public to define the desired future conditions (DFC) of the watershed (Vick 2003) through what became known as the "Vision Process." The purpose of this process was to create a document based on consensus, outlining common goals for managing the watershed. The overarching future vision for the watershed was articulated by the stakeholder group in the following statement (Vick 2003):

> *The Redwood Creek watershed exists as an intact natural ecosystem that offers opportunities for people to learn about, experience, and protect a rich blend of nature, rural character, and cultural history in an urbanized area.*

Thirty-three DFCs were identified that relate to four aspects of the watershed: natural resources, cultural resources, resident community, and visitor experience. Ten DFCs were described for natural resources, of which two may be considered guiding principles for natural resources management in the watershed:

- The watershed is managed as an intact, continuous, and linked system from the ridge tops to the ocean, with all parts contributing to the health of the whole; and

- Ecosystem management in the watershed is founded on the restoration and protection of natural processes and disturbance regimes, such as fire and flooding.

Within the framework of these DFCs, this Watershed Assessment document provides a common knowledge base regarding natural resource conditions and management in the watershed, identifies key challenges in understanding and management of these natural resources, and outlines approaches for addressing these issues. Chapter 2, *Watershed Characterization*, synthesizes information about existing natural resource conditions. Chapter 3, *Human Uses and Values*, describes current and historical human uses of the watershed and how they are or could be affecting natural resources. These two chapters provide an information base for addressing critical management issues and filling important knowledge gaps regarding natural resources and processes in the watershed. In Chapter 4, *Issues and Associated Indicators*, the information provided in the two previous chapters is applied to identify: (1) key issues for watershed management within the framework outlined by the DFCs, (2) where natural resources and processes are most affected by agency management, and (3) actions that are likely to improve watershed health. Chapter 5, *Priority Actions and Studie*s, provides work plans for implementing select actions and studies that were identified through the development of this Watershed Assessment.

Overall, this document is meant to serve as a common technical reference point for jurisdictions and stakeholders, provide specific guidance regarding agreed-on priority issues and potential actions to address those issues and, most importantly, facilitate joint and/or coordinated efforts to improve the health and management of the Redwood Creek watershed. It is understood that sources of stress and disturbance, stakeholder concerns, and approaches to management will change through time as the watershed evolves, and this document is to be periodically updated and directed to serve the most current needs of the watershed.

1.3 Funding

Funding to support this Watershed Assessment came from the Golden Gate National Recreation Area (GGNRA) of the National Park Service (NPS) and through the Golden Gate National Parks Conservancy. Additional support was provided through in-kind services such as volunteer time from stakeholders and agency personnel.

1.4 Technical and Stakeholder Input

Although the GGNRA led this initial watershed assessment effort, input from various agency representatives and stakeholders was critical and will continue to be needed for ongoing, integrated management in the watershed. Based on the Vision Process, development of the watershed assessment involved a series of meetings with agency representatives and public stakeholders. In total, five meetings with multiple agency representatives including two public meetings with stakeholders took place, in addition to exchanges and opportunities for public comment on draft portions of the assessment.

Public land owners, agencies, and numerous other stakeholders that have contributed to development of this Redwood Creek Watershed Assessment include:

- Golden Gate National Recreation Area, a unit of the National Park Service (includes Muir Woods National Monument).
- Marin Municipal Water District
- California Department of Parks and Recreation (Mt. Tamalpais State Park)
- Marin County (Departments of Public Works and Community Planning)
- San Francisco Bay Regional Water Quality Control Board
- National Marine and Fisheries Service
- Muir Beach Community Services District
- Muir Woods Park (residential community)
- Green Gulch Farm Zen Center
- Ocean Riders
- Marin Conservation League
- Sierra Club, Marin Chapter

The current version of this document, as well as information regarding on-going management actions, research, and public meetings, can be accessed at the Golden Gate National Recreation Area web site:

http://parkplanning.nps.gov/parkHome.cfm?parkID=303

1.5 The Watershed Assessment as a Living Document

This Watershed Assessment is intended to serve as a vehicle for improved, integrated management of the Redwood Creek watershed. As processes and conditions affecting the watershed as well as human needs and opportunities change, the assessment will need to be updated with new knowledge and concerns. The priority studies and actions also will need periodic updates, to acknowledge action and studies completed and to define new priorities as they arise. Updates are expected to be performed every 5 years, with the possibility that some interim updates may be required to address changes caused by major events (e.g., floods, wildfires). Meetings for interested stakeholders will be held on a quarterly basis, or as determined by participants, and will include the public land owners, agencies, and stakeholders listed above. Communication between these entities likely will include regular e-mail updates or a common web site; however, most participants have indicated that face-to-face meetings also are important and should be held at regular intervals or according to need.

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2 WATERSHED CHARACTERIZATION

This chapter presents a natural resource characterization of the Redwood Creek watershed in Marin County, California. It incorporates information and analysis from a report summarizing available data and existing conditions the Redwood Creek watershed (GGNRA 2003), synthesis and analysis of water quality and flow data available through October 2005, and updated information from more recent studies including:

- Sediment Budget for Redwood Creek Watershed, Marin County, California (Stillwater Sciences 2004)
- Muir Woods National Monument: State of the Parks Natural Resources Assessment (Hall 2008)
- Updated fire management plans (NPS 2005a, Marin County Fire Department 2005, Leonard Charles & Associates and Wildland Resources Management 2008)
- Documents on the Redwood Creek Restoration at Muir Beach and Banducci sites (Jones & Stokes 2007, Moffatt & Nichol and Jeff Anderson & Associates 2009)
- Rare plant and wetland surveys (Faden 2002, 2003b; Taylor 2003; Castellini et al. 2006; Baxter et al. 2009; Garcia and Associates 2009; NPS 2009)
- Wildlife and fish studies and monitoring (Heady and Frick 2004, Fellers and Guscio 2004, Jensen et al. 2004, Reichmuth et al. 2005, Fong and Manning 2007, Carlisle et al. 2008)
- Stream flow and water quality data (Stillwater Sciences 2005a, San Francisco Bay Regional Water Quality Control Board [SFBRWQCB] 2008a, 2008b)

Preparation of this assessment document did not include original data collection and analysis or synthesis of raw data collected after October 2005.

Public agencies and stakeholders have defined DFCs for the watershed, as described in Chapter 1. The following discussion provides a synthesis of existing natural resource conditions within this DFC framework. Since this document provides technical support for natural resource planning and decision making, the focus is on those issues that interface with the natural resources. (Additional information on cultural resources and visitor experience can be found in Auwaerter and Sears (2006) and Manning (2007), respectively.)

The information provided in this chapter can be used to: (1) identify key issues for watershed management within the framework outlined by the DFCs, (2) identify where natural resources and processes are most affected by agency management, and (3) identify actions that are likely to improve watershed health. Together with Chapter 3, *Human Uses and Values*, the watershed characterization provides an information base for addressing critical management issues highlighted in Chapter 4, *Issues and Associated Indicators* for the Redwood Creek watershed. As a common technical reference point for jurisdictions and stakeholders, this document is intended to facilitate joint and/or coordinated efforts to improve the health and management of Redwood Creek watershed.

2.1 Regional Setting

Redwood Creek originates in steep headwaters on the southwestern slopes of Mt. Tamalpais, a 2,571-foot peak in south central Marin County, north of San Francisco, California (Figure ES-1). The creek flows through Mt. Tamalpais State Park, forming Redwood Creek Canyon before passing through the heart of Muir Woods National Monument. Camino del Canon joins Redwood Creek near the downstream end of the Monument as Redwood Creek Canyon gives way to Frank Valley, where the creek and its tributaries have incised into a relatively broad alluvial floodplain. After winding through Frank Valley and flowing through the Big Lagoon area further downstream, Redwood Creek empties into the Pacific Ocean at Muir Beach.

The total drainage area of Redwood Creek at its mouth is 8.8 mi^2. Named tributaries in the headwaters include Bootjack, Rattlesnake, Spike Buck, and Fern creeks. Kent Canyon Creek, another major tributary (drainage area = 1.0 mi^2) joins Redwood Creek in Frank Valley (Figure ES-1). Green Gulch Creek drains the southeastern 1.1 mi^2 of the watershed, contributing to the mainstem in the Big Lagoon area.

2.2 Ownership and Land Use

2.2.1 Public Land Ownership

Most of the Redwood Creek watershed is owned publicly by the Marin Municipal Water District (MMWD), the California Department of Parks and Recreation (Mt. Tamalpais State Park), and GGNRA (Muir Woods National Monument), which own and manage 17 percent, 52 percent, and 26 percent of the watershed, respectively (Figure ES-2). The remaining 5 percent of the watershed includes roads (managed by the California Department of Transportation, Marin County, and local service districts) and private properties in the communities of Muir Beach, Muir Woods Park, and Green Gulch Farm and Zen Center.

Marin Municipal Water District

The MMWD owns 969 acres in the upper watershed (17 percent of the total watershed land area). The MMWD land includes an extensive network of trails, fire roads, and numerous fuel breaks. From 1942 to 2005, a 106-acre parcel of the MMWD land straddling the upper watershed divide was leased by the federal government, first for an Air Force station, beginning in 1950, and later as part of the GGNRA, beginning in 1982 (Figure ES-2). The federal lease expired on June 30, 2005, and the land has since reverted to management by the MMWD. The MMWD manages the land according to the *Mt. Tamalpais Vegetation Management Plan* (MMWD 1995), the Vegetation Management Plan 2009 Update No. 4 (Leonard Charles & Associates 2009a), the Mt. Tamalpais Watershed Road and Trail Management Plan (2005), and the MMWD *Mt. Tamalpais Watershed Management Policy* (MMWD 2010, Leonard Charles & Associates 2009b). The Protection Policy is designed "to retain MMWD watershed lands in perpetuity for water supply, natural wildland, scenic open space and limited passive recreational purposes…" (MMWD 2010).

To this policy, the Vegetation Management Plan adds the goals of managing the MMWD lands to:

- maintain existing important biological resources;
- restore degraded habitats;

- use adaptive management to respond to changing conditions (e.g., associated with climate change and Sudden Oak Death [SOD]); and

- prevent loss of watershed resources from uncontrolled wildfire [while]… carefully restor[ing] the role of fire in ecosystem management and will use fire as a tool for specific management objectives (MMWD 2010).

- The Watershed Road and Trail Management Plan adds goals to:

- improve water quality and minimize sediment input to creeks and reservoirs

- reduce impact of roads and trails on wetlands, riparian areas, and other sensivie habitats; and

- reduce the impacts of roads and trails on the watershed's natural ecological functions.

Mt. Tamalpais State Park

The California Department of Parks and Recreation (State Parks) owns and manages Mt. Tamalpais State Park, which was established in 1928. In the 1960s, the Park expanded into the Redwood Creek watershed. It has since grown to encompass 2,915 acres within Redwood Creek watershed (52 percent of the total watershed land area) and 6,314 acres overall. The *Mount Tamalpais State Park General Management Plan* (CDPR 1980) describes land use and facilities development plans, which have been subject to ongoing revision. Park facilities include an extensive network of hiking trails and fire roads, the East Peak Visitor Center/Gardner Outlook, the Pantoll State Park Headquarters and camping area, the Alice Eastwood group camping area, the Frank Valley horse camp, the Bootjack picnic area, and the Mountain Theater. In addition to these public facilities, State Parks operates a park ranger shooting range and staff housing in Frank Valley, at the mouth of Kent Canyon.

Muir Woods National Monument/GGNRA

The NPS lands in the watershed include Muir Woods National Monument (established in 1908), and portions of the GGNRA, established in 1972; today the combined extent of these NPS lands approximates 1,470 acres, or 26 percent of the watershed land area. The GGNRA was established in 1972 to preserve land for public enjoyment and open space (U.S. Congress 1972). In addition to Muir Woods National Monument, GGNRA manages areas in the watershed along Frank Valley, at Muir Beach, and along Coyote and Dias Ridges (Figure ES-1). GGNRA facilities in the watershed include an extensive network of trails, a parking lot and picnic area at Muir Beach, and Golden Gate Dairy, which is currently occupied by the Muir Beach Volunteer Fire Department and the Ocean Riders, a local equestrian group (Figure ES-1). Land use and zoning are described in greater detail in the *Golden Gate/Point Reyes General Management Plan* (NPS 1980).

Muir Woods National Monument's 554 acres are located entirely within the watershed. Facilities at Muir Woods include hiking trails, a visitor center, parking lots, administrative offices, a native plant nursery, and maintenance shops. Acquisition of the Camino del Canon area at the southern end of the Monument was completed by the NPS by 1983. Under special agreements with the NPS, a few former owners continue to live in Camino del Canon, and local groups, including the Hillwood School, the Society for Comparative Philosophy, and Cameron House, continue to use structures in Camino del Canon for summer camps and other youth-oriented programs.

2.2.2 Private Land Ownership

Community of Muir Beach

The community of Muir Beach lies at the mouth of Redwood Creek (Figure ES-1). Land use in Muir Beach is described in the *Muir Beach Community Plan* (Muir Beach Improvement Association 1978). When the community plan was written, approximately 300 people resided in the community in 129 single-family homes (not all of which are in the watershed). The most recent census data note 147 homes with 350 residents at Muir Beach (Martin 2000). Lot sizes range from 3,000 square feet to 10 acres, with some on coastal hillslopes and others on the floodplain adjacent to Redwood Creek. Residents along Highway 1, between the point where Highway 1 crosses over Redwood Creek and Pacific Way, are within the Muir Beach Community, including the Pelican Inn and the Golden Gate Dairy equestrian center. The community water supply is provided from two wells that draw subsurface stream flow from Redwood Creek in Frank Valley; these wells are owned and operated by the Muir Beach Community Services District (MBCSD) (SWRCB 2001).

Green Gulch Farm and Zen Center

Green Gulch Farm and Zen Center is located along Green Gulch Creek, a tributary to lower Redwood Creek on the south end of the watershed (Figure ES-1). The community is Soto Zen Buddhist and one of three branches of the San Francisco Zen Center. The farm was established in 1972, on land formerly owned and operated as a ranch by George Wheelwright (co-founder of Polaroid). Currently operated as an organic farm and a Zen learning center, the community offers public lectures and classes on gardening, meditation, and Buddhist philosophy and practices. The farm relies on Green Gulch Creek, its tributaries, and several springs for drinking water and irrigation. Many current land use practices at the farm are described in the *Green Gulch Farm Maintenance Manual* (Larsen 1984).

Muir Woods Park

The Muir Woods Park neighborhood lies along the northeastern ridge of the watershed, in unincorporated Marin County (Figure ES-1). Land use and zoning for the neighborhood are described in the *Tamalpais Area Community Plan* (Marin County 1992). The neighborhood is zoned single-family-rural and open space. The Muir Woods Park neighborhood includes 590 parcels; 318 are commercial or residential developments and the remainder includes churches, schools, and public buildings (Berto 2002, as cited in GGNRA 2003); roughly 35 of these structures lie within the watershed. Of the remaining 272 undeveloped parcels (some of which are within the watershed), Marin County estimates that 77 could potentially be developed with one or more housing units, under the parameters of the *Marin County General Plan* and the *Tamalpais Area Community Plan* (Berto 2002, as cited in GGNRA 2003). The *Tamalpais Area Community Plan* states that “the County will consider programs to acquire the many forested undeveloped parcels in close proximity to Mt. Tamalpais State Park, Muir Woods National Monument and the lands of MMWD… In the event that acquisition is not feasible, the County will implement design guidelines to ensure that new development does not harm the park or water district lands” (Marin County 1992). Water to the area is provided by MMWD.

2.2.3 Watershed History

A comprehensive history of the Redwood Creek watershed and Marin County region was presented as part of a detailed NPS report on historical land-use in Muir Woods National Monument and incorporated in the *Land Use History of Muir Woods National Monument* (Auwaerter 2005, Auwaerter and Sears 2006). These reports are the basis for the watershed history summarized here, with exceptions cited.

Native Americans

Native people lived throughout present-day Marin and southern Sonoma counties for an estimated 7,000 years before Euro-American colonization (Duncan 1989). The Redwood Creek watershed was apparently occupied by the Huimen, the southernmost of about fifteen Coast Miwok tribes (Bennett 1998). Archeological sites, including at least three shell middens on the historic perimeter of Big Lagoon, attest to its Coast Miwok heritage (Meyer 2003), and prominent nearby places bear names derived from the Coast Miwok language. For example, the name “Tamalpais” is a Spanish adaptation of a Coast Miwok word meaning “west hill” or “coast hill.”

Coast Miwok people managed the land with fire, burning large areas to drive and harvest game animals, and to manage vegetation for grazing, travel, growth of desirable species, and the collection of acorns and seeds (Duncan 1989, MMWD 1995). Over thousands of years, these management practices shaped the distribution and species composition of native plant communities. Anecdotal accounts and a study by Bicknell et al. (1993) suggest that hillsides were dominated by native perennial bunch grasses, with trees and woody vegetation occurring mainly in ravines and canyons. For example, after ascending slopes near Big Lagoon in 1849, Lieutenant Henry Wise of the U.S. Navy reported, “There was no timber to be seen, and except the stunted undergrowth netted together in valleys and ravines, all was one rolling scene of grass, wild oats, and flowers” (Toogood 1980). At the time of Wise’s account, the onset of cattle grazing in the region was probably already affecting vegetation distributions locally. Nevertheless, it seems safe to assume that, at the coarse scale of the observation, landscape conditions were still largely reflecting the prolonged influence of Coast Miwok culture, rather than exhibiting the effects of a more recent shift in management practice. Although it is also likely that under pre-Euro-American contact conditions, redwood forests covered a greater part of the watershed than exists today, particularly along the north and east facing slopes and drainages (Bicknell et al. 1993).

Cattle Grazing and Timber Harvesting

The Spanish founded the Presidio at San Francisco in 1776, and began establishing mission communities that ultimately supplanted the tribal cultures of the Coast Miwok and other indigenous peoples. Parts of the Redwood Creek watershed may have been grazed by cattle and harvested for timber starting about 1817, with the formation of Mission San Rafael Arcangel (Munro–Fraser 1880).

Cattle grazing and timber harvesting intensified after 1838, when the Redwood Creek watershed was officially deeded to William Richardson as part of a grant that included much of the Marin peninsula (19,571 acres in all). Richardson named the area “Rancho Saucelito” (*saucelito* is Spanish for “little willow grove”) and began grazing longhorn cattle. According to an 1847 census, as many as 2,800 head of cattle—the largest herd in Marin County—roamed the open range of Richardson’s rancho. Richardson and his neighbor, David Reed, of the Rancho de Corte Madera del Presidio, harvested redwoods and other trees from the east side of Mt. Tamalpais and, as partners, opened the first timber mill in Marin County in the 1840s (GGNRA 2003). By the 1850s, all of the easily accessible large timber on the bay-side of the mountain had been harvested. Timber harvesters turned their focus on old growth redwoods on the hills around Bolinas Lagoon and Lagunitas Creek watershed, both north of Redwood Creek, while continuing to harvest smaller trees along Richardson Bay for cordwood to heat homes and brick kilns. Logging had spread to the ridges above Muir Woods by the late 1800s. By the early twentieth century, most of the old growth redwoods in the region had been harvested. Exceptions are the stand in present-day Muir Woods and 1,300 acres in Kent Canyon, which was selectively logged under its agricultural owner in the 1960s, before being sold to State Parks (PWA 2000).

Dairy Farming

In 1856, the Richardson family sold Rancho Saucelito to San Francisco financier Samuel Throckmorton, who subdivided parts of it into 500- to 1,500-acre parcels for dairy farming (Auwaerter 2005, Auwaerter and Sears 2006). Demand for dairy products grew with San Francisco's expanding population, and by 1880, Rancho Saucelito had been carved into 24 dairies, most of which were leased by Portuguese and Swiss immigrants. The beach was the center of the community, with farmhouses scattered throughout the valleys under an agrarian culture that reflected Euro-American immigrant heritage (PWA 2003).

In 1889, six years after Throckmorton's death, the rancho was acquired by the Tamalpais Land and Water Company (Auwaerter 2005, Auwaerter and Sears 2006). Much of the land was sold for tenant dairy farming. The largest ranches were: the Dias (or Hill) Ranch, which extended from Homestead Valley across Dias Ridge to the Pacific Ocean; the Brazil brothers' ranch, which extended from Frank Valley up Mt. Tamalpais past the Dipsea Trail; the Silva Ranch, located in lower Frank Valley; and the Bello Ranch (a.k.a. Golden Gate Dairy), which included Green Gulch, Muir Beach, and a portion of Frank Valley (Livingston 1994, Spitz 1997, Baron 2001, Jebens 2001, NPS 2006b). Many of the tenant dairy farms continued operating into the mid-twentieth century.

Other Agricultural Uses

The dairies of Green Gulch and Frank Valley were eventually converted to other agricultural uses. In Frank Valley, Amadeo Banducci, Sr. began leasing portions of the Silva dairy in the 1930s, for flower and vegetable farming (Livingston 1994). In 1948, Banducci purchased the property and operated the entire parcel as a flower farm (Culp 1998). Three years earlier, Green Gulch and Muir Beach had been purchased by George Wheelwright, who raised beef cattle. Wheelwright planted New Zealand grasses on new pastures, claimed from the Big Lagoon area using levees along Redwood Creek. In an effort to increase the area available for grazing, he burned and chained the pervasive shrub vegetation, and, for 3 to 4 years in the late 1950s, sprayed herbicides by helicopter over his property. By 1969, Wheelwright had donated Muir Beach to the State Park system and, by 1972, he had sold Green Gulch to the San Francisco Zen Center under terms that would keep the area in agriculture with only minimal construction of buildings and facilities (Jebens 2001).

Railroads, Roads, and Other Infrastructure

The natural beauty and resources of Mt. Tamalpais and the Marin Coast have attracted recreational users from San Francisco and other nearby areas since the late 1800s (Auwaerter 2005, Auwaerter and Sears 2006). The first ferry service to Marin began in 1855, providing transportation from San Francisco to Point San Quentin. Ferry service to Sausalito was added in 1868. The area's first wagon road, completed in 1870, extended from Sausalito to Bolinas along the present grade of Highway 1. The Eldridge Grade Road, from San Rafael to the summit of Mt. Tamalpais, was completed in 1879.

The powerful locomotives on the "crookedest railroad in the world" are the only ones of their type used in passenger service

Biggest Little Journey in the World

Its starting point is by the Golden Gate. The ticket that you buy at the beginning is not merely a bit of pasteboard—it is the "open sesame" to a Western wonderland: a key to the treasure-house of Nature, whose glories await you in generous measure. Much magic, you will admit, in exchange for the moderate sum of silver left behind you at the ticket window! For you glide at ease over the sheltered waters of a magnificent harbor, you thrill with the novelty of climbing skyward over the queerest, crookedest railroad ever built, to a Tavern whose site in scenic richness is unsurpassed. Tamalpais is verily the Mountain of Magic.

A 1917 brochure for the Mt. Tamalpais & Muir Woods Railroad (Courtesy of Marin County Free Library).

Recreation at the summit expanded in 1896, with the opening of the Mill Valley and Mt. Tamalpais Scenic Railway by the Tamalpais Land and Water Company, which had backing from local financiers Sidney Cushing and Albert Kent. Dubbed "The Crookedest Railroad in the World," it carried tourists up 8.2 miles of track through 281 curves, from Mill Valley to the East Peak of Mt. Tamalpais. At the top, tourists could climb further to the Marine Exchange lookout on East Peak, visit the Weather Bureau station (opened in 1898), and follow hiking trails to outlying areas. In 1907, Albert Kent's son, William built a spur to connect Muir Woods to the Mill Valley and Mt. Tamalpais Scenic Railway line. In 1913, the railroad was incorporated and named the Mt. Tamalpais and Muir Woods Railway.

Introduction of automobiles and extension of local roadways provided recreational users with alternative transport up Mt. Tamalpais. The Muir Woods Road was built in 1893, and from approximately 1905 to 1910, was extended to Frank Valley (Jebens 2001). Pacific Way was connected to Muir Beach in 1908. In 1925 and 1926, the Frank Valley and Muir Woods roads were upgraded (Jebens 2001). Panoramic Highway was opened in 1928. The "Great Tamalpais Fire" of 1929 put an end to the railroad, which had been in decline because of the rising popularity of automobiles (Auwaerter 2005, Auwaerter and Sears 2006). The railroad was abandoned in summer 1930, and its rails, ties, engines, cars, and other equipment were removed from the watershed.

In October 1933, approximately 200 men from the Civilian Conservation Corps arrived in the watershed and began work on infrastructure in Muir Woods and Mt. Tamalpais State Park. One Corps construction project featured excavation of a wide, flat channel and placement of rock revetment along Redwood Creek in Muir Woods National Monument. Stone for the rock revetment work was quarried in Kent Canyon. Today, the rock revetment armors 57 percent of the total bank length (i.e., 3,541 feet) within the Monument. Current park policy is to not restore areas of revetment that fall into disrepair and removal of the revetment was recommended in the *Coastal Zone Plan* (Hall 2008, California Coastal Commission 1980). The NPS has removed portions of the rock revetment along the channel in Muir Woods, and the banks along these reaches are recovering their natural form; several areas of the bank revetment have been left as reminders of the work done by the Corps (M. Monroe, Site Supervisor, Muir Woods National Monument, Mill Valley, California, pers. comm., 2010; GGNRA 2008). Other Corps projects included a stone-faced concrete bridge over Fern Creek, utility buildings and benches, and the Sidney B. Cushing Memorial Amphitheater (a.k.a. the Mountain Theater), which was built from native, serpentine stone near Rock Springs on Mt. Tamalpais. The Corps completed its last project in Muir Woods in May 1941.

In 1937, when the Golden Gate Bridge was completed, annual visitation to Muir Woods had tripled to more than 180,000 visitors per year. By 1947, an estimated 58 miles of roads and trails had been constructed in the watershed (PacWA 2002). Many were used primarily for ranching purposes. An additional 5 miles of roads and trails were built between 1953 and 1965, and 4 more miles were added between 1971 and 1982 (PacWA 2002).

Hunting and Hiking

In the mid-1800s, Redwood Creek land owner William Richardson and his family and friends hunted extensively in the area. Accounts from his hunting expeditions report abundant elk, deer, bears, and mountain lions on the slopes of Mt. Tamalpais (GGNRA 2003). After acquiring the land and leasing parcels for dairy farming, Samuel Throckmorton lined much of his remaining property with fences, guarding it for personal use as a game refuge and allowing access to only a select group of friends (Auwaerter 2005, Auwaerter and Sears 2006).

Hunting became increasingly popular as public access expanded after Throckmorton's death in 1883. However, efforts to reserve the land for private recreational use and limited public access continued as members-only hunting and outdoor clubs began leasing large sections of the mountain slopes from local ranchers. By the end of the 1880s, most of the large game animals had been wiped out (GGNRA 2003). With large predators gone, the deer population grew and became the chief target of hunters.

The Tourist Club continues to be a popular hiking destination in the watershed (courtesy of the Tourist Club).

As access improved with increasing infrastructure, hikers transformed the mountain into an outdoor recreation center (Auwaerter 2005, Auwaerter and Sears 2006). The Tamalpais Club (founded before 1880) maintained a summit register on East Peak. The first volume, spanning 1880–1887, records the names of more than 850 men, women, and children from throughout the U.S. and Europe (GGNRA 2003). In the 1890s and early 1900s, several hiking clubs were formed (Auwaerter 2005, Auwaerter and Sears 2006). Among them were the Sight-seers in 1887, the Cross-County Club in 1890, the California Camera Club in 1890, the Columbia Park Boy's Club in 1894, the Sempervirens Club in 1900, the Sierra Club Local Walks Committee in 1906, the Tourist Club in 1912, and the California Alpine Club in 1914. These clubs organized hikes, built and maintained trails, established camps, and built a "Trailman's Cabin" at Bootjack Camp. In 1904, hikers from San Francisco's Olympic Club held a foot race from Mill Valley to the Dipsea Inn in Bolinas, along the Lone Tree Trail. This was the first Dipsea Race, a still-popular annual event.

The first trail map of the mountain, published in 1898, shows several trails—the Lone Tree (a portion of today's Dipsea), Cataract, Kent, Throckmorton, Bootjack, and West Point (now Rock Spring) trails—which still exist today. By the 1920s, hiking and overnight camping on the mountain were so popular that the San Francisco Examiner newspaper published daily weather predictions for Mt. Tamalpais. Hiking continues to be an important activity in the watershed today.

Commercial Recreation

In 1896, the Tavern of Tamalpais was constructed near the summit, at the end of the Mt. Tamalpais Scenic Railway. In 1909, William Kent opened Muir Inn, which provided luxury accommodations at the end of his Muir Woods railroad spur, at the site now occupied by Camp Alice Eastwood. In 1912, the Mountain Home Inn was opened just outside the watershed, midway down the railroad spur between "Double Bow Knot" and Muir Woods. After many changes, the inn currently operates as a restaurant and bed and breakfast. Kent's Muir Inn burned down in 1913, was later reconstructed, and then was torn down after the demise of the railroad. Joe's Place, a small food stand and weekend dance hall, was opened near the entrance to Muir Woods during World War I by Joe Bickeroff. In about 1930, Coffee Joe's was built nearby, and Joe's Place closed in about 1942. Coffee Joe's became the Muir Woods Inn, and, after being moved into the Monument in the 1970s, it was converted to house the NPS gift shop.

Muir Beach has long been a popular tourist destination. In 1919, the Portuguese dairyman Antonio Bello established a hotel at Muir Beach (GGNRA 2003). The hotel burned down and was replaced in 1928 by a tavern and small cabins. The tavern closed in the 1960s, after it was acquired by State Parks, which demolished it and all of the cabins. Accommodations at Muir Beach are now provided by the Pelican Inn bed and breakfast, located between Redwood Creek and Highway 1 and built by a British man Charles Felix in 1978 to look like a sixteenth century English inn, and now under private ownership (SFGate.com 2007).

The Mountain Play Association

In a long-standing tradition that dates back to 1913, the Mountain Play Association regularly hosts plays on the upper slopes of Mt. Tamalpais (Auwaerter 2005, Auwaerter and Sears 2006). The first Mountain Play was held at a natural depression in the hillside, with about 600 hikers in attendance. Plays continued on land donated by William Kent in 1916. Land ownership was transferred to Mt. Tamalpais State Park in 1936, and the Mountain Theatre, the present-day site of the plays, was completed by the Corps in 1939.

Conservation Efforts

By the end of the 1800s, recreational users had begun supporting efforts to preserve the area's natural and scenic resources from impending urban encroachment. A local water company identified Redwood Canyon as a potential reservoir site, and housing and road developers became increasingly interested in the as-yet untouched hillslopes of Mt. Tamalpais. The watershed was defended by a succession of local and regional conservation-minded groups including the Mount Tamalpais Forestry Association, the local hikers of the "Hill Tribe," the Mount Tamalpais National Park Association, the Tamalpais Conservation Club, the Sempervirens Club, the Sierra Club, and the California Club. William Kent, builder of Muir Inn and namesake of Kentfield, became a key participant in the conservation efforts. Outmaneuvering businessmen who wanted to dam the creek as a source of water for Mill Valley, Kent purchased Redwood Canyon and, in December 1907, donated much of it to the federal government under the proviso that it be made a national monument. Just days after Kent's grant, President Theodore Roosevelt invoked the Antiquities Act, designating Redwood Canyon a national monument with the name "Muir Woods," in honor of the famous conservationist and writer, John Muir. Kent eventually went on to serve in Congress, and he introduced the legislation that established the NPS in 1916 (Auwaerter and Sears 2006).

The establishment of Muir Woods National Monument was the first in a series of notable conservation actions for the Redwood Creek watershed. In 1912, the MMWD was formed to protect the natural land resources in the upper part of the watershed and use it to provide water to Marin citizens. In July 1917, after years of conflict between hunters and hikers, the Mt. Tamalpais Game Refuge was established, ending hunting on most of the mountain—as well as in the Lagunitas Creek watershed from Alpine Lake downstream to the outlet.

In 1928, Mt. Tamalpais State Park was established after three decades of pressure from conservation groups. Only 200 acres at its inception, Mt. Tamalpais State Park has since acquired, among other holdings, the Dias and Brazil dairy farms (in the 1960s), and has grown to include more than 6,300 acres of land on the mountain. The GGNRA was founded in 1972. The NPS began purchasing existing and defunct farms and incorporating them into GGNRA. By 1995, cattle grazing and farming within the watershed was completely phased out, and the GGNRA had grown to include Muir Beach, Coyote Ridge, a portion of Dias Ridge, and the lower part of Frank Valley.

2.3 Climate

2.3.1 Current and Historical Records

The Redwood Creek watershed experiences a typical Mediterranean climate with warm, dry summers and mild, wet winters. Average daily temperatures range from 40 to 70°F throughout the year; freezing temperatures are extremely rare. Mean annual precipitation is 39.4 inches near sea level and 47.2 inches at the higher elevations along Mt. Tamalpais (Weeks 2006). Fog drip can add 10–20 inches of water to vegetation per year in the San Francisco Bay region; exact contributions of fog drip in the Redwood Creek watershed have not been measured (Weeks 2006).

The NPS began measuring precipitation at Muir Woods National Monument in 1941 and continues to record its daily rainfall. Annual rainfall for 1941 thru 2004 is shown in Figure 2-1. The average annual rainfall at the Muir Woods gauge is 37.5 inches. Mean monthly precipitation is listed in Table 2-1 and plotted in Figure 2-2. Roughly 95 percent of the average annual total occurs between October 1 and April 30 (Figure 2-2). Table 2-1 includes “Available Water” estimates, calculated from mean precipitation values and mean potential evapotranspiration values, which are based on evaporation from the nearby Lagunitas Reservoir evaporation pan and an estimated pan coefficient of 0.7 (PWA 2003).

Table 2-1. Monthly Precipitation, Potential Evapotranspiration, and Available Water

Month	Mean Monthly Precipitation		Mean PET[1]		Available Water	
		(mm)	(in)	(mm)	(in)	(mm)
January	7.7	196	0.3	8	7.5	191
February	6.2	157	0.6	15	5.6	142
March	4.9	124	1.9	48	3.0	76
April	2.4	61	2.6	66	0	0
May	1.1	28	3.9	99	0	0
June	0.4	10	4.5	114	0	0
July	0.1	3	5.1	130	0	0
August	0.1	3	4.0	102	0	0
September	0.4	10	2.7	69	0	0
October	2.0	51	1.7	43	0.3	8
November	5.3	135	0.7	18	4.6	117
December	7.3	185	0.4	10	7.0	(in)
Total	**37.9**	**963**	**28.3**	**719**	**9.7**	7.7

[1] Potential Evapotranspiration (PET) values from PWA 2003. Available water is what remains after evapotranspiration losses (total precipitation minus total PET).

(Source: Stillwater Sciences 2005a)

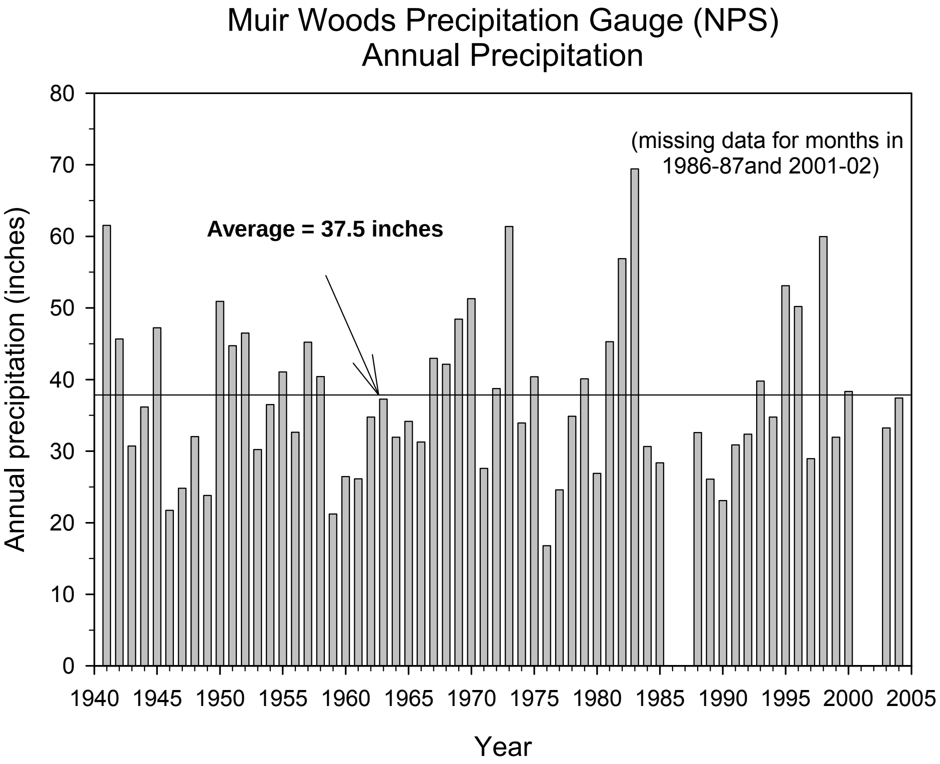


Figure 2-1. Annual precipitation at the Muir Woods precipitation gauge (1941–2004).

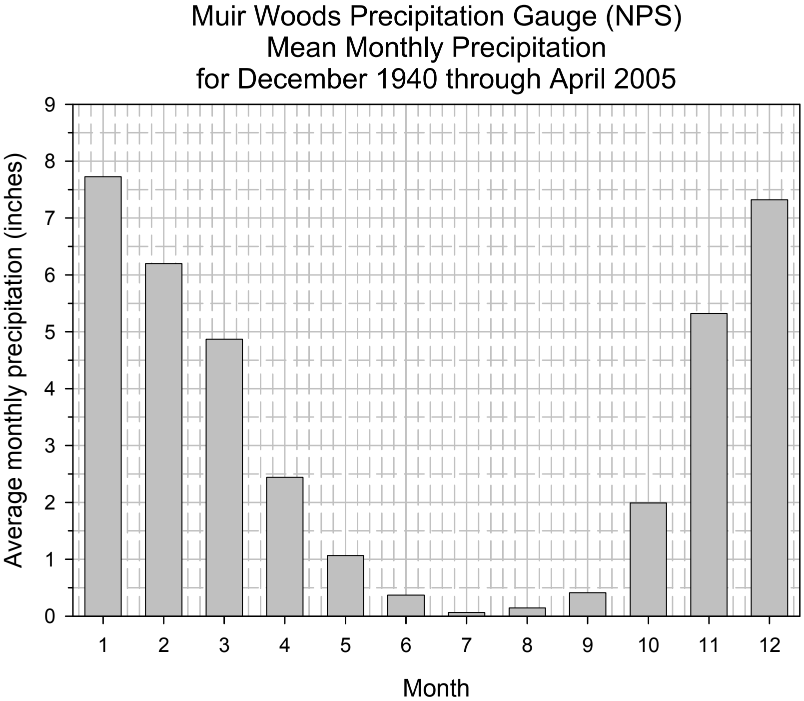


Figure 2-2. MEAN MONTHLY PRECIPITATION AT THE MUIR WOODS.

2.3.2 Climate Projections

Weather along the California coast is subject to climatic cycles, including the Pacific-North American Oscillation, the El Nino Southern Oscillation, and the Pacific Decadal Oscillation (Andrews et al. 2004). These cycles, which occur on 3 year or more scales, effect changes in temperature and precipitation as well as frequency of extreme weather events. A uni-directional change in the climate of the Redwood Creek watershed also has occurred over the past 50 years, with average annual temperatures likely increasing similar to the California average of approximately 1.5°F. On average, the eight major global climate change models (global circulation models) projected continued increases in annual temperatures for the Redwood Creek watershed area, ranging from 3°F to 6°F increases by 2080 (TNC 2009). The greatest increases in temperature are projected to occur from July through September, with smaller changes occurring during mid-winter. Model projections are in agreement that increased temperatures will be accompanied by increased frequency and severity of extreme events such as heat waves, flooding, and wildfires (Cayan et al. 2008). The projected increase in mean annual temperature and frequency in extreme events also could result in an increase in the frequency of scouring floods and prolonged droughts (Karl et al. 2009). The 'ensemble' of major model projections regarding the effects of climate change on precipitation and fog along north coastal California average an approximately 5 percent decrease in precipitation for the low, moderate, and high atmospheric carbon dioxide scenarios (TNC 2009). However, differences among models for the precipitation changes are great and nearly evenly split between projections of substantial increases versus substantial decreases in precipitation by 2080.

Coastal fog is a critical climate element in the North Coast region, providing from 10 to 40 percent of the annual water supply for coastal vegetation, particularly during the summer months when precipitation is low and fog cover is frequent (Dawson and Siegwolf 2007). Coastal fog is held in a cool, moist marine boundary layer that is trapped by high pressure warm and dry cells approximately 1,300 feet above and to the east (i.e., inland) of the coast, a weather pattern that represents a coastal-inland surface temperature inversion (i.e., cooler temperatures at the coast than inland). Fog moisture moves inland when the temperature inversion weakens, reducing the extent of coastal fog. Although the net effects of climate change on coastal fog formation are not clear, recent work suggests linkages between fog formation, the Pacific Decadal Oscillation (PDO), and the strength of the surface temperature inversion. The PDO is a recurring pattern in northern Pacific Ocean temperatures, occurring over decadal time scales, that alternates between cool cycles associated with increased precipitation during October through March, and warm cycles associated with decreased precipitation (Nigam et al. 1999). An inflection point from a cool to a warm cycle appears to have occurred in 1977 (Mantua et al. 1997), and recent evidence suggests another cool cycle may have begun as early as 1998 (Mantua 1997, ISAB 2007).

Using the historical relationship between the coastal-inland surface temperature differential and fog frequency, a 2008 study estimated that a 33 percent decrease in fog frequency appears to have occurred from 1901–1925 and from 1951–2008 (Dawson and Johnstone 2008). From 1951–2008, recorded intervals of high fog frequency correlate with those of the warm PDO cycle and its primary indicator, high sea surface temperatures along the northern coast of California. Other PDO characteristics also correlate with increased fog frequency, such as location of the North Pacific high pressure cell, strong northerly coastal winds, and coastal upwelling. The suggested link between PDO and coastal fog formation, and its implications for the future climate in the North Coast region, differs from earlier predictions of increased coastal fog under climate change. These earlier predictions were based on the assumption that increased inland air temperatures would draw more fog off the ocean toward the coast (Bakun 1990, Snyder et al. 2003). In summary, most recent science demonstrates an overall downward trend in California coastal fog frequency during the twentieth century, with potential linkages between reduced fog frequency and the cool (negative) phase of the PDO cycle. More research on the mechanism behind this relationship and on the drivers of the PDO cycle itself is required.

The intensity and frequency of storm events may shift as a result of changes to the El Niño Southern Oscillation (ENSO). In California and the Pacific Northwest, ENSO produces predominantly cool and dry weather, with events lasting 6–18 months, and complete cycles building and declining over a 2–7-year period (ISAB 2007). With continued global warming, the frequency of ENSO events may increase and/or the variation between ENSO and non-ENSO events may become more extreme (Kiparksy and Gleick 2003). Currently, river basins which are south of 41ºN, including the Redwood Creek watershed, display higher flood peaks during ENSO conditions (NOAA 2008), with the difference between average ENSO and non-ENSO floods being greatest in southern California and generally less pronounced along the North Coast (Andrews et al. 2004). However, a climate-change induced shift in the North Pacific high pressure cell situated over northern California/southern Oregon may alter the ENSO hydrograph and the associated inter-annual timing and magnitude of peak floods in the assessment area. Increased erosion and sedimentation may occur in the assessment area as a result of the increased intensity and frequency of storm events.

Mean sea level (MSL) along the California coast is projected to rise from 4 to 28 inches in the next 80 years (Cayan et al. 2006b). Combined with the increase in extreme events, MSL rise is likely to cause an increase in the frequency of coastal storm surges or coastal flooding events. Increases in MSL also will result in ‘marine transgression’ (landward migration of the shoreline), landward migration of coastal wetland salinity gradients, and changes in size and extent of estuaries and coastal lagoons (see Section 2.8.3). However, the current ambiguity in the ENSO response to global climate change and the need for further resolution of PDO cycle length, frequency, and underlying mechanism means that predicted direct and indirect effects of climate change on the Redwood Creek watershed are still highly uncertain.

2.4 Hydrology

2.4.1 Available Stream Flow Records

Stream flow records for the watershed are discontinuous, with the largest data gap between the early 1970s and late 1980s. From 1962 to 1973, the U.S. Geological Survey (USGS) measured annual peak flows in Redwood Creek at the Frank Valley Bridge (contributing area = 6.4 mi^2). From 1986–1988, the USGS quantified “summer” and “winter” flows at the Pacific Way Bridge, at the Muir Woods Bridge, and in Green Gulch. The timing, location, and magnitude of measured flows from 1962–1988 are listed in Table 2-2.

Table 2-2. Streamflow Point Measurements for Redwood Creek Watershed, 1962–1988

Date	Location	Type of Measurement	Source	Flow	
				(cfs)	(m^3s^{-1})
Redwood Creek					
2/13/1962	Frank Valley Road	Annual storm peak	USGS	880	24.9
10/13/1962	Frank Valley Road	Annual storm peak	USGS	800	22.7
1/20/1964	Frank Valley Road	Annual storm peak	USGS	100	2.83
1/6/1965	Frank Valley Road	Annual storm peak	USGS	410	11.6
1/4/1966	Frank Valley Road	Annual storm peak	USGS	1,300	36.8
1/21/1967	Frank Valley Road	Annual storm peak	USGS	295	8.35
1/30/1968	Frank Valley Road	Annual storm peak	USGS	630	17.8

Date	Location	Type of Measurement	Source	Flow	
				(cfs)	(m^3s^{-1})
12/15/1968	Frank Valley Road	Annual storm peak	USGS	1,040	29.4
1/21/1970	Frank Valley Road	Annual storm peak	USGS	1,780	50.4
1971[1]	Frank Valley Road	Storm peak	USGS	*	*
1972[1]	Frank Valley Road	Storm peak	USGS	*	*
1973[1]	Frank Valley Road	Storm peak	USGS	*	*
8/1974	Lower Redwood Creek	Summer	NPS	0.56	0.016
9/1974	Lower Redwood Creek	Summer	NPS	0.31	0.0088
1/31/1986	Muir Woods	Winter	USGS	51	1.4
1/31/1986	Pacific Way	Winter	USGS	86	2.4
6/26/1986	Muir Woods	Summer	USGS	0.77	0.022
6/26/1986	Pacific Way	Summer	USGS	0.66	0.019
2/13/1987	Muir Woods	Winter	USGS	114	3.22
3/13/1987	Pacific Way	Winter	USGS	30	0.85
6/10/1987	Muir Woods	Summer	USGS	0.62	0.018
6/12/1987	Pacific Way	Summer	USGS	0.68	0.019
1/5/1988	Muir Woods	Winter	USGS	42	1.2
1/5/1988	Pacific Way	Winter	USGS	73	2.1
6/7/1988	Muir Woods	Summer	USGS	0.70	0.020
6/7/1988	Pacific Way	Summer	USGS	0.78	0.022
9/4/1988	Frank Valley Road	Summer	NPS	0.06	0.002
Green Gulch Creek					
1/30/1986	Green Gulch Farm	Winter	USGS	909	0.28
6/25/1986	Green Gulch Farm	Summer	USGS	0.01	0.0003
3/13/1987	Green Gulch Farm	Winter	USGS	1.2	0.034
6/12/1987	Green Gulch Farm	Summer	USGS	0.01	0.0003
3/23/1988	Green Gulch Farm	Winter	USGS	0.04	0.001
6/2/1988	Green Gulch Farm	Summer	USGS	0.01	0.0003

1. Records from 1971, 1972, and 1973 are referenced but not reported in any of the data sources.

(Source: Adapted from PWA et al. 1994 and PWA 2003 by Stillwater Sciences 2005a)

From March 1992 to September 1993, flow was continuously monitored in Redwood Creek at the Pacific Way Bridge using an automatic water level recorder (PWA et al. 1994). The NPS has been monitoring flow, with some data gaps, at the Highway 1 Bridge since Water Year (WY) 1998. The NPS also monitored stream level in both main branches of Green Gulch Creek from 2003–2005. In an effort to refine the rating curve at the Highway 1 Bridge (and also to quantify sediment transport rates), the NPS hired an independent contractor to measure flow and suspended sediment concentration during high flow events in WY 2003 and WY 2004 (Stillwater Sciences 2004, EDS 2004). Stage was continuously monitored at Muir Woods Road Bridge during portions of the high flow periods of 2003 and 2004. The timing and location of continuous flow monitoring efforts for Redwood Creek are summarized in Table 2-3. Figure 2-3 shows the location of the gages on a watershed map.

Table 2-3. Continuous Records of Stream Flow for the Redwood Creek Watershed

Dates		Location	Notes	Source
From	To			
Redwood Creek				
March 1992	Sept. 1993	Pacific Way	Discontinued effort	PWA
1998	Present	Highway 1 Bridge	Ongoing, semi-continuous measurements	NPS
January 2003	March 2004	Muir Woods Road	Discontinued effort	EDS
Green Gulch Creek				
2003	2005	Green Gulch Farm	Two gauges, semi-continuous[1]	NPS

1. Data from Green Gulch Creek are semi-quantitative.

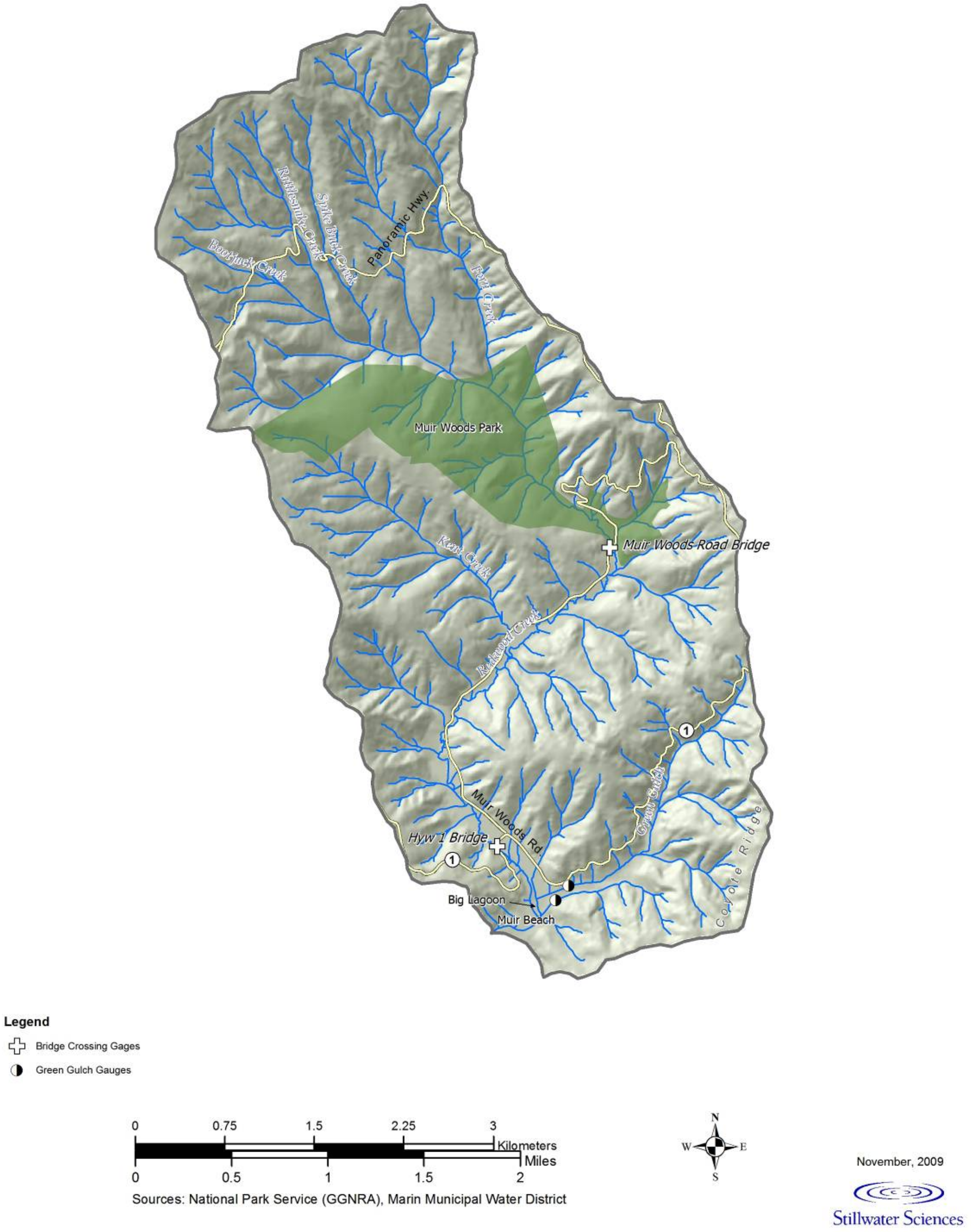
(Sources: PWA 2000, EDS 2004)

Although development of reliable empirical flood frequency estimates for Redwood Creek is limited by the short record of annual peak flows, flood-frequency has been estimated for different locations in Redwood Creek using various methods (Lehre 1974, PWA 2000, JAA 2009, NHE 2010). Lehre (1974) developed a flood-frequency curve for Redwood Creek at Frank Valley Bridge based on 12 years of crest-stage data collected by the USGS from 1962 to 1973. Phillip Williams & Associates (PWA 2000) conducted a flood-frequency analysis for Redwood Creek at the Highway 101 Bridge based on data used by Lehre (1974), as well as annual peak flow data from Arroyo Corte Madera Del Presidio at Mill Valley, CA (USGS No. 11460100) from 1976 to 1985 and Redwood Creek at the Highway 1 Bridge from 1998 to 1999. Northern Hydrology and Engineering (NHE) recently updated flood frequency estimates (NHE 2010) based on several accepted methods, including those established in Bulletin 17B (Interagency Advisory Committee on Water Data 1982), the California regional equations (Waananen and Crippen, 1977), and the weighting methods described in the NSS Program (Ries 2007). Weighted peak flow estimates were made by NHE (2011) for three sites on Redwood Creek: near Tamalpais Valley, at Highway 1 Bridge, and at Pacific Way Bridge (Table 2-4).

Table 2-4. Weighted peak flood-frequency estimates

Location	Weighted estimates for peak flood recurrence interval (cfs)					
	2-yr	**5-yr**	**10-yr**	**25-yr**	**50-yr**	**100-yr**
Redwood Creek at Tamalpais Valley	737	1,295	1,681	2,177	2,549	2,917
Redwood Creek at Highway 1 Bridge	634	1,197	1,629	2,217	2,677	3,148
Redwood Creek at Pacific Way Bridge[1]	647	1,218	1,655	2,248	2,712	3,186

1. Weighted flood-frequency estimate for Redwood Creek at Pacific Way Bridge is based on the composite 31-year record of annual peak flows at the Highway 1 Bridge gaging station
(Source: NHE 2010)



Sources: National Park Service (GGNRA), Marin Municipal Water District

November, 2009

Figure 2-3. Locations of continuous-monitoring stream gauges.

(Source: EDS 2004)

2.4.2 Water Surface Level as a Function of Time

The time series of daily average water surface level data from WY 1999–2005 at the Highway 1 Bridge and Muir Woods Road Bridge gauges are plotted in Figures 2-4 and 2-5, respectively. Many of the stage measurements for the Muir Woods Road Bridge gauge are zero, representing days of sensor operation in which stage never rose above the pressure transducer. These are plotted as red "X" symbols in Figure 2-5 The pressure transducer was located at 104.91 feet NAVD (the North American Vertical Datum of 1988 is the vertical control datum of orthometric height, established for vertical control surveying), or approximately 0.78 inches above the bed at the edge of the creek. Hence stage measurements for "zero-pressure" days are only semi-quantitative. Data gaps in Figures 2-4 and 2-5 represent periods in which the water level sensor was either not installed or installed and not operating.

2.4.3 Stage-Discharge Relationships

To convert the time-series of Figures 2-4 and 2-5 into time series of mean daily flow, it is necessary to first develop site-specific relationships between discharge and stage. Point measurements of stream discharge and stage for some of the Redwood Creek watershed gauges have been repeatedly recorded by NPS personnel and others (EDS 2004) and can be used to develop site-specific stage-discharge relationships as described next.

Highway 1 Bridge

The stage-discharge data at the Highway 1 Bridge site are plotted in Figure 2-6. For a given stage, substantial variability in discharge exists, particularly at low flows. For example, discharge varies by up to three orders of magnitude at stage readings below about 2.5 feet (EDS 2004).

Estimation of discharge from stage using a simple regression analysis of Figure 2-6 data would lead to large uncertainties for the low- to mid-range flows that dominate the time-series of stage data for Redwood Creek. Instead, a stratified analysis of the data is warranted, because substantial shifts have occurred in the relationship between stage and discharge over time. Under the date-based groupings shown in Figure 2-7 for low flows, the data define three distinctly different, non-linear power law relationships of the form

$$\text{stage} = a \times \text{discharge}^{b}$$

where a and b, the power-law intercept and the power-law slope, are fitted regression parameters. Regression statistics are summarized in Table 2-5.

Date-based grouping of data also helps resolve stage-discharge relationships for mid-range flows, as shown in Figure 2-8 (with regression statistics reported in Table 2-5). Two clearly different relationships are apparent for the mid-range flows. Possible reasons for the shift in flow rating curves for low and mid-range flows are discussed in Section 2.4.4.

Paired measurements of flow and stage for high flows are available only for WY 2003–2005. As a result, a rating curve for high-flow conditions only can be constructed for WY 2003–2005. This makes unambiguous identification of shifts in the high-flow rating curve over time impossible. Nevertheless, because both the mid-flow and low-flow curves show substantial offset from one interval to the next, it seems likely that the high flow curve would exhibit an offset as well (if data from the earlier interval were available for comparison). Application of the 2003–2005 high-flow rating curve to the preceding period is not easy to justify.

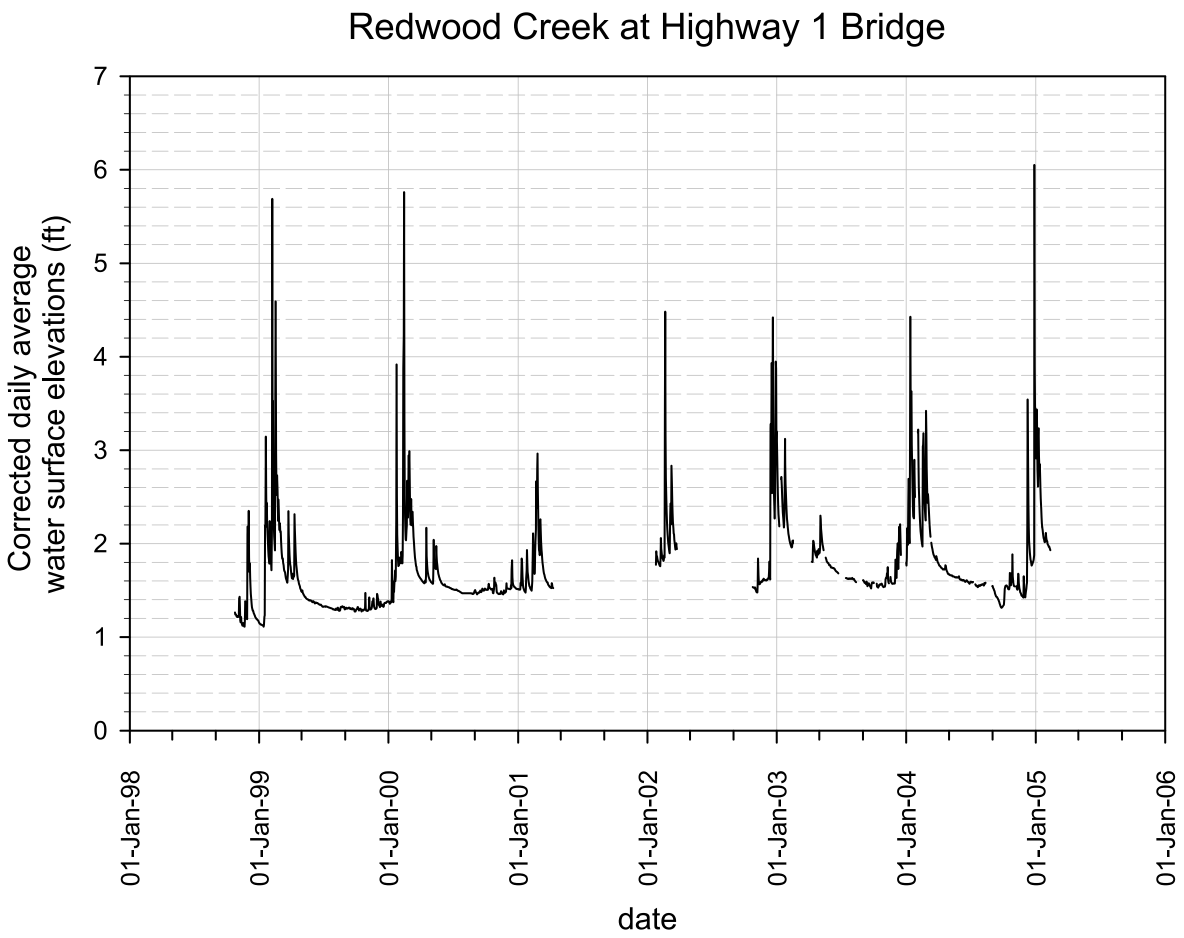


Figure 2-4. Time series of daily average water surface elevations (referenced to the top of the pressure transducer) from Redwood Creek at the Highway 1 Bridge gauge. Data are corrected for sensor drift by interpolation, using sensor calibration measurements that were periodically recorded during site visits by NPS personnel. Gaps are intervals for which no data are available.

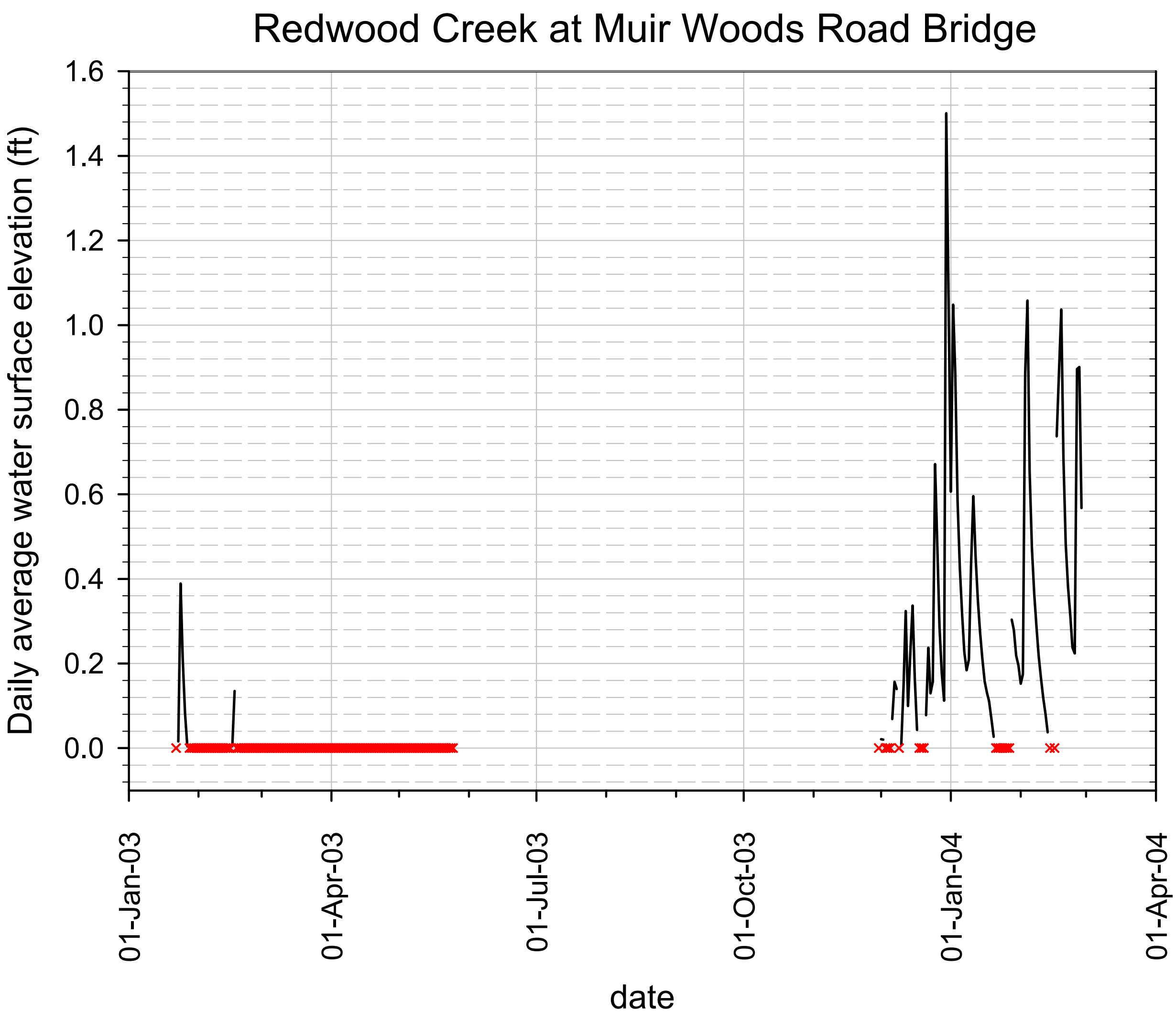


Figure 2-5. Time series of daily average water surface elevation (referenced to the top of the pressure transducer) for Redwood Creek at the Muir Woods Road Bridge gauge. Red "X" symbols mark days of sensor operation in which stage never rose above the sensor (see text). Gaps are intervals for which no data are available (i.e., in periods when the sensor was not operating). (Data source: EDS 2004)

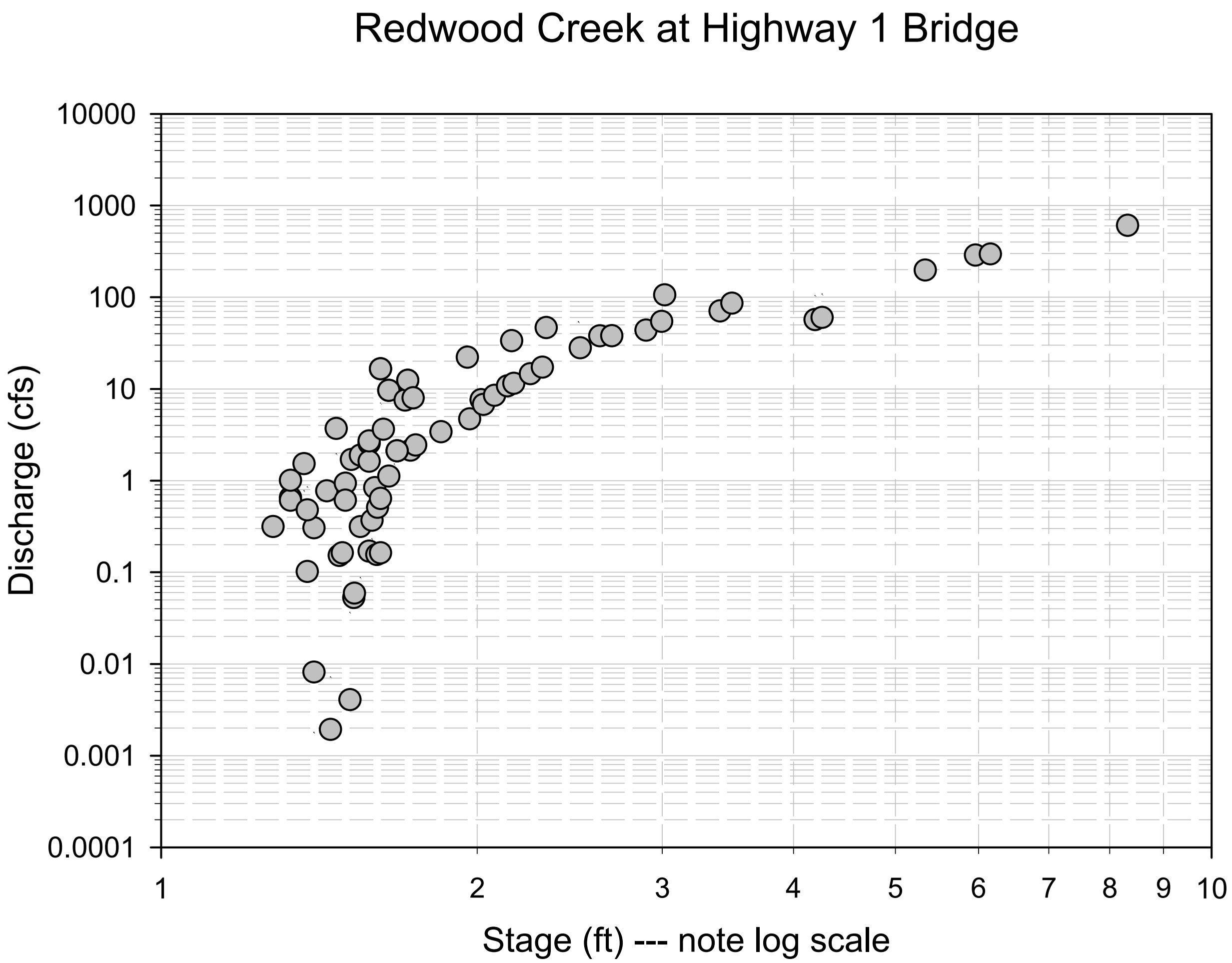


Figure 2-6. Stage-discharge data for Redwood Creek at the Highway 1 Bridge. The data show substantial scatter, particularly at low stages.

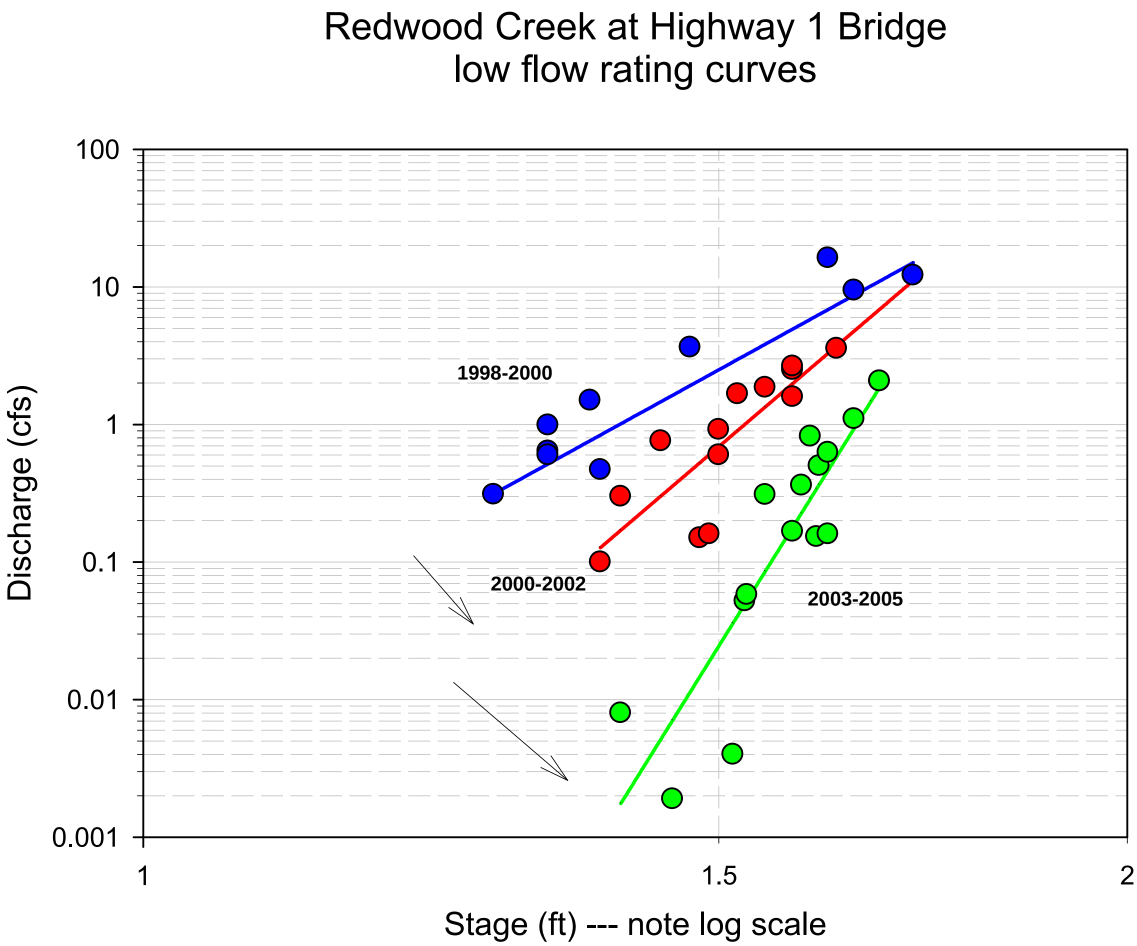


Figure 2-7. Stage-discharge relationships for low flows on Redwood Creek at the Highway 1 Bridge. Blue circles are data from Oct. 1998–Jan. 5, 2000, red circles are data from Jan. 6, 2000–Sept. 30, 2001, and green circles are data from WY 2003–2005. Lines show best fits to data, based on nonlinear regression (see text). The regression analysis produces statistically significant power law relationships (See Table 2-5 for regression statistics).

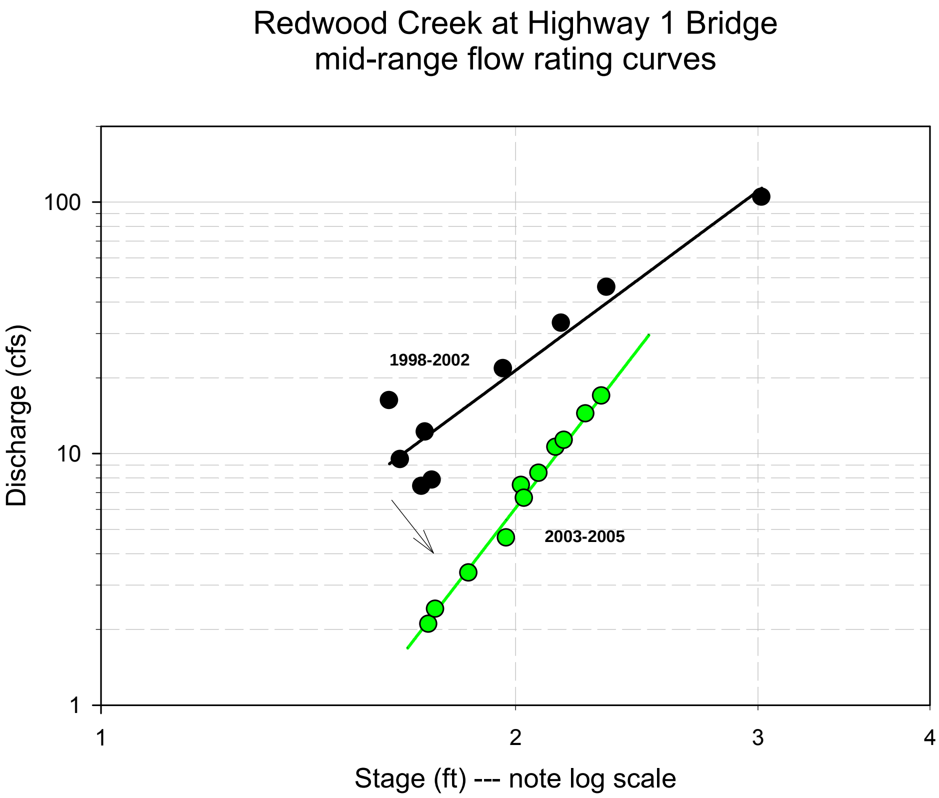


Figure 2-8. Stage-discharge relationships for mid-range flows on Redwood Creek at the Highway 1 Bridge. Black circles are data from Oct. 1, 1998–Sept. 30, 2001 and green circles are data from WY 2003–2005. Lines show best fits to data, based on nonlinear regression (see text). The regression analysis produces statistically significant power law relationships (See Table 2-5 for regression statistics).

The power-law slope of the mid-flow regression for 2003–2005 is significantly steeper than the power-law slope of the 2003–2005 high-flow curve (Figure 2-9), with a clear break in slope at a stage height of approximately 2.5 feet.

In developing an estimate of the high-flow rating curve for 1998–2002, it seems reasonable as part of a first approximation to assume that channel geometry is such that the threshold between high- and mid-flows has remained at the 2.5-foot stage (indicated in Figure 2-9), and that the regression slope from the WY 2003–2005 high-flow curve is applicable to the preceding period. These assumptions permit assessment of a hypothetical stage-discharge relationship that can be used to estimate discharge for high flows of the 1998–2002 interval. The hypothetical line is plotted in Figure 2-10 (dashed black line). The slope and intercept estimates are listed in Table 2-5.

Table 2-5. Stage-Discharge Relationships: Power Law Regression Statistics

Range of Dates with Measurements[1]		Power Law		Curve Applies to Data from Period[2]		Type of Flow with Range of Applicable Stages (H)
From	To	Intercept	Slope	Start	End	
Highway 1 Bridge						
12/5/1998[3]	1/5/2000	12.3×10^{-3} $\pm0.6\times10^{-3}$	13.1 ±1.5	10/25/1998	1/5/2000	Low (H ≤1.67 ft)
3/30/2000	7/16/2001	1.9×10^{-4} $\pm0.5\times10^{-4}$	20.3 ±4.1	1/6/2000	9/30/2002	Low (H ≤1.72 ft)
10/10/2002	12/2/2004	4.6×10^{-9} $\pm3.6\times10^{-9}$	38.2 ±5.1	10/1/2002	2/15/2005[6]	Low (H ≤1.67 ft)
12/5/1998[3]	3/8/2001	1.290 ±0.002	4.1 ±0.6	10/25/1998	9/30/2002	Mid (H ≤2.5 ft)[4]
1/8/2003	2/15/2005	0.0442 ±0.0004	7.1 ±0.23	10/1/2002	2/15/2005[6]	Mid (1.67<H ≤2.5 ft)
--[5]	--[5]	5.9 ±1.4	2.4 ±0.2	10/25/1998	9/30/2002	High (H>2.5 ft)
12/18/2002	2/21/2005	3.33 ±0.03	2.4 ±0.2	10/1/2002	2/15/2005[6]	High (H>2.5 ft)
Muir Woods Road Bridge						
1/24/2003	2/25/2004	125 ±10	0.72 ±0.18	11/28/2003	2/25/2004	All

1. Indicates range of dates for which stage and discharge measurements are available.
2. Indicates period over which the regression statistics apply in the analysis.
3. Stage and discharge measurements from early October 1998 were ignored in this analysis because of complications from hydraulic changes related to removal of a weir at the gauge.
4. Mid-level regression statistics apply to flows with stage H>1.67 feet (0.51 m) and H≤2.5 feet (0.76 m) for 10/25/98 to 1/5/00, and to flows with stage H>1.72 feet (0.52) and H≤2.5 feet (0.76 m) for 1/6/00 to 9/30/02.
5. No stage-discharge data are available for high flows in Water Years 1998–2002.
6. Data after 2/21/2005 are not considered in this analysis because of channel changes (and complications) related to effects of a piece of large woody debris that settled in the channel near the gauge. A new rating curve likely will be necessary for data that post-date 2/21/05.

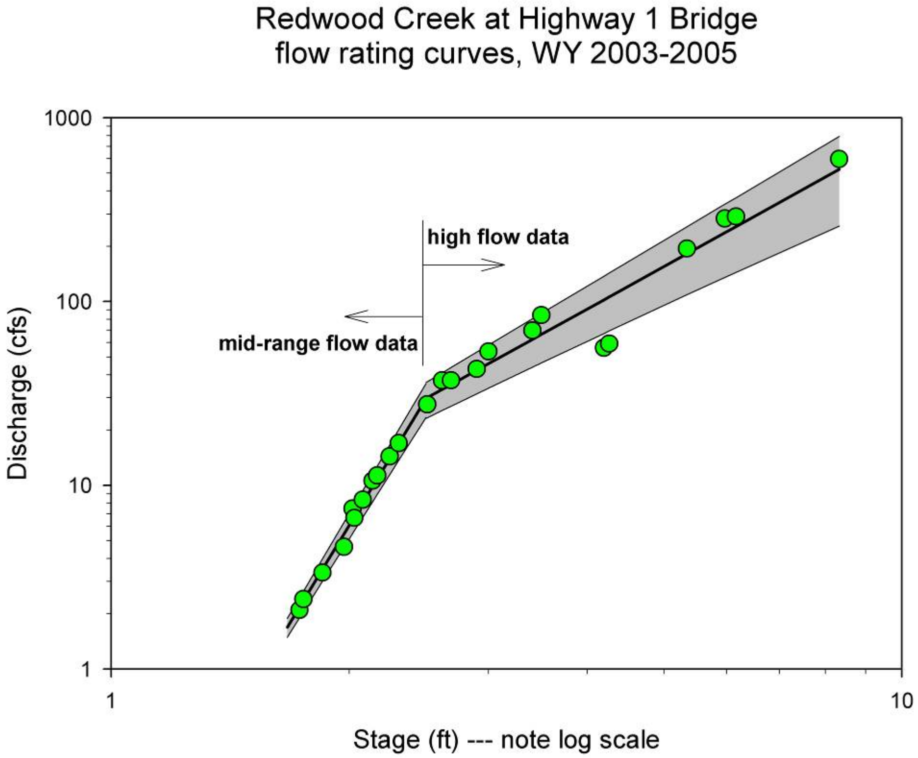


Figure 2-9. High- and mid-range stage-discharge data for Redwood Creek at the Highway 1 Bridge gauge for WY2003–2005. Thick lines through data show best-fit regressions, with uncertainties (shaded areas) propagated from one standard error of the mean of the regression parameters. The mid-range curve has a significantly steeper slope, implying that the hydraulic geometry and roughness of the channel are such that the stage-discharge relationship changes above a threshold stage of about 2.5 ft (0.8 m).

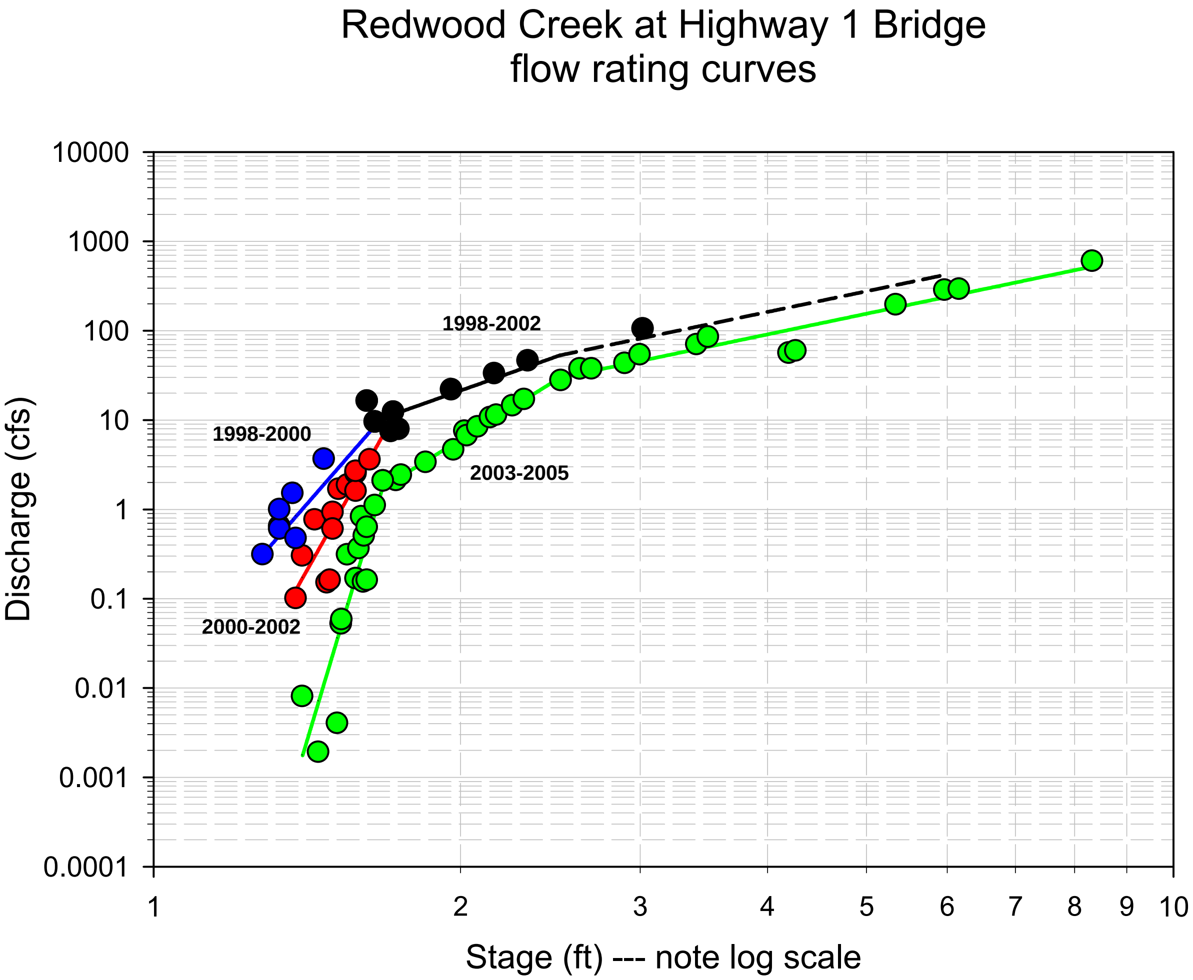


Figure 2-10. Stage-discharge data for Redwood Creek at the Highway 1 Bridge for all flows. Dashed black line shows estimated high-flow curve for 1998–2002.

Muir Woods Road Bridge

Staff plate at Muir Woods Road Bridge

The stage-discharge data for the Muir Woods Road Bridge are plotted in Figure 2-11. Unlike the data from the Highway 1 Bridge, the data from the Muir Woods Road are more or less consistent with a single power-law relationship between stage and discharge. Even if they wer e not, the small sample size (n=6) would have precluded any breakdown of the data into subgroups. The estimated slope and intercept of the power-law relationship are shown in Table 2-5. The significance of the stage-discharge relationship for the Muir Woods Road Bridge may be artificially high because of the grouping of data at low and high stages (with no observations in between).

Green Gulch Creek Gauges

Data from the two gauges in the Green Gulch Creek subwatershed are discontinuous and regarded as semi-quantitative because of technical problems with the pressure transducers (DeBlasi, pers. comm., 2005). One of the Green Gulch Creek gauges is located within the backwater influence of Redwood Creek, making it only minimally diagnostic for flow from the Green Gulch Creek subwatershed.

2.4.4 Potential Causes of Flow Rating Curve Shifts

Changes in cross-sectional area and flow dynamics at a gauge lead to fundamental changes in its stage-discharge relationship. The shift in the flow rating curves shown in Figure 2-10 suggests that the gauge at the Highway 1 Bridge has been prone to substantial changes in channel conditions and flow dynamics over the period of record. This is consistent with anecdotal observations of conditions at the gauge. For example, when the NPS installed the Highway 1 Bridge gauge in 1998, the concrete bottom of the box culvert at the bridge was visible. By fall 2005, it was covered with sediment about 1 foot deep (Shoulders, Ecologist, pers. comm., 2006). At least two plausible explanations exist for the shift in rating curve over time: effects of natural variability in channel geometry and flow dynamics, or effects of modifications in the channel downstream of the gauge.

Effects of Natural Variability in Channel Slope and Shape on the Rating Curve

Channel slope drops from 0.9 percent at the upstream end of Frank Valley to 0.4 percent near the Highway 1 Bridge and drops even more to 0.1 percent further downstream where channel bed material shifts from gravel to sand (Stillwater Sciences 2004). Hence, channel slope and morphology change substantially near the gauge, such that the area may be naturally prone to episodic scour and deposition of sediment during rising and falling flood stages. The apparent shift in the rating curves over time (Figure 2-10) is consistent with progressive aggradation (with decreasing discharge for a given stage as a function of time), which may be a natural response to ongoing delivery of sediment from the upper watershed.

A case in point of natural channel changes at the Highway 1 Bridge gauge occurred after WY 2005 storms, when a large piece of wood began migrating downstream toward the bridge and caused noticeable changes in flow dynamics at the gauge (DeBlasi, pers. comm., 2005). At first, these observations seem to cast doubt on the reliably of data from WY 2005. However, stage-discharge data from the early part of the water year fit within patterns observed for WY 2003–2004, suggesting that changes in WY 2005 were minor, at least until sometime before the March 22, 2005 flow and discharge measurements, when NPS field technicians first included a comment about the wood lodging in sediment near the bridge and affecting flow at the gauge. Precisely when the wood began to affect flow at the gauge is not known. As part of a conservative approach, data from after February 15, 2005 were not considered in this analysis because of the potential effects of the wood on flow dynamics at the gauge. A new set of rating curves will need to be developed for the gauge for post-March 2005 stage data.

Effects of Channel Modifications by Humans on the Rating Curve

As discussed in greater detail in Section 2.4.3, the channel and floodplain in the reach below the Highway 1 Bridge have been extensively modified over the last several decades, resulting in altered channel hydraulics and sediment transport capacity. Human modifications also have reduced floodplain area downstream of the Pacific Way Bridge. These effects, together with delivery of sediment from large storms in the late 1990s and several large log jams downstream of the Pacific Way Bridge, promoted sediment build-up in the channel near the Pacific Way Bridge. The zone of aggradation eventually extended approximately 800 feet downstream of the bridge and grew in depth by 5 feet at the bridge between 1993 and 2002 (Klein et al. 2002). It is possible that the downstream aggradation may have affected flow and sediment transport dynamics further upstream, at the gauge. This may have contributed to the aggradation at the Highway 1 Bridge, and thus may help explain the shift in the flow rating curves from 1998–2002 (Figures 2-7 and 2-10).

In 2002, in response to increased flooding at the Pacific Way Bridge and the increased potential for avulsion to adjacent pastureland, the NPS and Marin County Department of Public Works implemented flood reduction measures, including removal of woody debris jams from the creek and excavation of sediment from 460 lineal feet of creek near the Pacific Way Bridge. These changes generally can be expected to lead to net degradation of the channel—which would be inconsistent with the observed aggradational shifts in the rating curves from 2002–2005 (Figures 2-7, 2-8, and 2-10). However, the remedial measures of 2002 were unable to remove a log jam which was preventing the creek from occupying the larger of its two channels downstream of the Pacific Way Bridge. This may have contributed to the continued aggradation, shown in a post-2002 time series of creek profiles (EDS 2005) to have reached pre-dredging levels at the bridge by summer 2004. The NPS responded to the observed aggradation by removing the wood jams that were blocking the right fork of the channel, and by excavating 2–3 feet of fine sediment from another 150 linear feet of channel. During the first storm after the 2004 dredging and wood removal, the mainstem of the creek reoccupied its right fork. This appeared to allow moderate flows to recede more quickly; however, a February 2005 profile for the bridge area shows that even more aggradation occurred there (Fong, pers. comm., 2006). A 40-foot-long log jam adjacent to the low-flow channel near the Muir Beach parking lot was removed in October 2005. In October 2005, the NPS also removed most of the fill pad that served as the visitor picnic area. This substantially added to the creek’s floodplain width at that point.

Because most of the post-2002 modifications were focused downstream of the Highway 1 Bridge (where flooding and economic impacts were greatest), it is not clear whether they could have affected the stage-discharge relationship at the gauge. It is possible that the post-2002 modifications had no effect on the trend of aggradation at the Highway 1 Bridge.

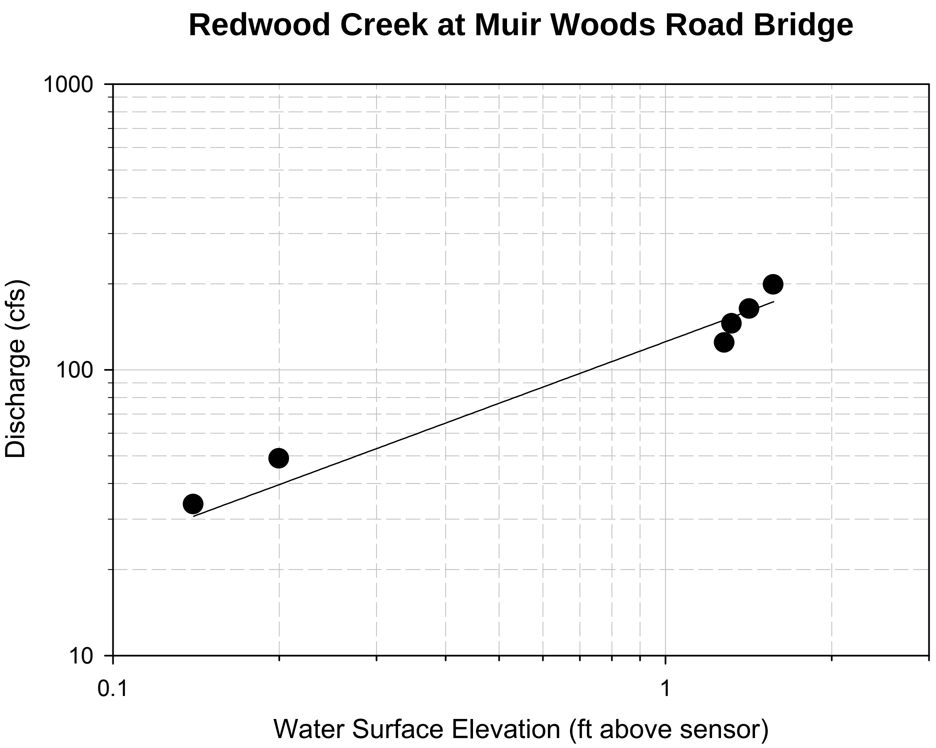


Figure 2-11. Stage-discharge relationship for the Muir Woods Road Bridge gauge. (Data source: EDS 2004)

2.4.5 Discharge as a Function of Time

Using the stage-discharge relationships developed in Section 2.4.3, time series of discharge were developed from the time series of stage measurements from each gauge.

Highway 1 Bridge

The time-series of mean daily flows for the Highway 1 Bridge gauge for October 25, 1998–February 15, 2005 are plotted in Figure 2-12. Annual peak mean daily flow ranges from 80 to approximately 390 cubic feet per second (cfs, or to approximately 11 cubic meters s-l [m^3s^{-1}]) and were highest in WY 1999 and 2000.

Figures 2-13 and 2-14 show subsets of data from Figure 2-12 and include uncertainties estimated from the power-law regression parameters of Table 2-5. Figure 2-13 shows mean daily flow for the wet season of WY 2004, a year with a relatively low peak mean daily flow, and Figure 2-14 shows mean daily flow for WY 1999, a year with a relatively high peak mean daily flow.

Muir Woods Road Bridge

The time series for mean daily flow at the Muir Woods Road Bridge is plotted in Figure 2-15. The record for the Muir Woods Road Bridge gauge is much shorter than the record for Highway 1 Bridge. Nevertheless, data from the two gauges can be compared to determine whether a correlation exists between the two data sets for the overlapping period of record. Figure 2-16 shows mean daily flow at the Muir Woods Road Bridge, plotted against mean daily flow for the Highway 1 Bridge. No correlation exists between the data for the overlapping period of record. If a strong correlation did exist, it might have been possible to use the relationship to scale daily flow from the Highway 1 Bridge gauge to the Muir Woods Road Bridge gauge, and thus greatly expand the interval of flow estimates for the Muir Woods Road Bridge.

The lack of correlation of Figure 2-16 could result from the spatial variations in precipitation rates across the watershed (which would lead to variations in relative contributions of flow from tributaries, such as Kent Canyon Creek, from storm to storm). It might instead be caused by differences in hydrologic response related to intrinsic differences in contributing areas. For example, it is possible that steep areas upstream of Muir Woods Road Bridge, with their thin soils, have quicker saturation and delivery of flow, in comparison to the thick alluvial fills of Frank Valley immediately upstream of the Highway 1 Bridge. The relative importance of these factors is difficult to determine in the absence of quantitative data on spatial variability in precipitation and flood response characteristics of contributing watershed areas.

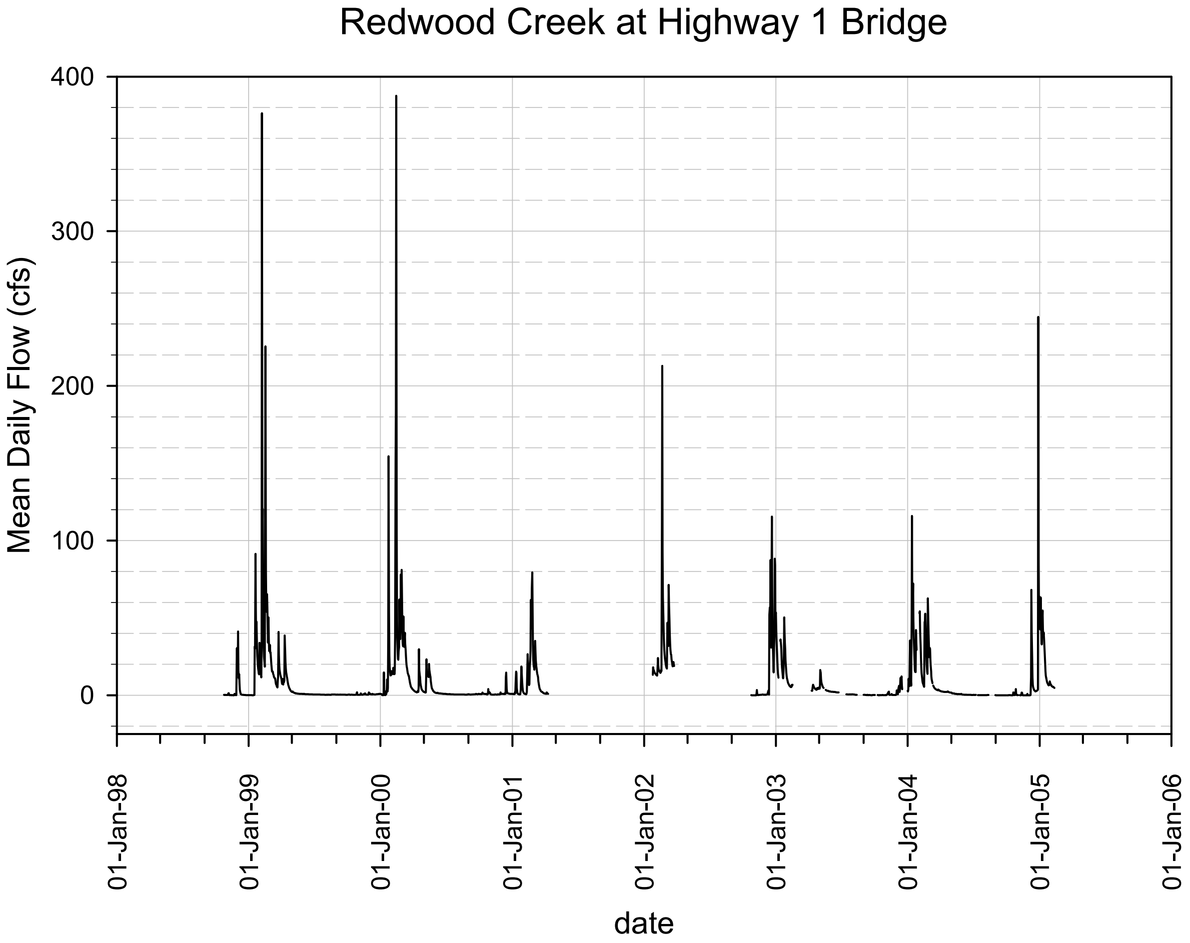


Figure 2-12. Time series of mean daily flows for Redwood Creek at the Highway 1 Bridge gauge. High flows (i.e., greater than about 100 cfs [2.8 m^3s^{-1}] from before January 2002 have high uncertainties, due to a lack of corroboratory data for the assumed high flow-rating curve.

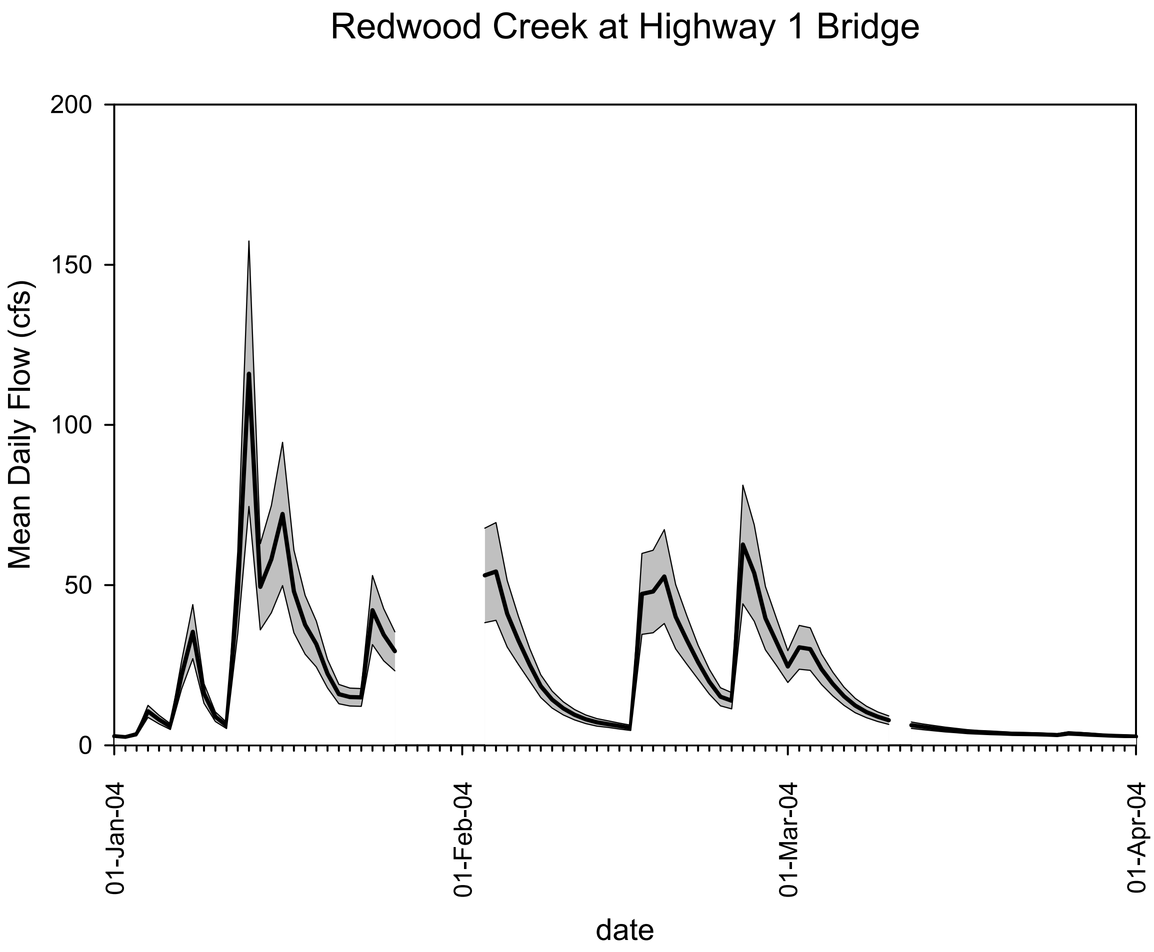


Figure 2-13. Mean daily flow for the wet season of WY 2004, a year with a relatively low peak mean daily flow. Shaded area shows uncertainty in mean daily flow, propagated from uncertainties in regression parameter estimates. Upper and lower confidence intervals are calculated from the mean (thick line) ± one standard error.

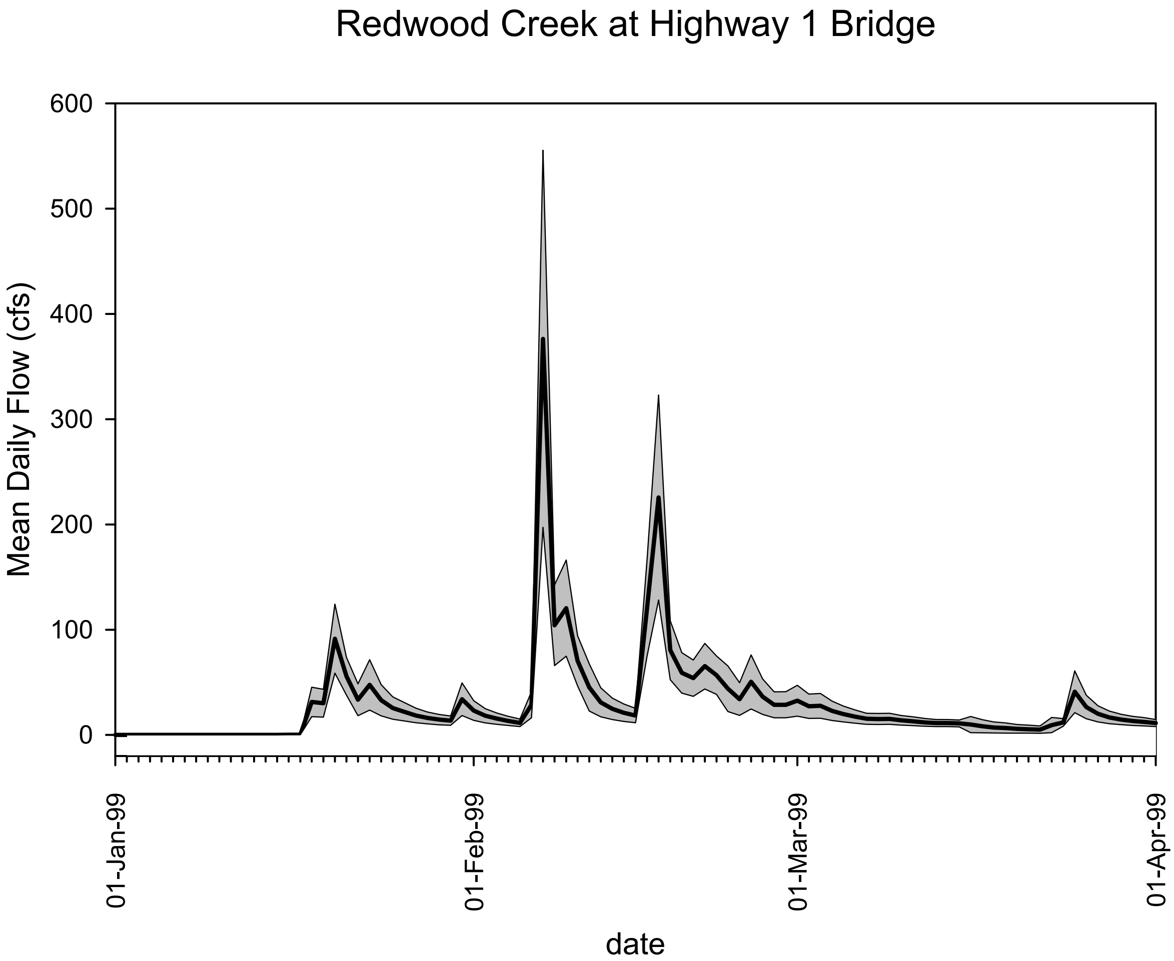


Figure 2-14. Mean daily flow for the wet season of WY 1999, a year with a relatively high peak mean daily flow. Shaded area shows uncertainty in mean daily flow, propagated from uncertainties in regression parameter estimates. Upper and lower confidence intervals are calculated from the mean (thick line) ± one standard error.

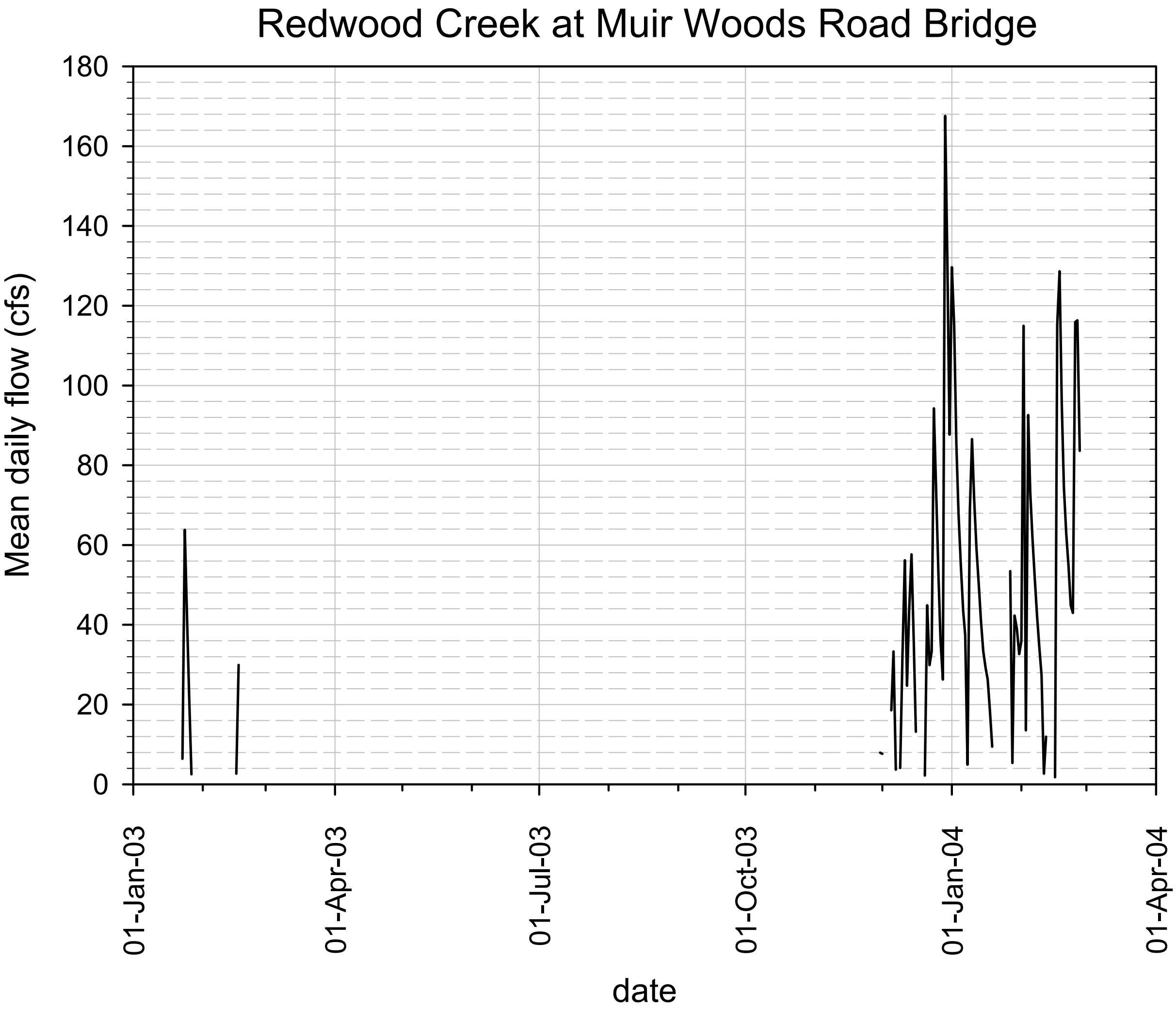


Figure 2-15. Time series of mean daily flows for Redwood Creek at the Muir Woods Road Bridge gauge based on the stage data of Figure 6 and the rating curves of Figure 12.

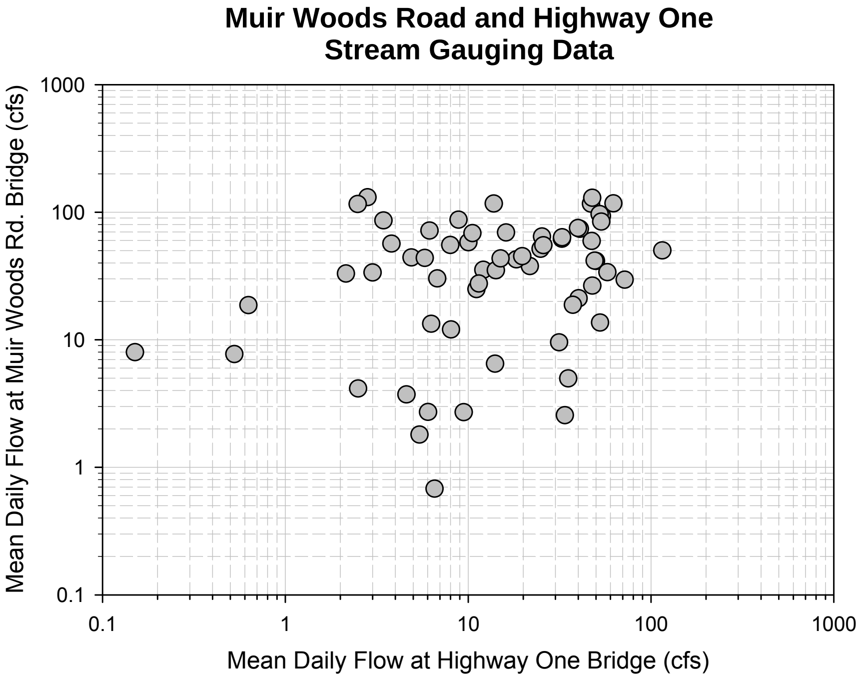


Figure 2-16. Mean daily flow at Muir Woods Road Bridge plotted against mean daily flow at the Highway 1 Bridge.

2.4.6 Peak Flows and Seasonality

Flow in Redwood Creek varies seasonally with precipitation (Figure 2-17). Low flow in the summer and fall typically are in the range of 0 to 1 cfs (0 to 0.03 m^3s^{-1}) at the Highway 1 Bridge. Winter baseflow, between storm events, typically is between 1 and 10 cfs (0.03 and 0.3 m^3s^{-1}), with short-duration, peak flows of 100 to 1,000 cfs (28 to 280 m^3s^{-1}) during winter storms. Annual peak flows for the analyzed period of record are listed in Table 2-6. The stage record for the WY 2002 wet season is incomplete, raising the possibility that the annual peak flood was not recorded (and is higher than the value listed in Table 2-6). Some indication exists that this may be the case, based on an inspection of the precipitation record shown in Figure 2-17; daily rainfall totals were often higher than 1 inch/day from late November through December 2001, and undoubtedly contributed to increased flows in the creek. However, whether flows rose above the 399 cfs (11.3 m^3s^{-1}), reported in Table 2-6, is difficult to determine in the absence of stage measurements for late 2001. The uncertainties in the peak floods for 1998–2002 are high, but difficult to quantify because of a lack of corroboratory data for the hypothetical high-flow rating curve for WY 1999–2002. Along with flood magnitude, Table 2-6 also lists each peak flood’s estimated return period—based on the peak flood-recurrence interval relationship generated in previous work (PWA 2000). Peak flow from WY 1999–2005 imply return intervals of 1 to 2 years, which is more or less the range to be expected, given the short sampling interval and the fact that annual rainfall was within about 20 percent of the 65-year average from 1999–2005 (Figure 2-1).

Table 2-6. Annual Peak Instantaneous Floods at Highway 1 Bridge, Water Year 1999–2005

Date	Water Year	Instantaneous Magnitude (cfs)	Implied Return Period[1] (years)
2/16/1999	1999	794	1.95
2/14/2000	2000	804	2
2/21/2001	2001	112	1
2/19/2002	2002	399[2]	1.15
12/12/2002	2003	268	1.05
1/11/2004	2004	540[3]	1.5
12/27/2004	2005	639	1.6

1. Based on peak flood-recurrence interval relationship as plotted in PWA 2000 (their Figure 7) and summarized in Table 2-4.
2. The record for the Water Year 2002 wet season is incomplete, raising the possibility that the annual peak flood was higher (but not recorded).
3. According to anecdotal accounts of the extent of flooding on the Banducci floodplain, it appears that December 30, 2003 and January 1, 2004 flood levels were higher than they were on January 11, 2004. Although data from the Muir Woods Road Bridge gauge (EDS 2004) confirm that this is the case, data are not available for the Highway 1 Bridge for either December 30, 2003 or January 1, 2004. This makes the magnitude of the peak instantaneous flood for Water Year 2004 a minimum estimate.

(Source: Data compiled by Stillwater Sciences)

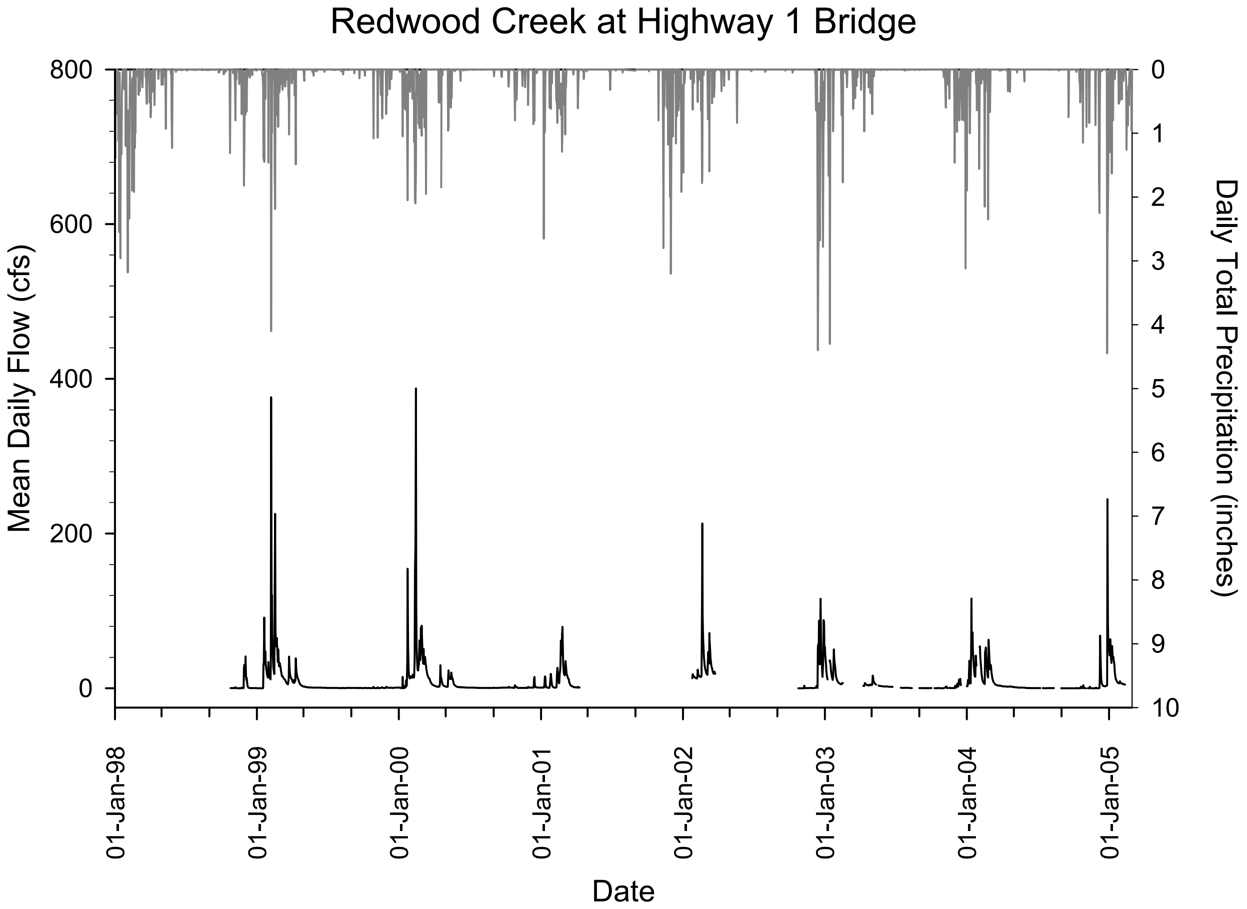


Figure 2-17. Mean daily flow at the Highway 1 Bridge (left axis, black line) and total daily precipitation at the Muir Woods rain gauge (right axis, gray line) plotted for the analyzed period of record.

2.4.7 Uncertainties in Flow Estimates

As noted in the discussion of Figures 2-6 through 2-10, the combined set of stage-discharge data for the Highway 1 Bridge gauge show wide scatter on a log-log plot, with clear relationships emerging only when the data are grouped by date. However, even when the data are grouped by date, residual scatter exists in the relationships between stage and discharge, particularly at low flows (Figure 2-7). One reason for this may be unreported (and difficult to quantify) uncertainties in the flow measurements themselves. When flows are low, velocities are also low and are difficult to measure precisely, even with well-calibrated current meters. Uncertainties in flow measurements are generally expected to be highest (on a percent-of-the-total basis) for low-flow measurements because of relatively high percent errors in velocity measurements. One way to assess this kind of measurement uncertainty is to measure flow repeatedly at times when flow is not changing much. The extent to which such repeated flow estimates differ from one another is a reflection of the uncertainty in the measurements.

The magnitude of low flows may be an important limiting factor for the sustainability of the creek's aquatic ecosystem. Therefore, assessment of a better-defined relationship between stage and discharge for low flows should be a priority of future work at the gauge.

Quantifying discharge at high flows also is important because the vast majority of the creek's total flow occurs during the high-flow season, between October 1 and April 30. Thus, an additional priority for ongoing maintenance of the gauge is higher frequency collection of discharge measurements at high flows, to better define the relationship between stage and discharge at high flows.

Daily peak instantaneous water surface elevations were available for all years (making development of Table 2-6 possible). However, some important inconsistencies occurred in the other types of data that were available for the period of record. In particular, the stage data supplied by the NPS for the Highway 1 Bridge gauge for some water years consisted of daily average estimates of stage, while data for other water years included instantaneous measurements of stage recorded every 15 minutes. For consistency in their analysis of the flow data, Stillwater Sciences (2005b) converted the 15-minute data into daily average water surface levels (Figure 2-4), and then calculated mean daily flows for each day using the instantaneous flow rating curves (Figure 2-10).

Errors are introduced into mean daily flows calculated in this way. In general, if some quantity of interest (in this case flow) is calculated from a nonlinear function of another quantity (in this case stage), the average value of the quantity of interest will not be equal to the function evaluated at the average of the other quantity (Ang and Tang 1975). Therefore, because of nonlinearities in the stage-discharge relationships, mean daily flows calculated directly from instantaneous measurements of stage will differ somewhat from mean daily flows calculated from average measurements of stage. This is shown in Figure 2-18 for data from WY 2005 at the Highway 1 Bridge. Data that plot above or below the 1:1 line shown in Figure 2-18 are estimates with errors that were introduced by the methods used in the analysis.

If 15-minute data were available for the entire dataset, the correct approach would have been to convert the 15-minute stage data into a time series of 15-minute flow data (rather than average the stage measurements by day), and then estimate mean daily flows by averaging flows by day. Nevertheless, the approach that Stillwater Sciences (2005b) used is appropriate for two reasons. First, it is the only approach that can be applied consistently for the entire dataset (because some 15-minute data were not made available). Second, most of the errors in the mean daily flow measurements are small and occur at low flows (Figure 2-18), and thus have minimal implications for the analysis. Even so, as a general rule for future analyses of Redwood Creek stream flow, time-averaging of flow data (to generate mean daily flow estimates, for example) should be carried out only after instantaneous discharge is inferred directly from instantaneous measurements of stage.

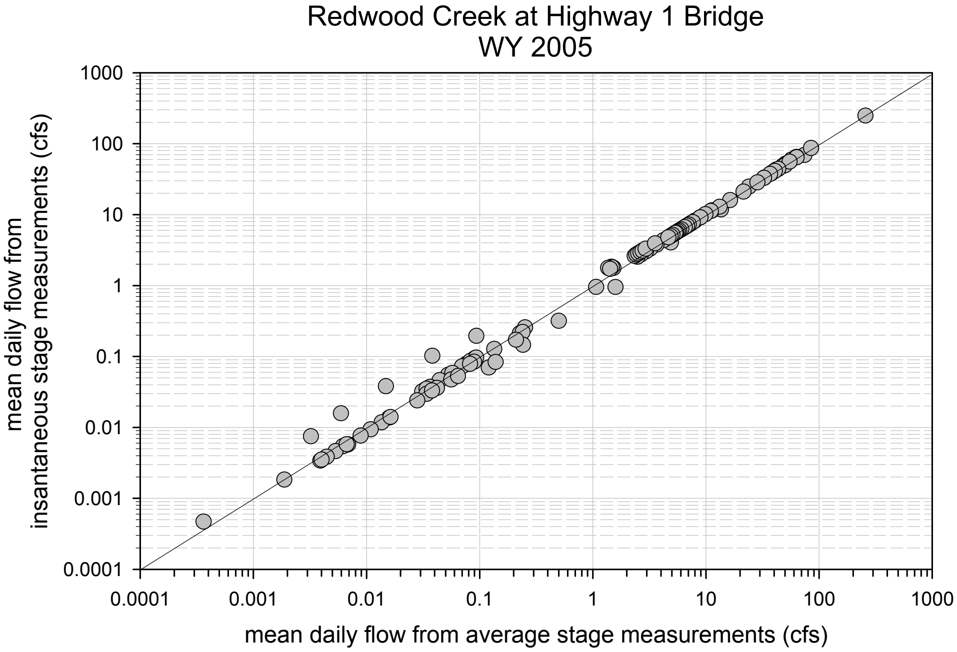


Figure 2-18. Mean daily flows, calculated from instantaneous measurements of discharge, plotted against mean daily flows, calculated from average measurements of discharge, for WY2005 at the Highway 1 Bridge. Data that plot above or below the 1:1 line are estimates with errors introduced by the methods used in this analysis.

2.4.8 Flow Diversions

Water is diverted directly from Redwood Creek and its tributaries by the MMWD and Green Gulch Farm (Johns 1993, PWA 1995, Martin 2000). The MMWD has rights to divert water at seven locations in the upper watershed, on Fern, Laguna, Spike Buck, and West Fork Rattlesnake creeks; the total water quantity associated with these rights are not precisely known (Johns 1993) (Figure 2-19). Diversions on Fern and Laguna creeks supply the West Point Inn (an overnight lodge on the upper south slope of Mt. Tamalpais). The West Fork Rattlesnake Creek diversion and groundwater wells supply water for Mt. Tamalpais State Park at Mt. Tamalpais Lookout, the Mountain Theater, Camp Alice Eastwood, and residences at Kent Canyon. Other diversions, marked on Figure 2-19 with black-centered circles, have not been used in recent years. The MMWD supplies water to Muir Woods National Monument and residences in Muir Woods Park from sources outside of the watershed. Camp Hillwood, in Camino del Canon, maintains a water tank for fire protection, with water drawn from a tributary. The Banducci residence in Frank Valley currently receives its domestic water supply from MMWD. (Continual sampling of their spring in the drainage west of the main house showed contaminants so service to the MMWD water was provided (Bjelajac, pers. comm., 2011).

Green Gulch Farm has developed an elaborate system of reservoirs to store and divert flow from Green Gulch Creek and its tributaries for irrigation, stock watering, fire protection, recreation, and domestic use. This system includes five small reservoirs, diversions on the mainstem Green Gulch Creek, and two reservoirs on tributaries to the creek. The farm has a state water right for diversion of 17 acre-feet per year from the mainstem of Redwood Creek. The farm also has an unused diversion on Redwood Creek in Big Lagoon, with an annual right to 47 acre-feet, contingent on withdrawal between April 15 and September 30 (Johns 1993). The farm’s domestic water supply is derived primarily from a spring on an unnamed tributary northeast of its visitor parking lot. Water is stored in a 20,000 gallon tank. Two other springs that previously supplied drinking water dried up in about 1997. A new back-up groundwater well was installed at the edge of the Green Gulch fields in about 2000.

The MBCSD supplies water to the Muir Beach community, serving approximately 350 people through 147 connections, and withdrawing up to 50.6 acre-feet per year (SWRCB 2001, Martin 2000). The MBCSD operates two wells on the Redwood Creek floodplain near the Banducci property. These wells are located approximately 100 feet from the channel edge and extend 36 and 59 feet below ground into unconsolidated alluvium (MBCWD 2011). In 2001, the MBCSD received a permit from the State Water Resources Control Board (SWRCB) to withdraw up to 50.6 acre-feet per year of water from the hyporheic zone into which the District well extends (“Redwood Creek underflow”) (SWRCB 2001, MBCSD 2005). Acquisition of the MBCSD water rights permit required development and implementation of the *Adaptive Management Plan* (AMP) with assistance from the Technical Advisory Committee (MBCSD 2005). The AMP includes a water conservation plan, a streamflow monitoring plan, and a pumping schedule, to protect instream flows for salmonids during critical low flow periods. According to the AMP, when reduced flow begins to affect the continuity of pools (creating adverse conditions for salmonids), the MBCSD must reduce its pumping rate from an average of about 45,000 gallons per day (gpd) to no more than 35,000 gpd, and enforced water conservation measures must go into effect. The AMP also required that the MBCSD increase its storage capacity (from 250,000 gallons to 300,000 gallons) and explore funding possibilities for additional increases in storage capacity, to permit reduced pumping during low flow periods.

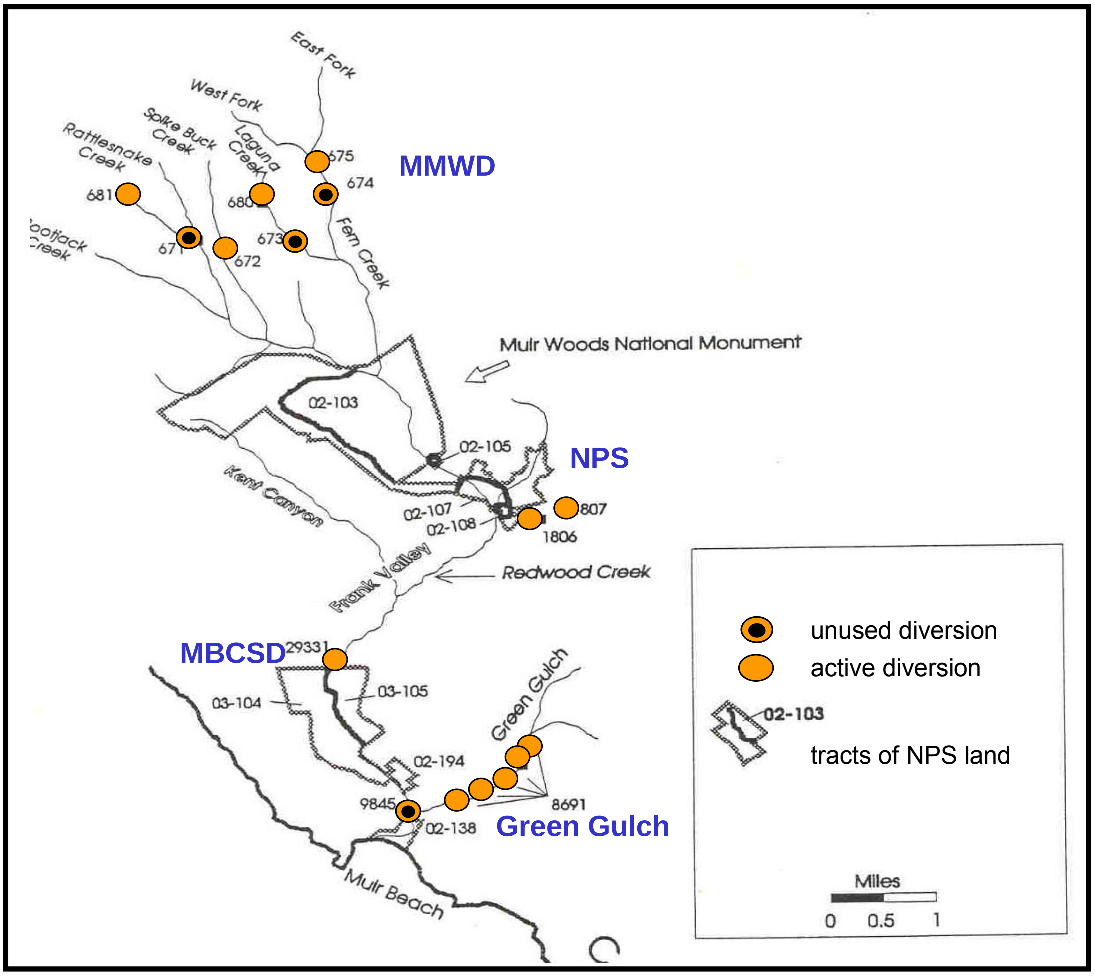


Figure 2-19. Active and unused water diversions in the Redwood Creek watershed. (Source: Johns 1993)

The District obtained permits and constructed a new tank adjacent to the original water storage tank on Seascape Drive above Muir Beach, with a 200,000 gallon capacity during summer 2010; funding came from community self-imposed parcel taxes. The existing tank is 150,000 gallons, the replacement tank capacity is 200,000 gallons, and along with the Lower Tank at 100,000 gallons capacity, current storage capacity for the District is 450,000 gallons. At 35,000 gallons per day consumption during noticed conservation periods, the Muir Beach Community would be able to go for approximately 12 days with no pumping or 24 days with a 50 percent reduction in pumping based on their current capacity, with no additional water stored in case of an end-of-season fire. The District would require additional outside funding to create greater storage capacity (e.g., 1.8 million gallons was identified as necessary to eliminate well pumping during the 45-day driest period of the year) or a desalination facility. Voluntary water conservation is encouraged via annual reminders.

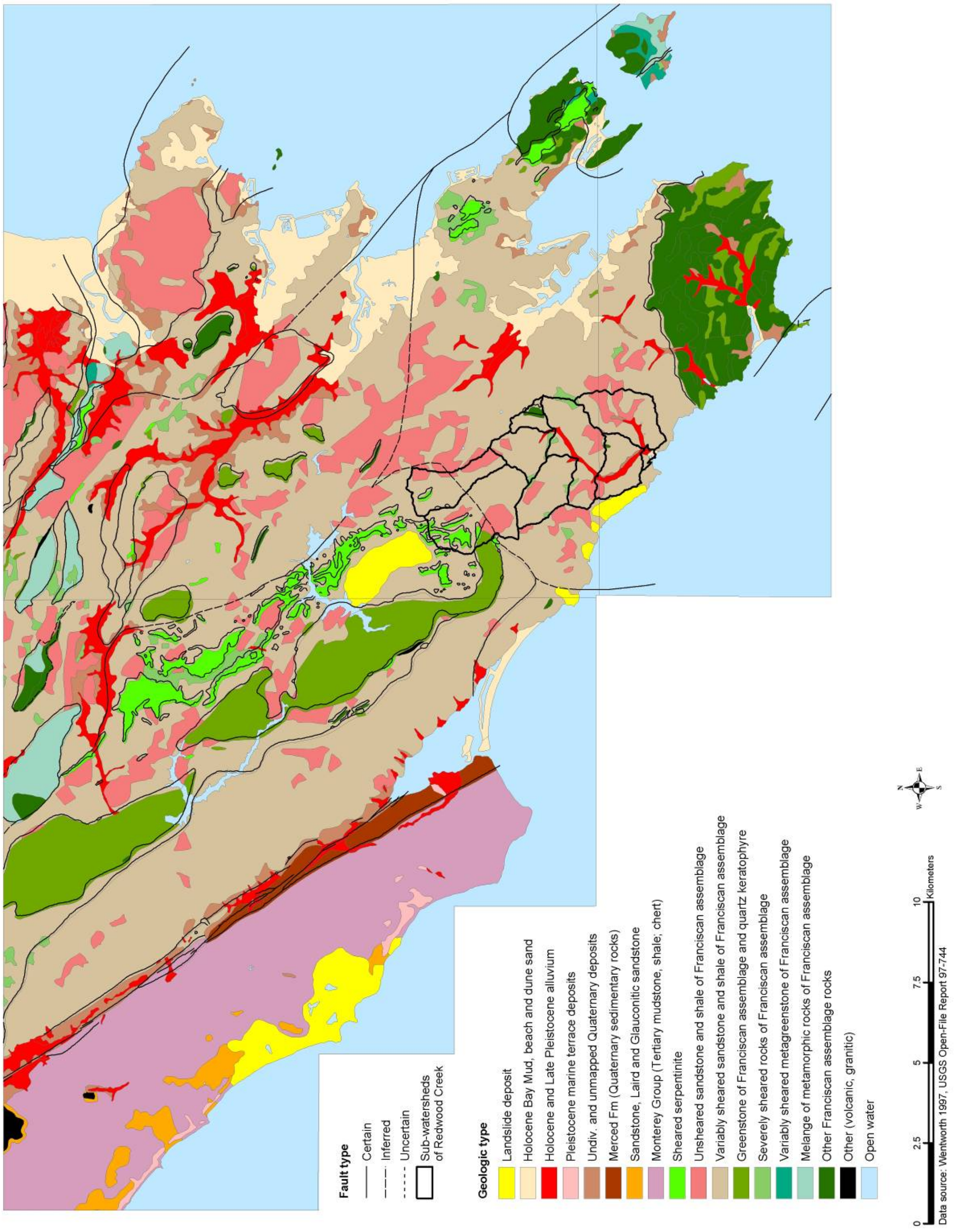
2.5 Geology and Geomorphic Processes

2.5.1 Geology and Soils

The Marin Headlands are part of the California Coast Ranges, which formed over the last several million years in response to crustal shortening associated with compression between the Pacific and North America tectonic plates (Wahrhaftig 1994). Most of the Redwood Creek watershed is underlain by rocks of the Franciscan accretionary assemblage (Figure 2-20), a highly deformed mixture of sedimentary, metamorphic, and igneous rocks of late Jurassic and Cretaceous marine origin (Wahrhaftig 1994, Blake et al. 2000). Incoherent shale and sandstone dominate (Figure 2-21), with slopes that tend to be highly susceptible to landsliding and debris flows. Occasional blocks of bedded limestone and chert occur in the watershed, as do coherent blocks of greywacke, a type of sandstone and serpentine (Blake et al. 2000).

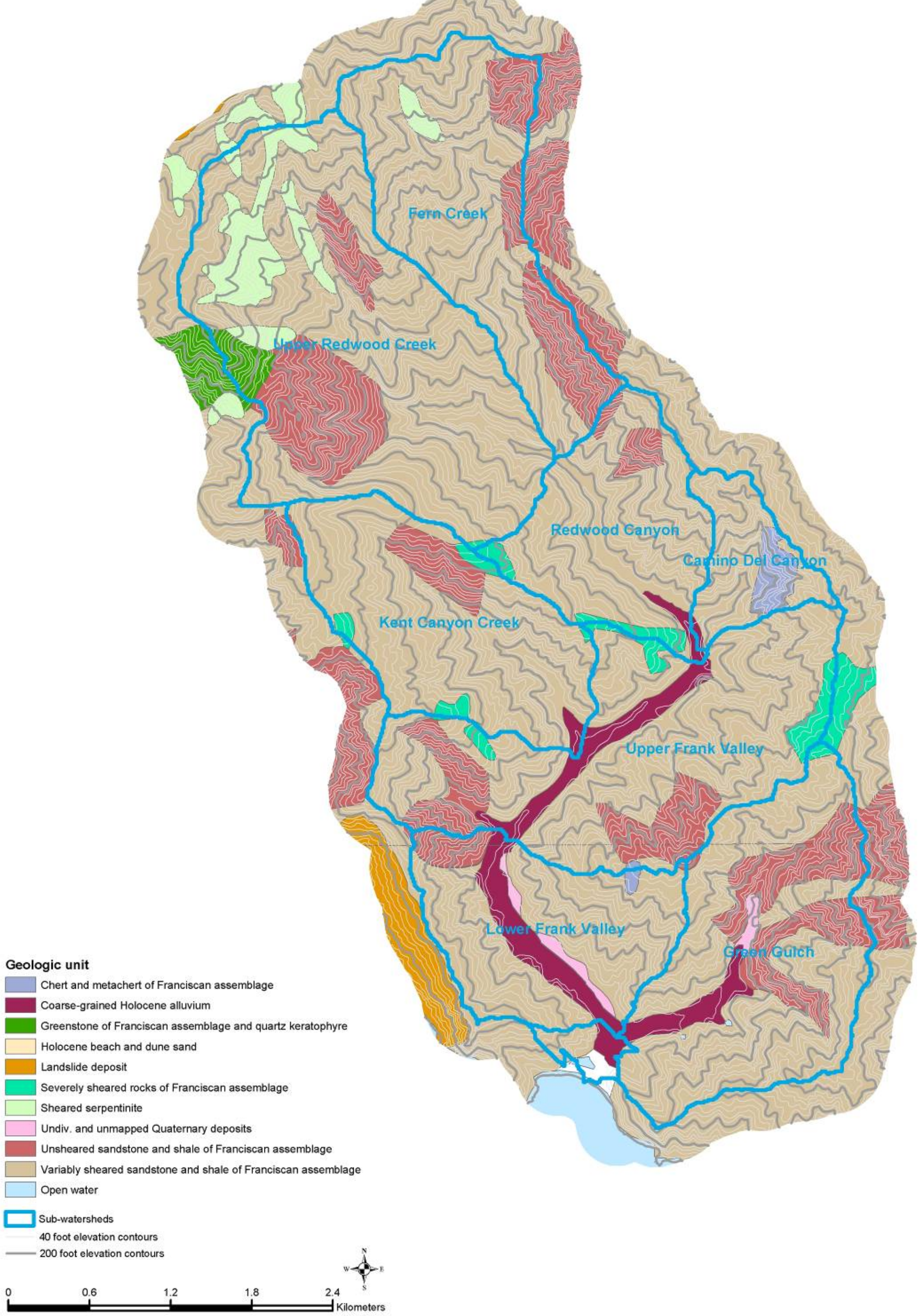
In the headwaters, bedrock weathers to a thin (1 foot), gravelly loam (U.S. Department of Agriculture, Natural Resources Conservation Service's Soil Survey Geographic classification) directly overlying bedrock. Lower in the watershed, surface soils are clay loams that give way to clay at depth, and ultimately to bedrock. The Frank Valley floor is covered in Quaternary alluvial fill, which presumably accumulated in response to rising base level associated with sea level rise over the last 10,000–15,000 years (Figure 2-21). Extensive alluvial deposits also occur in the lower part of Green Gulch Creek, upstream of the Big Lagoon area. Exposures reveal that the floodplain deposits are dominated by fine loam, which is interspersed with layers of fine gravel that increase in frequency and grain size with depth. The mainstem alluvial valley fill in lower Frank Valley is at least 37 feet deep, and may be locally as deep as 90 feet (Laudon 1988, as cited in PWA 2000; Martin 2000). Muir Beach is a Holocene beach and sand deposits at the mouth of Redwood Creek (Figure 2-21).

Just offshore, the San Andreas Fault forms the strike-slip boundary between the Pacific and North America tectonic plates, running along an approximately north-by-northwest trend. Since the early 1900s, ruptures on the San Andreas Fault system have produced locally three large (magnitude greater than 6.5) earthquakes, including "The Great San Francisco Quake" of 1906 and the Loma Prieta earthquake of 1989.



Data source: Wentworth 1997, USGS Open-File Report 97-744

Figure 2-20. Generalized map of geology and faults: Marin Peninsula, California. (Source: Wentworth 1997, as presented by Stillwater Sciences 2004)



Data source: Wentworth 1997, USGS Open-File Report 97-744

Figure 2-21. Watershed geology.(Source: Wentworth 1997, as presented by Stillwater Sciences 2004)

2.5.2 Geomorphic Processes

Geomorphic processes in Coast Range watersheds can be grouped into two main categories, according to whether they are induced by natural processes or human disturbances (Table 2-7). A suite of processes can be identified under each category, with different processes occurring preferentially in certain areas of the watershed (Table 2-7). For example, production of sediment occurs in upper watershed areas by conversion of bedrock to soil, whereas sediment transport on slopes is generally accomplished by a combination of mass wasting processes including soil creep, biogenic transport (e.g., tree-throw, rooting, and animal burrowing) and shallow landsliding (Stillwater Sciences 2004).

Sediment delivery from hillslopes in the Redwood Creek watershed occurs primarily by mass movements in the forms of landsliding and debris flows. Roughly 46 percent of the watershed's hillslope surfaces have been mapped as landslide deposits (Wentworth et al. 1997). El Niño storms in January 1982 triggered 20 debris flows in the Redwood Creek watershed, with a majority occurring in the Green Gulch subwatershed, a tributary canyon upstream of the Banducci property, and in the Camino del Canon subwatershed. In January 1997, heavy rainfall triggered a large landslide which blocked the Camino del Canon road. Rains in 1997 also destabilized the slope behind the Muir Woods concession building, causing failure of an old dirt road, which made notable contributions of sediment to Redwood Creek. Landslides on watershed slopes sometimes do not affect sediment delivery to the Redwood Creek mainstem because of a lack of connectivity between the landslide and the channel network (Stillwater Sciences 2004). Hillslope processes are described in greater detail in Section 2.4.4. A shaded relief topographic map of the watershed is shown in Figure 2-22.

Table 2-7. Sediment Production and Transport Processes of Watersheds of the California Coast Range

Category	Process
Natural Processes	
Production of sediment	o Conversion of underlying bedrock to soil mantle
	o Landsliding of bedrock
	o Scree generation
Hillslope mass wasting processes (mostly sediment delivery)	o Creep and biogenic transport
	o Shallow landsliding
	o Deep-seated landsliding
Hillslope overland flow erosion	o Sheetwash, rainsplash, and rill erosion
Channel incision processes	o Channel head advance
	o Gully incision
	o Bank erosion
	o Mainstem incision
Channel sediment routing and storage	o Sediment transport
Human Disturbances	
Road-related	o Cut and sidecast failures
	o Surface wash
	o Bed surface erosion
	o Crossing failures
	o Drainage gullying and slope destabilization
	o Accelerated runoff and channel destabilization
Agricultural	o Surface wash rilling and gullying
	o Accelerated runoff and channel destabilization
	o Hillslope vegetation removal and landsliding
	o Riparian vegetation removal and channel destabilization
Urban	o Construction phase sediment pulse
	o Connection of drainage network
	o Post-construction low sediment and accelerated runoff
Channel management	o Channel destabilization via straightening and relocation
	o Channel destabilization via LWD removal
	o Sediment reduction through bank revetment, dams

Source: Stillwater Sciences 2004

Data sources:
Elevation - USGS 1: 24,000 DLG data
Streams - USGS 1: 24,000 DLG data
Stillwater Sciences modeled network

Figure 2-22. Shaded-relief topographic map of the Redwood Creek watershed. (Adapted from Stillwater Sciences 2004)

2.5.3 Channel Morphology

A digital elevation model with an assumed channel initiation threshold of 2.5 acres indicates that the watershed contains 76 miles of channel and has a drainage density of 5.4 mi/mi^2. Low-order headwater streams coalesce into several major tributaries including Bootjack, Rattlesnake, Spike Buck, and Fern creeks (Figure ES-1). Contributing drainage areas of subwatersheds are summarized in Table 2-8.

The narrow, upper watershed tributaries are incised into the underlying Franciscan mélange. Above the confluence of Fern and Upper Redwood creeks, where Redwood Creek becomes a fifth-order channel (Strahler 1952), streams are steep, with slopes typically greater than about 12 percent and often exceeding 20 percent (Figure 2-23). No detailed, quantitative field surveys of channel conditions have been conducted in the upper tributaries, but reconnaissance indicates that a dominantly step-pool channel morphology, with bouldery creek beds and gravel and cobbles occurring locally in small pools.


Headwaters of Fern Creek

Channel slope in the mainstem Redwood Creek and the Fern Creek tributary drops to between 4 and 8 percent, about a quarter of a mile upstream of the Fern Creek confluence, near the upstream border of Muir Woods National Monument (Figure 2-23). The channel has a mixed gravel-cobble bed below the confluence of Fern Creek (Kimball and Kondolf 2002), and channel slope decreases to less than 2 percent within Muir Woods, where a distinct alluvial floodplain of limited extent begins. Channel straightening, a large weir, and rock revetments along the banks constructed by the Corps in the 1930s have resulted in a highly static channel morphology throughout the Muir Woods National Monument. Large woody debris (LWD) jams in channels play an important role in forming bars and pools (Montgomery et al. 1995), and are probably reduced in Muir Woods relative to pre-disturbance conditions, owing to channel straightening and the legacy of routine wood removal that was practiced by the NPS until 1986. Current California State Park practices require leaving downed wood in the watershed per MOW guidelines consistent with the *Best management Practices of Woody Debris in Riparian Areas of Salmon Bearing Streams in the Lagunitas Creek Watershed* (Marin Municipal Water District et al. 2007). A plane-bed morphology dominates in the Monument, and a total of 45 pools span the 7,500-foot reach, with an average spacing of three bankfull channel widths (Kimball and Kondolf 2002); bankfull widths are suspected of being greater now than before the channelization work. Although the estimated pool spacing is lower than the 5–7 bankfull-width average for free-formed reaches of unregulated rivers (Leopold and Wolman 1957, Leopold et al. 1964, Keller and Melhorn 1978), it is in general agreement with the 1–4 bankfull-width average for steeper, step-pool reaches (Whittaker 1987, Chin 1989, Grant et al. 1990). Even so, indications that pool spacing is often a sensitive function of LWD loading (Montgomery et al. 1995) imply that the now-abandoned wood removal practices of the NPS may have substantially reduced pool spacing relative to historical conditions in the Monument. In 2001, the NPS placed LWD at one location in the Monument and continues to monitor pool development at the site. Additional LWD has accumulated over the past decade from trees falling into the channel.

Table 2-8. Drainage Areas of Redwood Creek Subwatersheds

Subwatershed[1]	Drainage Area (square miles)
Upper Redwood Creek	2.0
Fern Creek	1.1
Kent Canyon	1.0
Camino del Canyon	0.3
Green Gulch	1.1
Redwood Canyon	0.8
Upper Frank Valley	1.5
Lower Frank Valley	0.8
Total Watershed	**8.8**

1. See Figure ES-1 for subwatershed boundaries.

Source: Stillwater Sciences 2004

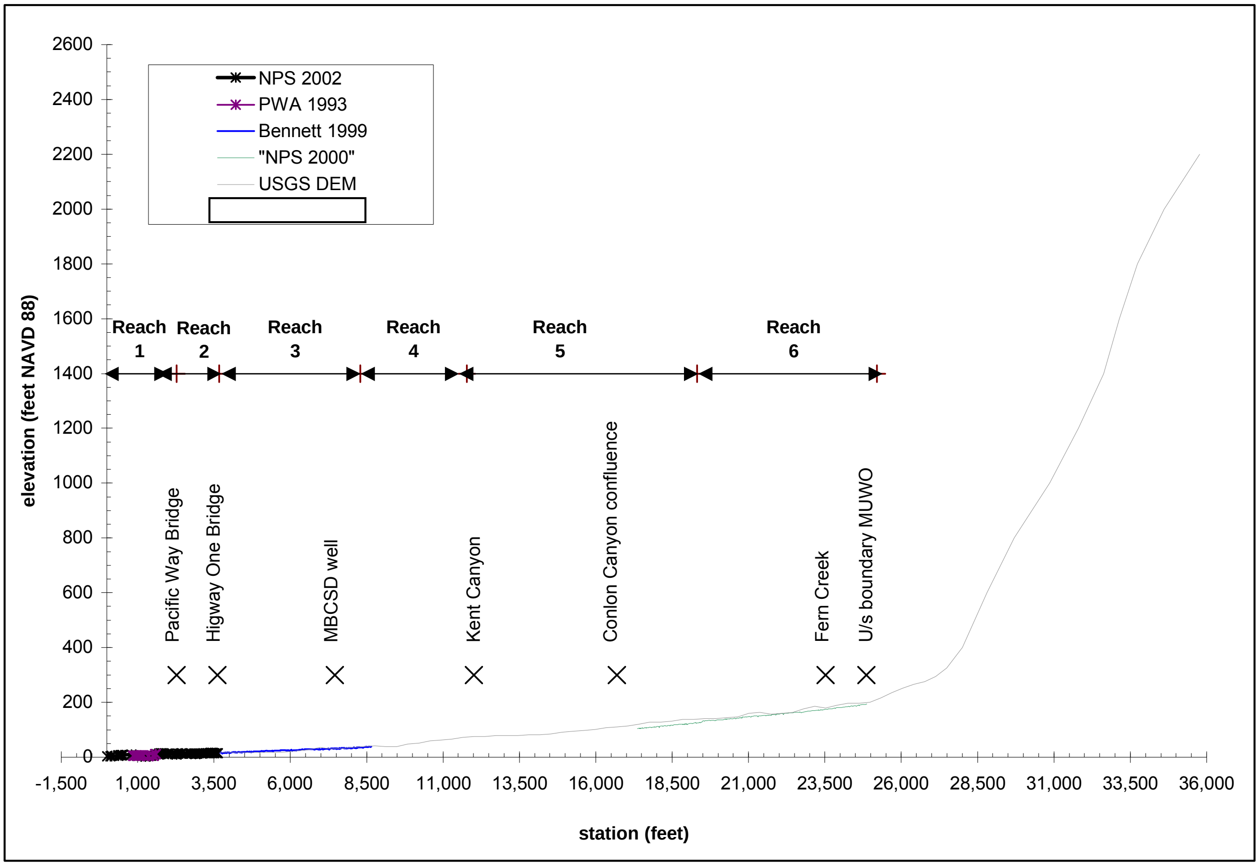
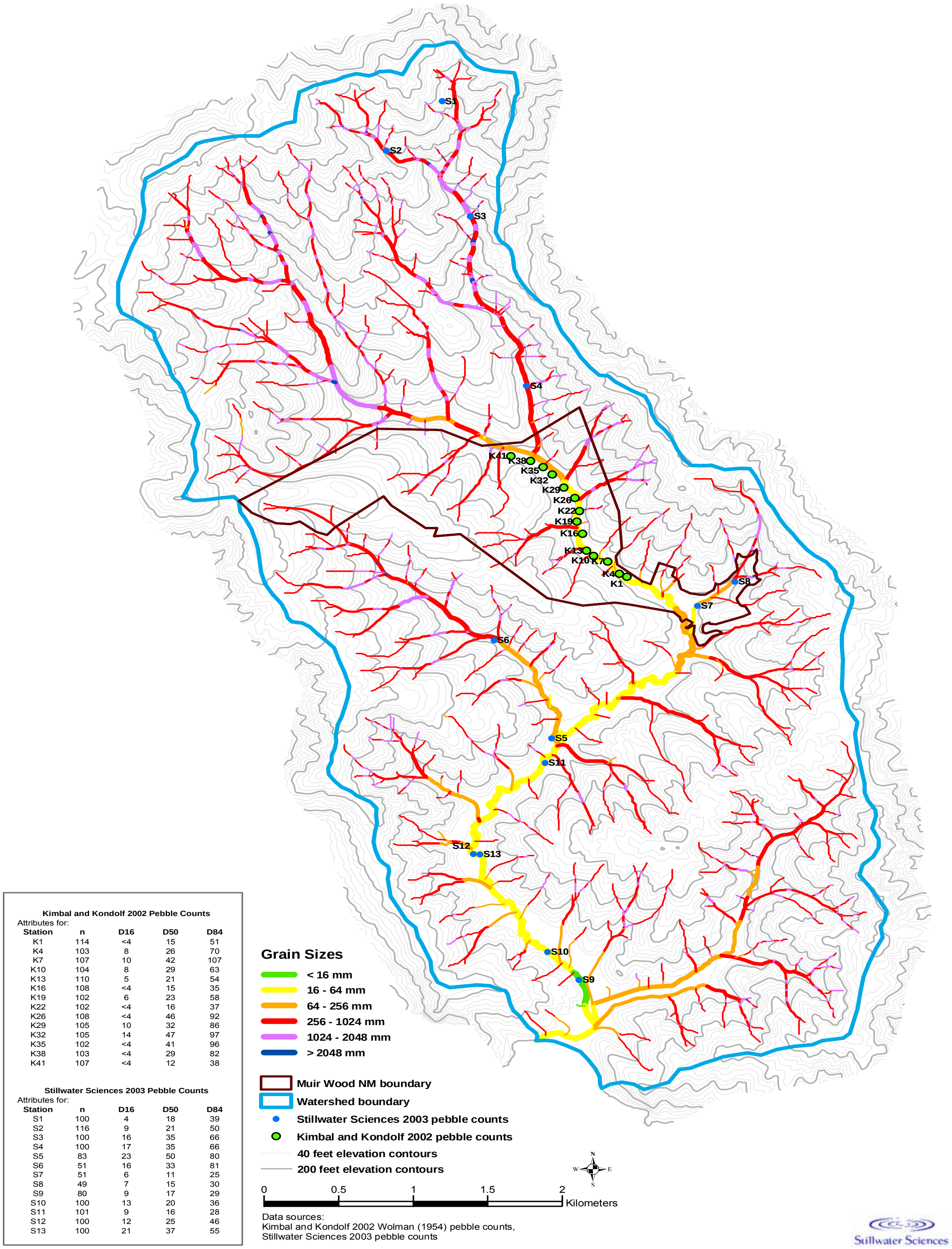


Figure 2-23. Redwood Creek channel profile with delineation of NPS habitat mapping reaches. (Sources: NPS unpublished data, USGS DEM, Fong 2002)

After flowing southeasterly through Redwood Canyon and out of Muir Woods, the creek turns sharply and flows southwesterly into Frank Valley, where it gains a significant alluvial floodplain. A series of short, steep tributaries join the mainstem after crossing alluvial fans that have been deposited along the margins of Frank Valley. A relatively large right-bank tributary, Kent Canyon Creek (1 mi^2) joins the mainstem in Frank Valley (Figure ES-1), and its alluvial fan appears to influence the planform of Redwood Creek in the vicinity, situated towards the left side of the valley. In lower Frank Valley, the channel turns back to the southeast before draining to the Pacific Ocean. Channel slope in Frank Valley drops from 0.9 percent at its upstream end to 0.4 percent at the Highway 1 Bridge. Bed texture is gravel and cobble in the valley (Figure 2-24) (Kimball and Kondolf 2002, Stillwater Sciences 2004). Throughout much of Frank Valley, the creek channel is incised and isolated from its floodplain (Stillwater Sciences 2004). Historical maps of GGNRA lands within Frank Valley indicate that sections of the channel were altered by farming practices between the late nineteenth century and mid-twentieth century (PWA 2000), including a realignment of the creek away from a valley-central position in several places. In Frank Valley, Redwood Creek flows immediately adjacent to Muir Woods Road, undermining road stability in two locations and reducing traffic to one lane.


Redwood Creek in the upper portion of Frank Valley

As in Muir Woods, the frequency of LWD deposits is thought to be low, compared to historical conditions. However, LWD frequency is on the rise because of contributions from tree fall—no longer removed from the creek—and a series of engineered wood jams, introduced by the NPS in a 3,800-foot reach of creek upstream of the Highway 1 Bridge as part of a series of enacted and proposed restoration actions designed to re-connect the incised Banducci Reach with its floodplain (PWA 2000, 2002; Kamman Hydrology & Engineering 2006; NPS 2007a, 2007b). In addition to installation of the engineered log jams, restoration of this reach have included regrading channel banks and lowering the floodplain in proximity to Redwood Creek to encourage greater seasonal floodplain inundation, better riparian habitat, and greater topographic complexity of the channel bed. Two years of monitoring since installation show that the installed wood has produced desirable results, such as increasing channel complexity, developing pools deep enough to support coho salmon (*Oncorhynchus kisutch*) rearing in summer, and increasing the likelihood of floodplain inundation (Shoulders, pers. comm., 2005).



Kimbal and Kondolf 2002 Pebble Counts

Attributes for:

Station	n	D16	D50	D84
K1	114	<4	15	51
K4	103	8	26	70
K7	107	10	42	107
K10	104	8	29	63
K13	110	5	21	54
K16	108	<4	15	35
K19	102	6	23	58
K22	102	<4	16	37
K26	108	<4	46	92
K29	105	10	32	86
K32	105	14	47	97
K35	102	<4	41	96
K38	103	<4	29	82
K41	107	<4	12	38

Stillwater Sciences 2003 Pebble Counts

Attributes for:

Station	n	D16	D50	D84
S1	100	4	18	39
S2	116	9	21	50
S3	100	16	35	66
S4	100	17	35	66
S5	83	23	50	80
S6	51	16	33	81
S7	51	6	11	25
S8	49	7	15	30
S9	80	9	17	29
S10	100	13	20	36
S11	101	9	16	28
S12	100	12	25	46
S13	100	21	37	55

Data sources:
Kimbal and Kondolf 2002 Wolman (1954) pebble counts,
Stillwater Sciences 2003 pebble counts

Figure 2-24. Median grain size estimated from slope-area relation and field sampling. (Source: Stillwater Sciences 2004)

Redwood Creek's gravel bed persists downstream of the Highway 1 Bridge and into the Big Lagoon area, where channel slope decreases to 0.1 percent and a higher proportion of sand is evident. The channel and floodplain in the reach below the Highway 1 Bridge have been modified substantially over the last several decades. Major modifications in the reach have included:

- construction of floodwalls, placement of bank revetment and realignment of the creek to the valley right between the Highway 1 and Pacific Way bridges resulting in a perched, static channel planform;
- construction of a levee across Big Lagoon, conversion of a portion of lagoon habitat to pasture, and isolation of most of the floodplain from the creek causing in-channel and near-channel sedimentation to be intensified (Stillwater Sciences 2004);
- realignment of Green Gulch Creek (a 1.1 mi^2 tributary that drains directly into Big Lagoon) into two straightened ditches to maximize available horse pasture;
- construction and then extension after 1982 of a dirt/gravel fill parking lot that projects tangentially into the lagoon and reduces the available river corridor for Redwood Creek;
- construction of the Pacific Way Bridge and concrete box culvert across Redwood Creek at the upstream end of Big Lagoon, promoting upstream sediment deposition and frequent avulsion of the creek into a lower elevation central valley location during large flood events causing flood hazard; and
- consequentially, a requirement for periodic dredging (now largely discontinued except in emergency–see below) of the creek channel to maintain conveyance capacity.

Redwood Creek at the Pacific Way Bridge

These channel modifications have reduced functional floodplain area and altered channel hydraulics and sediment transport capacity that, combined with delivery of sediment derived from large storms in 1998, have resulted in substantial aggradation in Redwood Creek below the Highway 1 Bridge and into the Big Lagoon area. Channel surveys indicate approximately 5 feet of channel aggradation occurred between 1993 and 2002 (Klein et al. 2002), resulting in increased flooding, an unstable channel alignment, and a heightened risk of avulsion to adjacent pasture (that is several feet lower than the creek bed). Measures to reduce flooding and the risk of avulsion were implemented in 2002 by Marin County and the NPS, and included (1) removing sediment from 460 feet of the lower creek, (2) removing approximately four woody debris jams from the creek, (3) excavating a 300-foot-long pilot channel through a sediment deposit that had closed off the mouth of the creek, (4) constructing two armored dips in a levee road to provide hydraulic connectivity while reducing erosion of the levee, (5) removing a flap gate in a levee culvert to facilitate flood routing from the wetland area to the Pacific Ocean, (6) removing dead trees at risk of falling into the channel to reduce the likelihood of future obstruction, (7) installing biotechnical bank protection (willow mattresses) upstream of the Pacific Way Bridge to prevent enlargement of floodplain channels, and (8) excavating a small trench at the low point on Pacific Way east of the Pacific Way Bridge. Strategically, the NPS has worked with consultants to understand the nature of sediment dynamics in the watershed (see Section 2.5.4) (Stillwater Sciences 2004) and to develop a long-term restoration plan for the lower reach of Redwood Creek at Muir Beach (PWA et al. 2004). Detailed descriptions and evaluations of restoration alternatives for this 38-acre project are aimed at restoring a functional, self-sustaining ecosystem and are presented in the Wetland and Creek Restoration at Big Lagoon, Muir Beach, Marin County Environmental Impact Statement/Environmental Impact Report (EIS/EIR) prepared by the NPS and Marin County (NPS and Marin County 2007). Restoration implementation began in summer 2009.

A large set of channel morphology data is available from salmonid habitat quality surveys conducted by the NPS in 1995 (Fong 2002). Mapped habitat types included pools (subdivided into main channel, scour, step, and backwater categories), riffle and flatwater, and miscellaneous (e.g., cascade and dry). Recorded channel characteristics included entrenchment, average bankfull channel depth, frequency and volume of large woody debris ("woody material" in Fong 2002), residual pool depth, length and width of undercut bank, overhanging and instream cover, and substrate size composition (by visual estimate only). The habitat typing methodologies referenced in Fong 2002 include those of Overton et al. (1993) and Dolloff et al. (1993). Of the methodologies referenced, Overton et al. gives the most complete definition of habitat types, which in turn are based on Bisson et al. (1982:62–73 and 376), although "flatwater" is not defined. It is assumed that flatwater is more or less synonymous with a "run" or a "glide," as described in Overton et al., but this is not certain. The minimum size threshold for what constitutes a measurable piece of large woody debris is not defined in Fong 2002, but it is assumed that it matches the criteria described in Overton et al., that "large woody debris is defined as pieces of wood at least 10 feet in length or two-thirds the channel width and 4 inches in diameter at one-third the distance from the large end." Habitat data were analyzed for the seven stream reaches listed in Table 2-9 and shown in Figure 2-23 on the Redwood Creek channel profile.

Table 2-9. Redwood Creek Habitat Survey Reaches

Reach No.	Description	Length (feet)	Length (meters)
1	Big Lagoon to Pacific Way	2,434	748
2	Pacific Way to Highway 1	1,391	424
3	Banducci (Highway 1 to State Park Boundary)	4,534	1,382
4	State Park Boundary to Kent Canyon	3,484	1,062
5	Kent Canyon to Dipsea Trail	7,539	2298
6	Dipsea Trail to Bridge 4	6,076	1852
7	Fern Creek	1,299	396

Source: Fong 2002

The frequency distribution of major habitat types (i.e., pool, riffle, and flatwater) by reach is shown in Figure 2-25. The frequency of large wood is quantified as the number of pieces per 328 feet and is shown for each reach in Figure 2-26. Most reaches had less than 15 pieces per 328 feet. Wood frequency is probably lower and the pieces smaller in diameter than under pre-disturbance conditions because of a legacy of channel wood removal practices (discontinued in the Monument in 1986) and replacement of old growth with second growth in areas outside of Muir Woods. A lower wood frequency will generally tend to reduce the frequency of complex debris jams and thus reduce frequency of deep pools. Few pools exist of sufficient depth (i.e., 1.6 feet) for summer coho salmon habitat in the Redwood Creek watershed (Figure 2-27). Pool habitat is particularly scarce in Reaches 6 and 7 (Table 2-9) within Muir Woods National Monument, probably owing—at least in part, in Reach 6—to the legacy of the 1930s channelization projects (noted previously). Pools in Reach 7 are probably scarce because of a transition to a step-pool morphological regime associated with natural variations in channel slope and sediment supply. Pools are more common in reaches downstream of Muir Woods and were most extensive in Reach 1. Pools deeper than 1.6 feet, however, were scarce in all reaches except Reach 1, accounting for just 3–32 percent of the surveyed channel length. More than 50 percent of Reach 1 was observed to have pools with a depth of 1.6 feet or greater, but much of that habitat was located in a single excavated borrow ditch that has probably been reduced in size because of increased sedimentation since 1996. Additional information about aquatic habitats is discussed in Section 2.7.

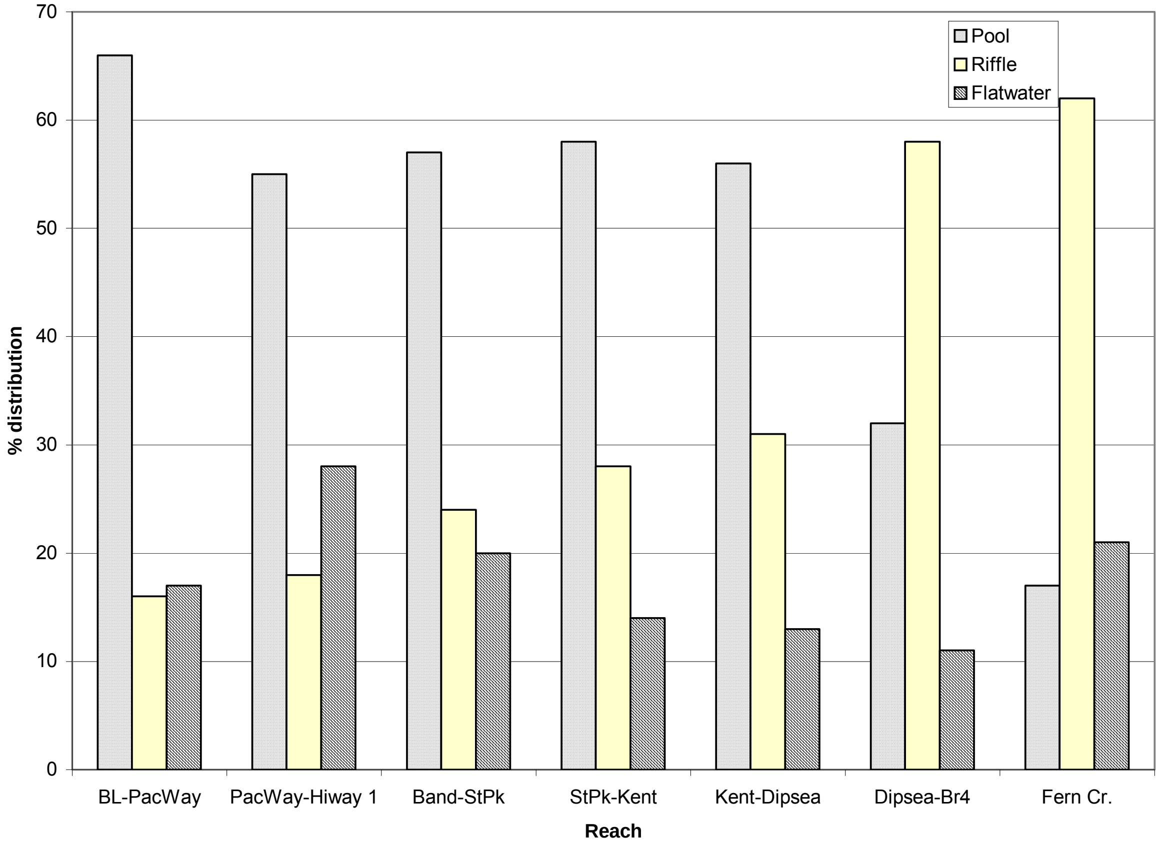


Figure 2-25. Habitat types and distribution in the mainstem Redwood Creek and Fern Creek showing a decline in riffle area and increase in pool area with increasing distance downstream from the Fern Creek reach. (Source: Fong 2002)

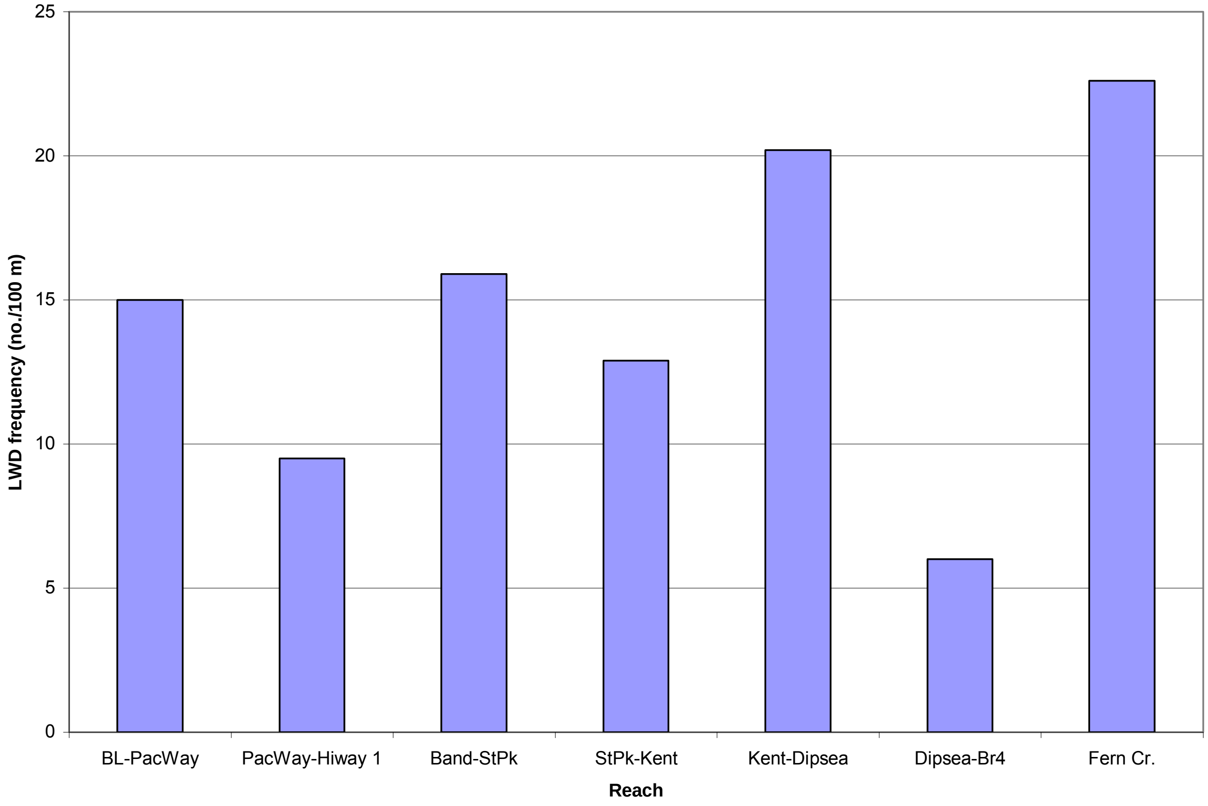


Figure 2-26. Large woody debris (LWD) distribution in Redwood and Fern creeks. (Source: NPS, unpubl. data; MMWD, unpubl. Data)

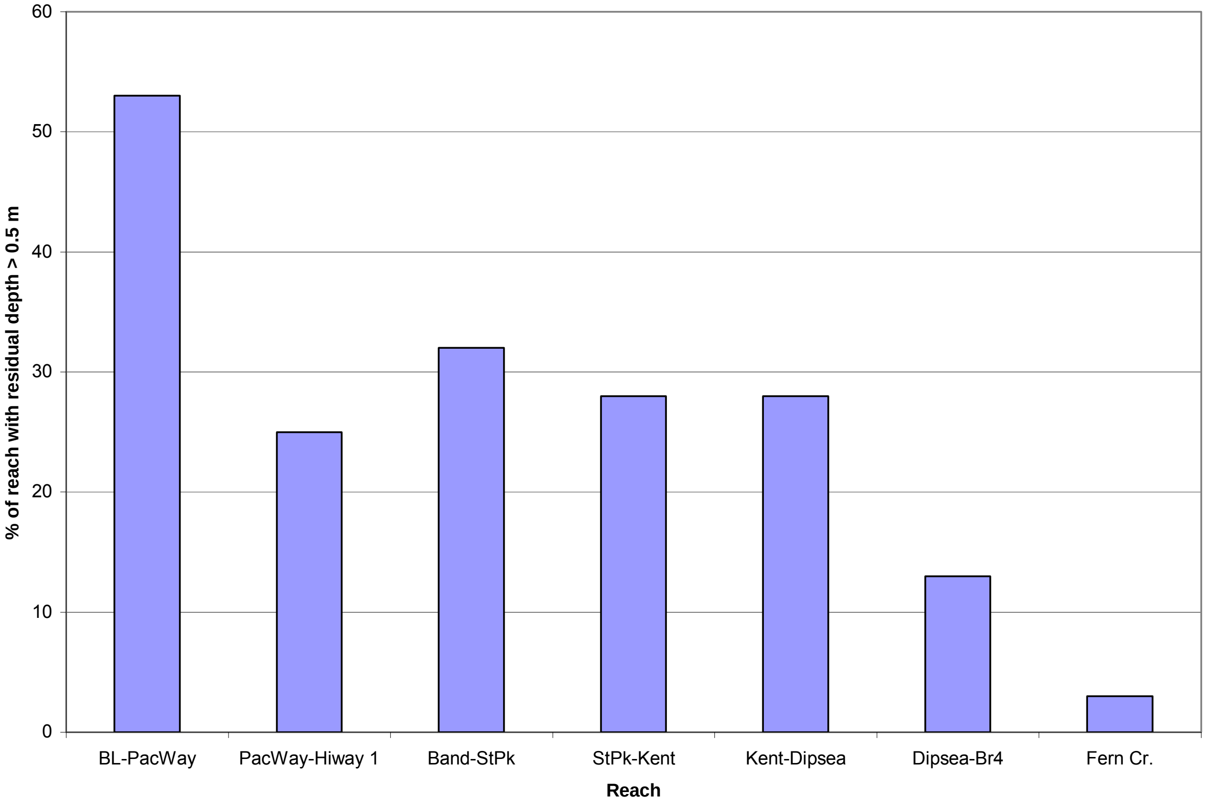


Figure 2-27. Distribution of pools deeper than 1.6 ft (0.5 m) in Redwood and Fern creeks, showing an increase in pool area with increasing distance downstream from Fern Creek. (Source: NPS, unpubl. data; MMWD unpubl. Data)

2.5.4 Sediment Budget

The morphology and natural maintenance of the Big Lagoon wetland ecosystem has been adversely affected by recent sedimentation from the Redwood Creek watershed (Stillwater Sciences 2004). To help in their evaluation of strategies for restoring the lagoon, the GGNRA retained Stillwater Sciences to develop a sediment budget for the watershed, using it to estimate the rate of sediment supply to the lagoon. Results from the sediment budget analysis were presented in a detailed report (Stillwater Sciences 2004) and are summarized here.

A sediment budget should provide a snapshot of the geomorphic evolution of watershed slopes and channels, including an assessment of available sediment transport rates, for evaluation of the relative importance of different processes and contributing areas (Reid and Dunne 1996). Key elements of a sediment budget include:

- an inventory of material that is (or may become) available for delivery from sediment sources (which include hillslope soils, colluvial hollows, and floodplain deposits);
- an inventory of material that is stored in sediment sinks (such as floodplains and hollows);
- estimates of transport rates among interconnected sediment sources and sinks; and
- an estimate of the net rate of sediment transport out of the watershed (at the mouth).

The Redwood Creek sediment budget was developed from: (1) a watershed elevation model based on existing digital data, (2) field reconnaissance of sediment source areas, (3) mainstem channel surveys and dendrochronology—which helped quantify rates of change of sediment storage in the lower reaches of the creek, (4) estimates of sediment production and transport rates derived from previous studies in neighboring watersheds, and (5) modeling of sediment transport in Redwood Creek (Stillwater Sciences 2004).

DELINEATION OF CHANGES IN THE REDWOOD CREEK SEDIMENT BUDGET OVER TIME

Changes in land use can cause significant changes in rates of sediment production and transport by accelerating erosion from sediment sources and by destabilizing material stored in sediment sinks. Human-induced changes in rates of sediment production and transport may continue to occur as a legacy, long after the cessation of changes in land use, with landscape elements adjusting slowly to new conditions. After consideration of Redwood Creek watershed history (Section 2.2.3) along with observations from initial field reconnaissance, it became clear that historical changes in land use may have caused substantial changes in the watershed's sediment budget over time (Stillwater Sciences 2004). Thus, it was necessary to develop separate sediment budgets for different time periods, with intervals defined by changes in human land use in the watershed.

To document factors that might have influenced sediment processes within the watershed and thus help delineate distinct intervals of human land use for the sediment budgets, a watershed disturbance chronology was developed from available historical data and previous studies (Stillwater Sciences 2004, based on Hildreth 1966, McBride and Jacobs 1978, Bicknell et al. 1993, PWA et al. 1994, PWA 1995, PWA 2000, Martin 2000, Jebens 2001, Kimball and Kondolf 2002, Klein et al. 2002 and PacWA 2002). Based on this synthesis of events (provided in Appendix A), four periods of development in the watershed were defined (Stillwater Sciences 2004):

- Pre-Euro-American (pre-1840). A period dominated by a combination of natural processes and the influence of Coast Miwok culture. Sediment production from upslope areas was retained for the most part in Frank Valley, resulting in a low sediment yield to Big Lagoon.
- Euro-American Arrival and Resource Development (1841–1920). The period of greatest land use change as Redwood Creek was settled by Euro-Americans. Runoff and sediment production rates in upslope areas was altered, causing incision in the alluvial reaches of Redwood Creek and thus increasing sediment yield to Big Lagoon.
- Engineering as Management (1921–1980). The period of greatest creek disturbance as land use intensified. Intensification of processes initiated in the previous period continued to promote incision of the creek and increase sediment yield to Big Lagoon.
- Recovery and Restoration (1981–2002). A period of increased conservation. Upslope processes began to recover towards pre-disturbance conditions. The legacy of human disturbance in the channel network kept sediment yields to Big Lagoon high, relative to pre-disturbance conditions.

Characteristics, activities, and the hypothesized sediment responses for each of the sediment budget periods are summarized in Table 2-10.

Table 2-10. Major Watershed Disturbances and Hypothesized Sediment Transport Responses

Period	Time Period	Characteristics and Activities	Hypothesized Sediment Response
Pre-Euro-American	Pre-1840	• Oak woodland and meadow floodplain with grassland on hillslopes, maintained by burning • Redwoods in canyons and valley • Upland prairies maintained by natural fires • Riparian fringe along Redwood Creek • Big Lagoon is lagoon-like, at least seasonally	• Low sediment production, primarily of fine sediment by creep and biogenic processes • Shallow landslides during storm events • Sediment supply to mainstem channel may be low because of lack of connection to Frank Valley tributaries • Tributary fan deposition and overbank flooding in non-incised channel allows sediment storage and valley alleviation
Euro-American Arrival and Resource Development	1841 to 1920	• Lower valley: removal of floodplain woodland, introduction of extensive then intensive grazing and dairy farming, replacement of native perennial grasses with annual exotics • Logging of Redwoods, late in Redwood Creek due to its relative inaccessibility, soil stripped for clay following logging • Construction of first roads, trails, trains, tourism, triggering of accidental fires • Riparian fringe along Redwood Creek removed, possible local realignment of lower Redwood Creek near Pacific Way • Levees, conversion of Big Lagoon to pasture • Beginnings of the land protection movement at Muir Woods to save “last remaining redwoods”	• Reduced tree cover and grazing causes greater volume sand and greater peakedness of storm flows • Replacement of native grasses with non-natives provides less effective resistance to erosion • Both factors combine to increase tributary sediment yields, increase tributary connectedness during high flow events and initiate incision of the channel mainstem • Incision confines flows, reverses former sediment storage and increases sediment yields further; incised channel capable of transporting coarser sediment

Period	Time Period	Characteristics and Activities	Hypothesized Sediment Response
Engineering as Management	1921 to 1980	• Riparian flower and hay farming • Progressive transfer of farms to State and National Parks • More exotics (eucalyptus, heather); tree removal firebreaks, fires suppressed • Logging of 1,300 ac (Kent Canyon, 1960s) • Muir Woods infrastructure created; parking lots through cut and fill, further trails constructed • Roads upgraded, Highway 1 embankment effectively dams lower watershed • Local water extraction in Frank Valley for irrigation and Muir Beach community • Redwood Creek in Muir Woods extensively “protected” by riprap and grade control, realigned (assumed), LWD removed • Redwood Creek in Frank Valley locally realigned for roads/bridges (assumed), leveed, subject to small-scale gravel extraction, floodplain regraded at Banducci farm • Redwood Creek in Big Lagoon dredged, dammed (then dam removed), leveed, Green Gulch channelized, reservoirs constructed, parking lot constructed	• Continuation of previous trends; potential decrease in tributary sediment production as former farmland is converted to parkland but increases because of riparian farming from Kent Canyon, caused by logging from Muir Woods, resulting from addition of roads and trails • Engineering measures halt incision in Redwood Canyon but may cause greater flashiness of flows • Sediment production may increase in lower watershed as channels are straightened and leveed • Most sediment production from Green Gulch intercepted by reservoirs • Effective depositional area in Big Lagoon reduced by levees and fill
Recovery and Restoration	1981 to 2002	• Land use conversion from grazing to park land; most of watershed publicly owned; exotic grasslands, forested tributaries, pines in upper watershed • Prescribed burn experiments • Some water pumping but no irrigation • Parking lot extended at Muir Beach • Riparian and large woody debris recovery • Terrestrial wetland species invade Big Lagoon	• Tributary sediment sources other than from roads and trails begin to wane as agriculture ceases • Increasing roughness of mainstem channel as large woody debris volume increases act to trap greater sediment volumes • Continuation of reduced area for sediment deposition in Big Lagoon and interception of Green Gulch sediments

Source: Stillwater Sciences 2004

Sediment Yields of Major Geomorphic Processes

Long-Term Average Sediment Production Rates

Taken together, field reconnaissance and cosmogenic dating from the neighboring Tennessee Valley suggest that significant portions of the upper watershed were probably not delivering much of their sediment to the Redwood Creek mainstem in the pre-1840 period (Stillwater Sciences 2004). Instead, the sediment derived from hillslopes appears to have been impounded in alluvial fans and floodplain deposits in Frank Valley. An estimated 30 percent of the watershed was isolated from the mainstem Redwood Creek in this way. In the absence of site-specific data on sediment production, the remaining 70 percent of the watershed was assumed to have a pre-1840 sediment delivery rate of approximately 169 t km-2 year-1—the long-term (i.e., 1,000- to 10,000-year) average soil production rate from neighboring Tennessee Valley (Heimsath et al. 1997). Averaged over the entire Redwood Creek watershed area, the 169 t km-2 year-1 from actively contributing areas is 117 t km-2 year-1 (accounts for the observed isolation of 30 percent of the watershed).

Hillslope and Streamside Landslides

Hillslope and streamside landslides were mapped using sequential aerial photography and field reconnaissance. Landslide mapping was used to estimate the area affected by landslides in the interval between each set of photos. These areas were converted to volumes using area-to-volume relationships determined in previous work for neighboring Lone Tree Creek (Lehre 1982). The net rate of sediment delivery to the Redwood Creek mainstem from hillslope and stream-side landslides was estimated to be 45 metric tons per square kilometer per year (t/km^2/year). This is lower than might be expected, based analysis of rates from neighboring basins. Several possible reasons exist for the discrepancy, including the relatively coarse scale of the aerial photography and difficulty in remote identification of landslide scars in heavily forested areas (which are common in the Redwood Creek watershed). The lower-than-expected estimated delivery from landslides also may be caused by a difference in land management practices with the conservation-oriented history of the Redwood Creek watershed contributing to a relatively lower rate of sediment delivery from landslides.

Erosion along Tributaries

Sediment delivery by erosion along the edges of tributaries is the sum of delivery from (1) soil creep and landsliding close to the channel, (2) channel enlargement because of changes in upstream runoff, and (3) incision driven by base level changes in Redwood Creek downstream. The estimated rate of sediment delivery from erosion along tributaries was based on measured lengths and widths of actively eroding stream banks in the Redwood Creek watershed coupled with an analysis of published data on bank erosion depths from neighboring Lone Tree Creek. Data compiled from field reconnaissance indicated that the combined sediment delivery from erosion along second-, third-, and fourth-order streams is 59 t/km^2/year.

Road-Related Erosion and Sediment Transport

Estimates of sediment transport rates from roads, trails, and road-crossing failures were based on data from a previous study (PacWA 2002). Sediment delivery from road and trail surfaces was estimated to be very low, at about 2 t km-2 year-1. The somewhat higher 6 t km-2 year-1 estimated rate of episodic, road-related sediment delivery is a minimum estimate because of a lack of survey data for the entire set of post-construction road-related erosion sites. Cutbank erosion was estimated to be much higher, with a watershed-wide total of about 40 t km-2 year-1. Rates of road-related sediment transport were applied to each of the sediment budget periods, according to the corresponding estimated extent of roads and trails completed during the period. For example, nearly 100 percent of watershed roads and trails were constructed (and contributing to erosion) by the start of the fourth period, the most recent sediment budget period, whereas an estimated 75 percent contributed to erosion in the third period, and approximately 15 percent contributed in the second period.

Sediment Delivery from Green Gulch Creek

Sediment trapping in Green Gulch reservoirs since the 1950s has made sediment yields to Big Lagoon from Green Gulch sub-basins negligible during the most recent sediment budget period. For the preceding three periods, Green Gulch was assumed to contribute sediment according to the estimated rates as outlined above.

Rate of Alluvial Fill on the Redwood Creek Mainstem

Lower Redwood Creek is developed in deep alluvial fill, which presumably accumulated in response to sea level rise during the late Holocene. Rates of alluvial valley fill in Redwood Creek (from Redwood Canyon to Big Lagoon) during the pre-1840 period were estimated by dividing the total volume of fill by radiocarbon dates of organic material found in basal sediments of Big Lagoon, lower Frank Valley, and Walker Creek (a neighboring watershed). Based on these calculations, Frank Valley appears to have aggraded at an average of 1 mm year-1 from 3,500 B.P. to 1840. This translates to 83 t km-2 year-1—or approximately 70 percent of the estimated long-term average production rate (117 t km-2 year-1) of watershed slopes—making the alluvial valley fill a relatively substantial sink for sediment during pre-Euro-American times.

Post-1840 Incision of the Redwood Creek Mainstem

Generally coincident with Euro-American arrival in the watershed, Redwood Creek appears to have begun incising into its Holocene alluvial fill, thus enhancing sediment delivery to Big Lagoon. Rates of incision along the mainstem for each period since 1840 were derived from estimated incision volumes (from cross-sectional survey) and a chronology of incision (constrained by alders that were dated using dendrochronology). Results indicate that the rate of incision has been highest in Upper Frank Valley. The average sediment yield from incision for the mainstem creek as a whole was generally constant, at about 180 t/km^2/year, from approximately 1841 to 1980, but dropped to just 48 t/km^2/year during the final period, from 1981 to 2002. Field surveys in mainstem Redwood Creek, coupled with field estimates of vegetation age, indicate that an additional 4 t/km^2/year of sediment has been produced by recent bank erosion.

Incision of Tributaries

Incision of the Redwood Creek mainstem has caused base level lowering for the watershed as a whole, and thus has led to incision (or gullying) of tributaries into their Holocene fills. Sediment delivery from incision of tributaries was estimated from the product of the cross-sectional area of incision (from field measurements of width and depth) and the affected stream length (from field reconnaissance). Incision rates of tributaries presumably progressed in step with mainstem incision rates, which changed over time (see above). Hence, in developing a time series of sediment budgets for Redwood Creek, it was important to scale the total sediment delivery from the incision of tributaries by the fractional amount of mainstem incision that occurred in each time period. It was also important to account for spatial variability in mainstem incision rates (i.e., the observation that incision rates were greatest in upper Frank Valley) because of the implied spatial variability in base level lowering rates. The sediment delivery rate from incision along tributaries was estimated to be 9, 7, and 2 t km-2 year-1 for the three most recent sediment budget periods.

Net Sediment Yield of the Redwood Creek Watershed

The net sediment yield from Redwood Creek watershed for each sediment budget period can be calculated as the sum of the components identified above. The results are summarized in Table 2-11 and plotted in Figure 2-28. Sediment yields in the periods that post-date Euro-American land use are up to an order of magnitude higher than the background, natural rate of sediment delivery of the pre-1840 period. Much of the inferred increase in sediment yields results from the inferred release of abundant sediment from the storage in the floodplain ("Channel yield" in Figure 2-29), which previously was an effective trap for sediment from the upper watershed (i.e., such that it was acting as a sediment sink rather than a source in the pre-1840 period). In the most recent sediment budget period (1981–2002), total sediment yield dropped by about a factor of two, but is still more than five times faster than it was in the pre-Euro-American period. The recent decline in sediment yield, relative to 1841–1980 rates, mainly reflects the inferred reduction in sediment eroded from the floodplain—a change that may be caused, at least in part, by the well-documented recent shift from agricultural to parkland uses in the lower watershed (see Table 2-10 and Appendix A).

Table 2-11. Watershed Sediment Yields Estimated from the Sediment Budget for Each Period

Measure	Unit Rate	Time Period			
		Pre-1840	1841–1920	1921–1980	1981–2002[1]
Delivery from hillslope and channel erosion processes	t/km^2/year	117	111	140	147
Sediment eroded from floodplain	t/km^2/year	-83[2]	193	184	50
Total sediment yield	**t/km^2/year**	**34**	**304**	**324**	**198**

1 Rate includes contributions from Green Gulch, which did not contribute to Big Lagoon during the 1981–2002 period.

2 Minus sign indicates sediment went into storage on the floodplain.

Source: Stillwater Sciences 2004

Uncertainties in Sediment Yields and Other Complications

Estimates of sediment yield summarized here have several sources of uncertainty that can be generally grouped into two categories: measurement uncertainties and uncertainties in assumptions. Each method for estimating sediment yields has its own specific set measurement uncertainties. For example, the land-cover-dependent uncertainties inherent in air-photo mapping of streamside and hillslope landslides are very different from uncertainties inherent in field estimates of bank erosion. Each method also has its own set of assumptions, which can have a wide range in inherent levels of speculation. For example, the extrapolative assumption that erosion from tributary banks has been constant over time is less plausible for earlier periods because the tributary bank erosion estimates are based on contemporary measurements (which are unlikely to strongly reflect rates from the past).

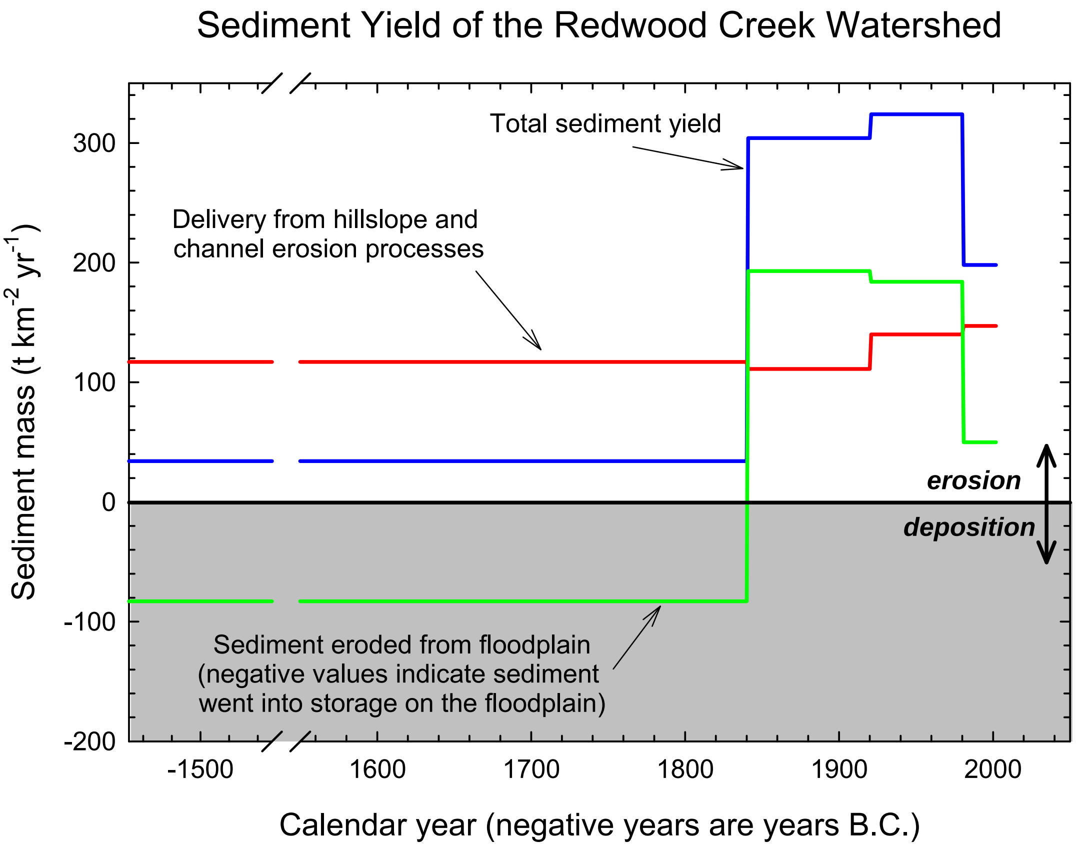
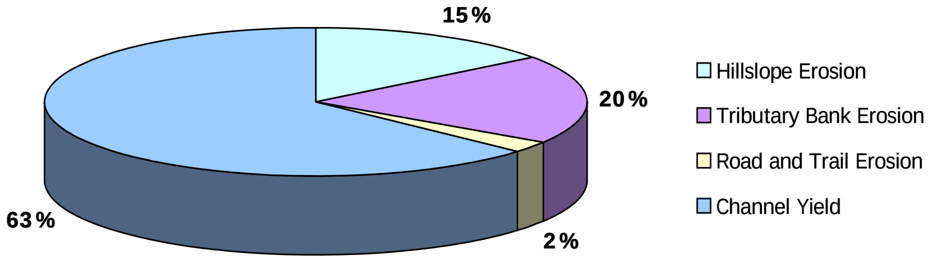
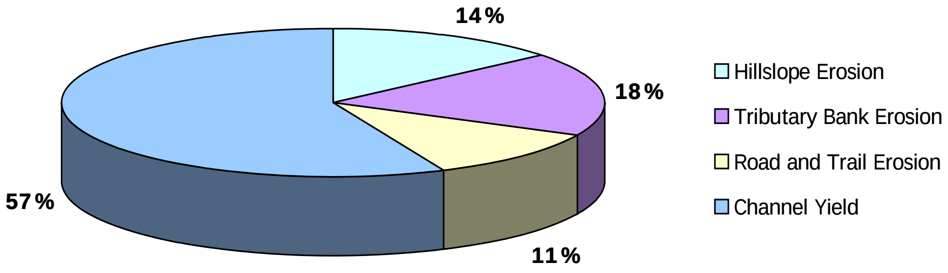


Figure 2-28. Estimated time series of total sediment yields from Redwood Creek. (Adapted from Stillwater Sciences 2004)

1841-1920
Total sediment yield = 304 t km^{-2} yr^{-1}



1921-1980
Total sediment yield = 324 t km^{-2} yr^{-1}



1981-2002 (excluding Green Gulch)
Total sediment yield = 178 t km^{-2} yr^{-1}

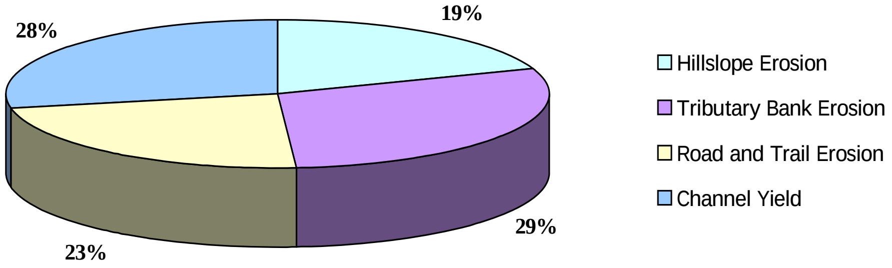


Figure 2-29. Relative contributions of sediment sources expressed in charts as percentages of the total sediment yield from the Redwood Creek watershed for the post-1840 sediment budget time periods. (Adapted from Stillwater Sciences 2004)

Rates for the most recent sediment budget period probably have the lowest uncertainties because of the availability of a large set of quantitative observations and data. Rates for the other periods are not as well constrained and in many cases are simply extrapolations of present rates. Errors in sediment yields are high for the two middle time periods (1841–1920 and 1921–1980) because of lack of information on erosion from construction of railroads, roads, trails, and buildings; erosion rates from these sources were excluded because they could not be reliably calculated, although they were probably significant because much of the construction occurred before implementation of Best Management Practices. Errors in sediment yields are high for the earliest time period because lack of data necessitated the greatest generalizations. An additional complication in the interpretation of the sediment budgets stems from a lack of specific data on erosion and sediment delivery from agricultural sources. Effects of changes in agricultural land use are subsumed more generally within the estimates of sediment delivery discussed above.

Sediment budget estimates could be refined substantially with additional information on landslides (i.e., their distribution, frequency, and size), erosion from surfaces adjacent to tributary streams, sediment production from roads and trails, and better constraints on mainstem incision rates. Additional information regarding direct effects of past construction and agricultural activities also would improve the estimates of the sediment budget.

Rates of Sediment Deposition in Big Lagoon

The sediment yields of Table 2-11 can be used to estimate sedimentation rates for Big Lagoon, but an essential additional step is estimation of the lagoon's sediment trapping efficiency. Sensitivity analysis shows that the proportion of total sediment yield deposited in the lagoon could range from 14 to 100 percent, depending on the assumed relationship between sediment size and trapping efficiency. Estimates of sediment deposition in Big Lagoon are summarized in Table 2-12.

Table 2-12. Rates of Sedimentation in Big Lagoon for Each Sediment Budget Period

Measure	Unit rate	Time Period			
		Pre-1840	1841–1920	1921–1980	1981–2002
Estimated volumetric sediment yield to Big Lagoon	$m^3\ yr^{-1}$	454	4057	4324	2376[1]
Estimated sedimentation rate from sediment yield[2]	$mm\ yr^{-1}$	0.6–4.5[3]	5.7–40.6[3]	6.1–43.2[4]	3.3–56.6[5]
Sedimentation rate assuming all bedload (14%) and 50% of remaining load is deposited[6]	$mm\ yr^{-1}$	2.6	23.3	24.7	32.3
Estimated sedimentation rate from various sources	$mm\ yr^{-1}$	1.12–1.18[7] 0.8–1.2[8]	11.2[9]	11.2[9]	5.8–86.8[10]
Rate of sea-level rise	$mm\ yr^{-1}$	1.05-1.5[11]	1.12[12]	2.13[12]	2.13[12]

1. Rate excludes sediment yield from Green Gulch Creek, which no longer contributes sediment to Big Lagoon.
2. The low-end estimate assumes that only bedload (14 percent of the yield) is trapped; the upper estimate assumes 100 percent trapping rate (such that the total yield settles in Big Lagoon).
3. Deposition area is 10 ha = 100,000 m^2.
4. Deposition area is 10 ha prior to 1960, and 4.2 ha for 1960–1980.
5. Deposition area is 4.2 ha = 42,000 m^2.
6. A hypothetical scenario that could be refined by sediment surveys above and below Big Lagoon.
7. Inferred from long core BL008 of Meyer (2003).
8. Long-term floodplain aggradation rate.
9. Inferred from cores by Wells (1994, as cited in PWA et al. 1994).
10. Based on in-channel field re-survey data 1992–2002 (PWA 2003) from Pacific Way to Willow/Alder Grove.
11. Atwater and Hedel 1976
12. Zervas 2001

(Source: Stillwater Sciences 2004)

Under the assumption that all bedload and 50 percent of the suspended load is deposited in the lagoon, the estimated sedimentation rates increased from 2.6 to 24 mm yr-1 from the first to second period, then held steady on average through the third period, and finally increased further to 35 mm yr-1 in the most recent period, despite a reduced overall sediment yield because a factor of approximately two decrease in the area available for sediment deposition (that resulted from engineering modifications of the lagoon).

The pre-1840 rate is nearly two times higher than the rate of eustatic sea level rise. The estimates of sedimentation rates for the pre 1840, 1841–1920, and 1921–1980 periods also are nearly two times higher than rates of sedimentation implied by analysis of lagoon sediment cores. This suggests that the assumed sediment trap efficiency may be too high. Even so, in all periods since 1840, the sediment budget and sediment core data independently predict rates of sedimentation in Big Lagoon that are at least an order of magnitude higher than rates of sea-level rise. This suggests that Big Lagoon has been filling since the onset of Euro-American settlement, with sedimentation that far exceeds than the rate of sea level rise.

Effects of Large Floods

The majority of sediment deposition in Big Lagoon presumably occurs during and shortly after large floods, rather than on a steady, average-annual basis. Hydrological records and narrative data indicate that notable floods in the watershed occurred approximately once per decade from 1920 to 1970 (i.e., in 1925, 1935, 1946, 1956, 1967), and twice per decade thereafter (i.e., in 1970, 1973, 1982, 1986, 1995, 1998). The two largest storm events since 1920 occurred on January 4, 1982 and, from narrative accounts, on February 11, 1925. Bedload transport modeling of the lower Frank Valley reach was conducted for three scenarios: (1) low flows, from 1998–2001, yielding a rate of 225 t/km^2/year, (2) “average” long-term data, from 1965–1986 (including the 1982 storm of record), yielding a rate of 480 t/km^2/year, and (3) high flows, from the 1982 high flow year, yielding a rate of 2,230 t/km^2/year.

Modeled sediment transport rates compare favorably with rates estimated from the sediment yield to Big Lagoon. Importantly, the transport modeling results suggest sediment delivery in wet years with high flows may be ten times higher than sediment delivery in dry years with low-flows (corresponding to 210 mm versus 21 mm of deposition per year into the existing 10.4-acre lagoon). Modeling results, taken together with the observation that notable storms are occurring more frequently, seem to corroborate anecdotal accounts of rapid, recent lagoon infilling. Furthermore, the results suggest that increases in El Nino-driven storm events will significantly increase the overall sediment yield from the watershed.

Projected Future Sediment Yields

Any use of Tables 2-11 and 2-12 for estimates of future sedimentation in Big Lagoon would be inherently speculative, in the absence of additional quantitative data on hillslope erosion and channel incision and migration. Moreover, the uncertainties in the available rates (from Tables 2-11 and 2-12) are undoubtedly high, and thus limit the confidence of any conclusions that might be drawn about differences among the rates. Nevertheless, some inter-comparisons are instructive and worth considering as a basis for speculation about future sediment yields. For example, contemporary rates of erosion from the watershed generally are similar to pre-disturbance rates (at 147 t/km^2/year now versus 117 t/km^2/year then—Table 2-11) and probably will stay that way. Even so, effects of Euro-American settlement appear to have resulted in a fundamental shift in the way sediment is routed through the watershed, with incision and degradation of floodplain deposits replacing the aggradation that seems to have dominated before about 1840. It is not clear how much certainty can be attached to the observation (Table 2-11) that the rate of sediment delivery from incision appears to have diminished in recent times (in the period 1981–2002 as compared to the period 1840–1981). Moreover, the pulse of incision that appears to have started in the mid-1800s has not yet finished working its way through the channel network and is, therefore, likely to continue influencing sediment delivery to the lagoon for some time to come. It is difficult to identify circumstances under which near-term, future sediment yield to Big Lagoon could plausibly drop very far below about 150 t/km^2/year (Stillwater Sciences 2004).

Effects of Human Land Use on Sediment Yields

Isolation of the effects of human disturbance on sediment budgets is problematic. Approximately 50 percent of the watershed's contemporary sediment yield is accounted for by erosion from roads and trails and by channel incision that has presumably resulted from human disturbance. In comparison, the overall effect of human disturbance on sedimentation in Big Lagoon has apparently been a five-fold increase in sediment deposition rates (because of the combined effects of increased sediment deposition and reduced depositional area). If differences in total sediment yield are used as a basis for comparison, the peak of human disturbance occurred from 1921–1980 and resulted in an additional yield of 303 t/km^2/year of sediment.

2.6 Water Quality

2.6.1 Regulatory Setting

In California, water quality is controlled under an interdependent system of federal and state laws that arose following the enactment of the federal Clean Water Act (CWA) of 1970. The SWRCB and the state's nine Regional Water Quality Control Boards (RWQCBs) work in a coordinated effort to implement and enforce the CWA, as provided in the Porter-Cologne Water Quality Act of 1969. The SWRCB carries out its water quality protection authority through the application of specific regional water quality control plans, formulated and adopted by the RWQCBs, which submit these plans to the SWRCB for review. The RWQCB basin plans provide standards through: (1) a designation of existing and potential beneficial uses; (2) water quality objectives to protect those beneficial uses; and (3) programs of implementation needed to achieve those objectives.

The 1995 *San Francisco Bay Region Water Quality Control Plan* (SFRWQCB 1995) is the master policy document for the San Francisco Bay Region. This plan identifies beneficial use designations for most water bodies, water quality objectives to protect those beneficial uses, and a strategy to achieve designated water quality objectives. Designated beneficial water uses of Redwood Creek depend on water quality from the surrounding watershed. Beneficial uses (abbreviations in parentheses) range from shellfish harvesting (SHELL), agricultural production (AGR), irrigation and potable water supply (MUN), recreation (REC-1, REC-2), and support of the fish (FRSH, WARM, COLD, SPWN) and wildlife (WILD) resources that inhabit the project study area (SFRWQCB 1995). The beneficial uses by ecological resources include cold and warm water aquatic habitat, spawning, shellfish, and wildlife. Table 2-13 presents water quality objectives developed under Section 303 of the CWA as they apply to beneficial uses within the Redwood Creek watershed.

Table 2-13. Surface Water Quality Criteria to Support Designated Beneficial Uses

Basin Plan Water Quality Objective (potentially affected beneficial uses)	Symbol or Abbrev.	Numeric Water Quality Criteria to Support Beneficial Use	Reference	Notes
Bacteria (MUN, REC-1)				
Total coliform	-	Marine and Fresh Water < 10,000 per 100 ml	USEPA 2003	Water contact recreation, Single Day Sample
		Marine and Fresh Water log mean <240 per 100 ml		Water contact recreation, 30 Day Average
		log mean <100 per 100 ml	SFBRWQCB 1995	Municipal Supply, 30 Day Average
Fecal coliform	-	Fresh: 90th percentile <400 per 100 ml	USEPA[1] 2003	Water contact recreation, 30 Day Average
		Marine and Fresh: log mean <200 per 100 ml		Water contact recreation, 30 Day Average
		Fresh: 90th percentile <4000 per 100 ml		Non-contact recreation, Single Day Sample
		Marine and Fresh: log mean <2000 per 100 ml		Non-contact recreation, 30 Day Average
		log mean <20 per 100 ml		Municipal Supply, 30 Day Average
Escherichia coli	-	Fresh: 235 per 100 ml	USEPA 2003	Water contact recreation, Single Day Sample
		Fresh: 126 per 100 ml	USEPA 2003	Water contact recreation, 30 Day Average
Enterococcus	-	Marine: 104 per 100 ml Fresh: 61 per 100 ml	USEPA 2003	Water contact recreation, Single Day Sample
		Marine: 35 per 100 ml; Fresh: 33 per 100 ml	USEPA 2003	Water contact recreation, 30 Day Average
Biostimulatory substances (COLD, WARM, SPAWN)				
Nitrate-nitrite	NO3-N+NO2-N	0.16 mg/L as N	USEPA 2000a	Regional Reference Value for EPA Ecoregion III
Total nitrogen	TKN	0.36 mg/L as N	USEPA 2000a	Regional Reference Value for EPA Ecoregion III
Total phosphorous	TP	0.030 mg/L as P	USEPA 2000a	Regional Reference Value for EPA Ecoregion III

Table 2-13. Surface Water Quality Criteria to Support Designated Beneficial Uses

Basin Plan Water Quality Objective (potentially affected beneficial uses)	Symbol or Abbrev.	Numeric Water Quality Criteria to Support Beneficial Use	Reference	Notes
Chemical constituents (AGR, COLD, MUN)				
Alkalinity	-	100 mg/L	Ayres and Wescott 1976	Irrigation Drainage
Aluminum	Al	0.2 mg/L	CDHS[2] 2005	Title 22 Secondary Maximum Contaminant Level (MCL)
Arsenic	As	0.34 mg/L (CMC); 0.15 mg/L (CCC)	CDHS 2005	Title 22 Primary MCL
Cadmium	Cd	0.005 mg/L	CDHS 2005	Title 22 Primary MCL
Calcium	Ca	None		
Chloride	Cl	250 mg/L	CDHS 2005	Title 22 Secondary MCL
Copper	Cu	1 mg/L	CDHS 2005	Title 22 Secondary MCL
Iron	Fe	0.3 mg/L	CDHS 2005	Title 22 Secondary MCL
Lead	Pb	0.015 mg/L	CDHS 2005	Title 22 Primary MCL
Magnesium	Mg	None		
Mercury	Hg	0.002 mg/L	CDHS 2005	Title 22 Primary MCL
Nickel	Ni	0.1 mg/L	CDHS 2005	Title 22 Primary MCL
Nitrate-nitrite	NO_3-N+NO_2-N	10 mg/L	CDHS 2005	Title 22 Primary MCL (“Blue baby Syndrome”)
Potassium	K	None		
Silver	Ag	0.1 mg/L	CDHS 2005	Title 22 Secondary MCL
Sodium	Na	None		
Zinc	Zn	5 mg/L	CDHS 2005	Title 22 Secondary MCL
Dissolved oxygen (COLD, WARM, SPAWN)				
Dissolved oxygen	DO	> 7 mg/L (minimum)	SFBRWQCB 1995	Aquatic life protection in cold water habitat; for non-tidal waters
		> 5 mg/L (minimum)	SFBRWQCB 1995	Aquatic life protection in cold water habitat; for non-tidal waters
		> 80% sat in 50% of samples	SFBRWQCB 1995	Aquatic life protection
pH (COLD, SPAWN, WILD)				
pH	-	6.5–8.5	SFBRWQCB 1995	Aquatic life protection

Table 2-13. Surface Water Quality Criteria to Support Designated Beneficial Uses

Basin Plan Water Quality Objective (potentially affected beneficial uses)	Symbol or Abbrev.	Numeric Water Quality Criteria to Support Beneficial Use	Reference	Notes
Temperature (COLD, SPAWN, WILD)				
Temperature	-	< 5ºF (2.8ºC) above natural receiving water temperature.	SFBRWQCB 1995	Site-specific criteria may be developed for representative species of each beneficial use
Toxicity (COLD, SPAWN)				
Aluminum	Al	0.75 mg/L (CMC*); 0.087 mg/L (CCC*)	CDHS 2005	Title 22 Secondary MCL
Ammonia as N	NH_3-N	24.1 mg/L (CMC); 4.1–5.9 mg/L (CCC)	USEPA 2000b	CTR criteria over 0–20°C assuming pH 7.0
		5.6 mg/L (CMC); 1.7–2.4 mg/L (CCC)	USEPA 2000b	CTR criteria over 0–20°C assuming pH 8.0
		0.9 mg/L (CMC); 0.3–0.5 mg/L (CCC)	USEPA 2000b	CTR criteria over 0–20°C assuming pH 9.0
Cadmium	Cd	0.4 mg/L (CMC); 0.34 mg/L (CCC)	USEPA 2000b	CTR for unfiltered sample assuming hardness of 10 mg/L as $CaCO_3$
		0.83 mg/L (CMC); 0.95 mg/L (CCC)	USEPA 2000b	CTR for unfiltered sample assuming hardness of 25 mg/L as $CaCO_3$
Copper	Cu	1.6 mg/L (CMC); 1.3 mg/L (CCC)	USEPA 2000b	CTR for unfiltered sample assuming hardness of 10 mg/L as $CaCO_3$
		3.79 mg/L (CMC); 2.85 mg/L (CCC)	USEPA 2000b	CTR for unfiltered sample assuming hardness of 25 mg/L as $CaCO_3$
Lead	Pb	4.35 mg/L (CMC); 0.17 mg/L (CCC)	USEPA 2000b	CTR for unfiltered sample assuming hardness of 10 mg/L as $CaCO_3$
		13.98 mg/L (CMC); 0.54 mg/L (CCC)	USEPA 2000b	CTR for unfiltered sample assuming hardness of 25 mg/L as $CaCO_3$
Nickel	Ni	68.44 mg/L (CMC); 7.44 mg/L (CCC)	USEPA 2000b	CTR for unfiltered sample assuming hardness of 10 mg/L as $CaCO_3$
		149.96 mg/L (CMC); 16.14 mg/L (CCC)	USEPA 2000b	CTR for unfiltered sample assuming hardness of 25 mg/L as $CaCO_3$
Silver	Ag	0.08 mg/L (CMC)	USEPA 2000b	CTR for unfiltered

Table 2-13. Surface Water Quality Criteria to Support Designated Beneficial Uses

Basin Plan Water Quality Objective (potentially affected beneficial uses)	Symbol or Abbrev.	Numeric Water Quality Criteria to Support Beneficial Use	Reference	Notes
				sample assuming hardness of 10 mg/L as $CaCO_3$
		0.37 mg/L (CMC)	USEPA 2000b	CTR for unfiltered sample assuming hardness of 25 mg/L as $CaCO_3$
Zinc	Zn	17.03 mg/L	USEPA 2000b	CTR for unfiltered sample assuming hardness of 10 mg/L as $CaCO_3$
		37.02 mg/L	USEPA 2000b	CTR for unfiltered sample assuming hardness of 25 mg/L as $CaCO_3$

1. U.S. Environmental Protection Agency
2. California Department of Health Services

(Source: SFRWQCB 1995)

For water quality objectives under biostimulatory substances, ambient water quality criteria recommendations from USEPA (2000a) were used to represent typical reference levels to determine whether nutrient levels were higher than those found at other locations of similar geologic, hydrologic, and plant communities. Although these were not originally proposed as hard criteria, USEPA developed these guidelines to provide for the protection and propagation of aquatic life and recreation. Table 2-13 includes criteria based on the lower 25th percentile of several thousand samples collected within the Sierra Nevada and California's Central Valley. USEPA adopted these levels to represent background levels in undisturbed watersheds.

For water quality objectives related to toxicity, Title 22 (CDHS 2005) and the California Toxics Rule (CTR) (USEPA 2000b) were used to determine acceptable levels of ammonia, nitrate, and trace metals. Section 131.38 of Title 40 Code of Federal Regulations establishes criterion maximum concentrations (CMC) as the highest concentration to which aquatic life can be exposed for a short period of time without deleterious effects. Criterion continuous concentrations (CCC) are defined as the highest concentration to which aquatic life can be exposed for an extended period of time (4 days) without deleterious effects. Because of differences in acute and chronic toxicity of many elements and compounds in Table 2-13 to aquatic organisms as well as variations in acute and chronic toxicity in relation to ambient water conditions such as pH or hardness, several entries have multiple criteria. The criteria for six of the metals (cadmium, copper, lead, nickel, silver, and zinc) are reported for unfiltered (i.e., total metals) samples from the CTR (USEPA 2000b) and calculated in 5 milligram per liter (mg/L) increments of hardness because the level at which each of these metals is reportedly toxic to aquatic life is lower at lower hardness levels. In addition, the CMC and CCC levels for ammonia are a function of both pH and temperature and are presented over a range of 0–20°C (32–68°F) in pH increments of 1 standard unit.

2.6.2 Available Water Quality Data

Madej (1989) summarized the results of six USGS water quality sampling events conducted twice per year from 1986 through 1988 at several locations in the lower Redwood Creek watershed. Two locations in Redwood Creek (Muir Woods Bridge and Pacific Way Bridge) were sampled along with samples from the lower portion of the Green Gulch tributary (lower Green Gulch). The report provides perhaps the earliest metals data for the watershed, mostly below detection limits and well below regulatory standards with the exception of anomalously high copper results (80 micrograms per liter [ug/L]) at Muir Woods and Pacific Way bridges in 1987. Although no follow-up sampling has been performed since that time to confirm these results within the mainstem of Redwood Creek, copper data collected for the stables at the Golden Gate Dairy tributary to Redwood Creek indicated dissolved copper levels from 1–10 ug/L in 2001, falling to below 1 ug/L in 2002 (NPS 2002). With background hardness levels on the order of 40 mg/L as $CaCO_3$, the historical samples for total copper within lower Redwood Creek are in excess of freshwater toxicity criteria for aquatic life (4–6 ug/L) established under the CTR (USEPA 2000b).

In the 1986–1988 monitoring, higher levels of coliform bacteria and phosphorus were identified within the lower Redwood Creek watershed than at other locations within the GGNRA (Madej 1989). For example, the highest concentration of phosphorus (PO_4) recorded in the Redwood Creek watershed was 0.08 mg/L at Muir Woods Road Bridge in February 1987, whereas the concentrations at downstream stations during the same period were one quarter of this value. Although no intensive sampling was conducted to determine compliance with the 30-day-log-mean criteria for bacteria (Table 2-13), high fecal coliform levels were documented, with the highest reading of 8,000 most-probable-number (MPN) fecal coliform/100 mL occurring at Muir Beach in March 1987. Because these findings raised concerns over septic contamination of the lower watershed, Muir Woods National Monument has since been taken off septic disposal of domestic wastewater. Sewage from Muir Woods currently is pumped out of the watershed to Mill Valley, where it is treated and discharged by the Sewerage Agency of Southern Marin.

Based on concerns over nutrients raised by USGS (Madej 1989), NPS hired PWA (1993) to collect and summarize water quality data at a number of sites in the lower Redwood Creek watershed from 1986 through 1993, particularly as it related to habitat conditions in the brackish backwater lagoon area (Big Lagoon) adjacent to Muir Beach. Harding-Lawson and Associates (1991) sampled upstream of the Highway 1 Bridge for a Muir Beach Community Services District water quality study. Upstream of the Golden Gate Dairy horse stables and Banducci flower farms in Frank Valley, fecal coliform measurements on Redwood Creek generally were within the range of 30 MPN/milliliter, with higher levels downstream of the stables. Samples from lower Green Gulch indicated that runoff from horse and agricultural activities in this area also were significant sources of coliform and nitrogen (PWA 2003).

Between February and May 1994, thirteen locations were sampled in the Redwood Creek watershed by researchers from the University of San Francisco (Podlech at al. 1994), including many headwater tributary locations. Samples were analyzed for physical water quality (i.e., temperature, dissolved oxygen [DO], conductivity, pH), nutrients, minerals, metals, bacteria and benthic macro-invertebrates (BMI). Elevated metals concentrations in headwater samples were attributed to serpentine soil formations. Nutrients and bacteria were lowest in headwater areas and increased below Muir Woods.

Beginning in the mid 1990s, the NPS implemented an intensive water quality monitoring program in the lower Redwood Creek watershed, related to equestrian trail use and management practices at the Golden Gate Dairy where 29 horses were in stables or pasture (Vore 1997). In the 1997–1998 water quality monitoring, waters were tested for fecal coliform at Muir Woods, Pacific Way, Muir Beach, Golden Gate Dairy, and Green Gulch Creek (Vore 1997). In these tests, median fecal coliform at Muir Woods and Green Gulch was within CDHS single-sample criteria (Table 2-13). Samples at Pacific Way, Golden Gate Dairy, and Big Lagoon exceeded laboratory detection limits and exceeded health standards, indicating fecal coliform contamination. The 1997–1998 monitoring also indicated elevated levels of total suspended solids (TSS) in runoff from the Golden Gate Dairy (Beutel 1998). In storm water samples taken at Muir Woods, Pacific Way, and the Golden Gate Dairy, mean TSS concentrations were 14 mg/L, 48 mg/L, and 263 mg/L, respectively. Since this study, the NPS and Ocean Riders, the occupant at Golden Gate Dairy, have implemented measures to reduce sediment erosion and runoff contamination from the dairy by reducing the number of horses, removing horses from the hillside pastures, removing stables next to the tributary, and creating a vegetated buffer zone, among other measures.

From 1999–2004, the NPS continued to monitor water quality in the vicinity of Golden Gate Dairy as well as Green Gulch to determine the need for additional management measures. Water quality monitoring studies completed during this period suggested that the stables in the Redwood Creek watersheds may be pollution sources to downstream waters within the Park (Vore 1997, Beutel 1998, Fong and Canevaro 1998). In particular, samples collected at sites downstream of the stables are higher in bacteria, nutrients (NH3, NO3, PO4), sediments (Conductivity, TSS), and oxygen demand (Low DO or high biochemical oxygen demand) than those at upstream sites. Subsequent monitoring conducted since improved management of stables at the Golden Gate Dairy showed general reductions in bacteria concentrations (PWA 2003). However, downstream locations continue to exhibit elevated nutrient concentrations and the beach was posted in summer 2003 for exceeding state standards for recreational contact, and in summer 2005 because of 20-day exceedance violations for Enterococcus bacteria in ocean water samples collected by the Marin County Department of Health and Human Services. A follow-up analysis of data collected by the NPS in 2004–2005 was conducted by Stillwater Sciences, suggesting land use practices at the stables and other locations continued to result in excess nutrients and bacteria to the lower watershed (Stillwater Sciences 2005a). Four additional sampling events, completed by DHS in August 2005, focused on low-flow conditions. Results from these efforts showed higher concentrations of bacteria at all sampled locations downstream of the Highway 1 Bridge than locations upstream of the Highway 1 Bridge (DHS, unpubl. data, August 2005), with individual samples regularly exceeding the single day criteria for E. coli. and Enterococcus (Table 2-13). However, no beach samples collected in August 2006 were found in excess of the applicable bacteria criteria for contact recreation.

2.6.3 Comparisons of Water Quality Data with Applicable Criteria

On the basis of the data compiled since the late 1980s in the Redwood Creek watershed (summarized above and detailed in Appendix B), a brief review of whether water quality supports designated beneficial uses is provided below. Overall, no known water quality impairments exist for agricultural and municipal uses.

Bacteria

In addition to State DHS requirements for bacteria in municipal water supplies, Table 2-13 shows the Basin Plan (SFRWQCB 1995) water quality objective for bacteria in waters designated for contact recreation (REC-1). For comparison to water quality objectives for bacteria, Appendix B provides a long-term data summary, and Stillwater Sciences (2005a) provides a summary of the log-mean (i.e., average) of the long-term bacterial results for the seven sampling events conducted from 2004–2005. Although no consecutive daily samples were collected on which to calculate the log-mean or exceedance probabilities, municipal water supply uses may not be supported below Muir Woods on the basis of high fecal coliform results, and downstream of Heather Horse Camp on the basis of total coliform. Water contact recreation (REC-1) uses also would not be supported at most downstream locations in lower Redwood Creek on the basis of total coliform and Enterococcus exceedances.

The results presented to date suggest the need for regular sampling events (greater than five events in 30 days) to confirm the nature of the apparent exceedances as well as targeted follow-up sampling at particular locations. Other potential sources of bacteria that have not been validated through sampling include: (1) fugitive leachate from septic systems within the town of Muir Beach and properties adjacent to Redwood Creek, and (2) equestrian related loadings at the Redwood Creek trail crossing upstream of the Banducci property. Although no comprehensive data on septic system management was reviewed for this report, the Pelican Inn reported undertaking septic maintenance in about 2003, and Green Gulch Farm replaced an old septic tank in the upper farm fields in summer 2005.

Biostimulatory Substances

The Basin Plan requires that water not contain biostimulatory substances which promote aquatic growths in concentrations that cause nuisance or adversely affect beneficial uses. Nutrient levels found from 2004–2005 as well as in separate surveys conducted by SFRWQCB (2008a) (Section 2.6.4) are consistent with historical data reported in PWA (2003) and suggest the continuing contribution of nutrients above regional reference levels. Because of the low dissolved oxygen levels encountered at several downstream locations during summer and autumn (Appendix B), it is apparent that nutrient enrichment (i.e., eutrophication) is occurring within the lower Redwood Creek watershed. On the basis of the estimated nitrogen to phosphorus ratios shown in Appendix B, the upper watershed appears to be largely nitrogen limited (TIN:PO4 less than 10), with ratios greater than this, indicating a switch to phosphorus limitation during some sample events and at locations within the lower watershed (Cooperider 2004). These measurements indicate that phosphorous should have a greater biostimulatory effect than nitrogen in the lower portions of the watershed. Phosphorous can be introduced to waters through residential or agricultural fertilizer applications, septic tank seepage, and associated with fine sediment. Because of the higher relative levels of downstream phosphorus at Heather Horse Camp, Golden Gate Dairy, and Green Gulch, additional sediment control measures and limitations on fertilizer use may reduce observed eutrophication effects and measured nutrient levels in the lower Redwood Creek watershed.

Chemical Constituents

The Basin Plan requires that water designated for use as domestic or municipal supply not contain concentrations of chemical constituents in excess of the maximum containment levels specified in the provisions of Title 22 of the California Code of Regulations. Observed levels of nitrate and ammonia (Appendix B) were well below regulatory levels for drinking water uses. Other than historical cadmium levels that exceeded the Table 2-13 criteria, no exceedances in Title 22 contaminants were found.

Dissolved Oxygen

Dissolved oxygen concentrations in water depend on several factors, including temperature (i.e., colder water absorbs more oxygen), the volume and velocity of water flowing in the water body (re-aeration), salinity, and the amount of organisms using oxygen for respiration. This last factor (respiratory consumption) is, in turn, strongly influenced by the availability of eutrophic nutrients (N and P), naturally derived from allochthonous sources (e.g., leaf litter), but more commonly arriving in runoff from fertilized agriculture, human, and animal wastes. The Basin Plan requires that the monthly median of the mean daily dissolved oxygen concentrations not fall below 85 percent of saturation in the main water mass. Minimum dissolved oxygen levels are required to remain above 7 mg/L at all times for cold water beneficial uses and above 5 mg/L for warm water uses (Table 2-13).

Appendix B shows that samples collected within the lower watershed from 1993 through 2005 are routinely at or below the cold water dissolved oxygen objective of 7 mg/L during August, September, and October (Table 2-13). Continuous water quality data within lower Redwood Creek (dissolved oxygen summarized in Table 2-13) was collected over 4 years: 1998, 1999, 2001, and 2002 (Fong and Manning 2007), as well as in SFRWQCB (2008a) surveys (Section 2.6.4) that also support the observations of low dissolved oxygen in prior surveys. On the basis of the low dissolved oxygen levels observed in one or more sampling events, it is apparent that sites within lower Redwood Creek do not support designated beneficial uses of cold and warm water aquatic habitat during the late summer/early fall period. Although conditions appear to improve with higher flows and pool connectivity (Fong and Manning 2007), continued episodes of lower dissolved oxygen at downstream locations suggest that existing land use practices result in DO levels that do not meet standards for cold and warm water aquatic habitat.

pH

The Basin Plan requires that the pH not be depressed below 6.5 nor raised above 8.5. Although a single sample exceedance for the Camino del Canon tributary occurred after the NPS limed the road for erosion control (Fong and Canevaro 1998), no other exceedances of Basin Plan criteria were identified (Appendix B).

Temperature

Water temperatures within the Redwood Creek watershed generally range from 51–59ºF (Appendix B), with occasionally higher temperatures up to 64–66º F in late summer and early fall (September–October). Although these temperatures are within the tolerance of many aquatic organisms, peak summertime temperatures within unshaded areas downstream of Pacific Way have been reported to exceed 68ºF (PWA 2003:Appendix B). Although later summer water temperatures in recent (SFRWQCB 2008a) and historical data (Appendix B) approach recommended criteria for coho salmon and steelhead trout (Sullivan et al. 2000), long-term monitoring using calibration-checked thermographs will be required to validate temperature exceedances at particular locations.

Toxicity

The Basin Plan requires that waters be maintained free of toxic substances in concentrations that produce detrimental physiological responses in human, plant, animal, or aquatic life. Of the parameters examined in Appendix B, ammonia levels were the only ones with the potential for aquatic toxicity. Observed ammonia concentrations (Table 2-13) were well below toxicity levels established under the California Toxics Rule (Table 2-13). At the pH values found in this study (pH=7–8 standard units), unionized ammonia (NH3 vs NH4+) represents 1–5 percent of the total ammonia levels, with corresponding concentrations well below the 0.025 mg/L water quality objective as an annual median concentration of the unionized ammonia shown in Table 2-13. In terms of direct toxicity caused by metals, the moderate levels of alkalinity and hardness found throughout the watershed decrease the proportion of free ions of many trace metals, making them less toxic. No exceedances of Basin Plan criteria (Table 2-13) were identified in the historical data (Appendix B).

2.6.4 Current Water Quality Monitoring Efforts

Between 2001 and 2005, the San Francisco Bay Region Surface Water Ambient Monitoring Program (SWAMP) used a rotating basin sampling design to perform year-long surveys of water quality conditions in a select number of watersheds around the region, including five sites in the Redwood Creek watershed: Muir Woods (downstream of Spike Buck Creek), Miwok Bridge (downstream of Muir Woods Bridge), lower Redwood Creek (at Pacific Way), Green Gulch tributary (lower), and at Muir Beach (at Pedestrian Bridge) (SFRWQCB 2008a).

Water quality monitoring included BMI and physical habitat sampling at the three Redwood Creek sites (number of taxa, percent of environmentally sensitive orders [EPT], fine sediment); continuous monitoring of in situ water quality at all sites (temperature, DO, pH, conductivity); analytical water chemistry (nutrients at the lower Redwood Creek and Green Gulch tributary sites); and dry season sampling of total coliform bacteria at Muir Beach. A summary of findings from these monitoring surveys is as follows:

- Although the BMI community metrics for mainstem Redwood Creek sites were indicative of minimal disturbance, BMI samples from Green Gulch tributary exhibited reduced taxonomic richness, EPT richness, and percent of EPT, with large accumulations of fine sediment (greater than 70 percent).

- Although the Basin Plan does not contain specific water temperature objectives for Redwood Creek (Table 2-13), water temperatures were generally were within thresholds for coho salmon and steelhead trout (Sullivan et al. 2000), with the exception of short-term excursions above 17ºC in lower Redwood Creek.

- Dissolved oxygen also was found to be generally above the 7 mg/L criterion for coldwater habitat (Table 2-13).

- No exceedances of water quality objectives for pH (6.5–8.5) or specific conductivity (less than 1,000 microsiements per centimeter) were observed in Redwood Creek or the Green Gulch tributary.

- Data for nutrients indicated exceedances of regional reference guidelines (USEPA 2000a) in lower Redwood Creek and within the Green Gulch tributary, although these reference conditions may be inappropriate for watershed with some degree of urban development (SFBRWQCB 2008a).

Follow-up sampling, for the parameters above as well as additional parameters, was planned for the Miwok Bridge site in the 2007–2008 SWAMP work plan (SFBRWQCB 2008b) with reporting expected in 2010.

2.7 Aquatic Species and Habitats

2.7.1 Fish, Amphibians, and Aquatic Reptiles

The Redwood Creek watershed is known to harbor at least 20 native aquatic vertebrate species, including nine native fishes (Table 2-14), nine native amphibians, and two native aquatic reptiles (one turtle and at least one species of garter snake). Two non-native fish species and one non-native turtle also have been identified in the watershed (Tables 2-14 and Appendix C).

Fish

Numerous investigations have been conducted since 1992 to document fish distribution and abundance in Redwood Creek and its estuary. Fish surveys were conducted in 1992 and 1993 for an Environmental Assessment (PWA et al. 1994). Subsequent investigations have included a report on the use of lower Redwood Creek and Big Lagoon by juvenile coho salmon and steelhead (Fong 1996), annual distribution and abundance surveys for juvenile coho salmon and steelhead (Smith 1994b, 1995, 1996, 1997, 1998, 2000, 2001), salmonid outmigrant trapping in 1996 (Fong 1997a), an anadromous salmonid spawner and carcass survey, conducted in winter 1996–1997 (Fong 1997b), and a usage study of the Big Lagoon estuary (and other central California estuaries) by rearing coho salmon and steelhead (Laidig 2003). Table 2-14 shows the fish species documented in the watershed from 1992–2002. In addition to the species documented during these identified surveys, the NPS has observed Sacramento blackfish (*Orthodon microlepidotus*) and yellowfin gobies (*Acanthogobius flavimanus*) in the tidal lagoon, and Fellers and Guscio (2004) observed Sacramento pikeminnow (*Ptchocheilus grandis*) in Green Gulch Creek (Table 2-14).

In addition to the 1996–97 anadromous salmonid spawner and carcass survey, the NPS has conducted annual surveys to document live adult coho salmon, carcasses, and redds in the Redwood Creek watershed from 1994–95 through 2004–05 (Reichmuth et al. 2005). One-time spawner surveys were also conducted by the California Department of Fish and Game in 1969, 1977–78, and 1985–86 (Reichmuth et al. 2005). The results of all adult coho salmon surveys to date are summarized in Section 2.7.3 (see Table 2-16).

Table 2-14. Fish Species Documented in Redwood Creek and the Big Lagoon Estuary (1992–2002)

Fish Species	Native (N) or Introduced (I)	Years Observed	Source	Tidal Lagoon	Redwood Creek
Sacramento blackfish[1] (*Orthodon microlepidotus*)	I	1992	PWA et al. (1994)	X	
Topsmelt (*Atherinops affinis*)	N	1995	Fong (1996)	X	
coho salmon (*Oncorhynchus kisutch*)	N	1992 1993 1994 1995 1996 1997	PWA et al. (1994); Fong (1996, 1997a, 1997b); Smith (1994b, 1995, 1996, 1997, 1998, 2000, 2001);	X	X

Table 2-14. Fish Species Documented in Redwood Creek and the Big Lagoon Estuary (1992–2002)

Fish Species	Native (N) or Introduced (I)	Years Observed	Source	Tidal Lagoon	Redwood Creek
		1998 2000 2001 2002	Laidig (2003)		
Steelhead (*Oncorhynchus mykiss*)	N	1992 1993 1994 1995 1996 1997 1998 2000 2001 2002	PWA et al. (1994); Fong (1996, 1997a, 1997b); Smith (1994b, 1995, 1996, 1997, 1998, 2000, 2001); Laidig (2003)	X	X
Threespine stickleback (*Gasterosteus aculeatus)*	N	1992 1993 1994 1995 1996 2001 2002	PWA et al. (1994); Smith (1994b); Fong (1996, 1997a); Laidig (2003)	X	X
Prickly sculpin (*Cottus asper*)	N	1992 1993 1994 1995 1996	PWA et al. (1994); Smith (1994b); Fong (1996, 1997a)	X	X
Coast range sculpin (*Cottus aleuticus*)	N	1995	Fong (1996)	X	
Riffle sculpin (*Cottus gulosus*)	N	1992 1993 2001	PWA et al. (1994); Smith (2001)		X
Pacific staghorn sculpin *Leptocottus armatus*)	N	1992 1993 1995	PWA et al. (1994); Fong (1996)	X	
Striped bass (*Morone saxatilis*)	I	1992 1995 2002	PWA et al. (1994); Fong (1996); Laidig (2003)	X	
Sacramento perch [1] (*Archoplites interruptus*)	I	1993	PWA et al. (1994)	X	
Yellowfin goby (*Acanthogobius flavimanus*)	I	1992 1993	PWA et al. (1994)	X	
Starry flounder (*Platichthys stellatus*)	N	1992 1993	PWA et al. (1994)	X	

1. Native to other California river systems; introduced into the Redwood Creek drainage.

Sources: (PWA et al. 1994; Fong 1996, 1997a, 1997b; Smith 1994b, 1995, 1996, 1997, 1998, 2000, 2001; Laidig 2003; and Guscio 2004.

Amphibians and Aquatic Reptiles

The following herpetological surveys have been conducted by NPS staff, USGS researchers, and contractors since 1992 in the Redwood Creek watershed:

- 1992–1993: surveys for amphibians and reptiles in wetland and riparian habitats in Big Lagoon and ponds in Green Gulch (PWA et al. 1994)
- 1993: frog and frog habitat surveys in upper Redwood Creek in the vicinity of Muir Woods National Monument and Frank's Valley (primarily focused on foothill yellow-legged frog [*Rana boylii*] habitat), as well as in the area of Big Lagoon (Ely 1993, PWA et al. 1994)
- 1997: California giant salamander [*Dicamptodon ensatus*] surveys in the upper Redwood Creek watershed (Fong and Howell 2006)
- 1998: California red-legged frog breeding surveys at ponds and wetlands in Green Gulch Valley (Cook 1998)
- 2002–2003: intensive California red-legged frog surveys—including radio-tracking—in and around Big Lagoon (further addressed in Section 2.7.3) (Fellers and Guscio 2004)
- 2004: California red-legged frog breeding season surveys in the Big Lagoon area (Wood 2004)
- 2003–2006: California red-legged frog surveys within the boundary of the GGNRA, including continued investigation of amphibians in Big Lagoon and lower Redwood Creek (Fong and Campo 2006)

All amphibians and reptiles recorded in Redwood Creek watershed (or predicted to occur based on habitat conditions), including terrestrial species, are listed in Appendix C. In Big Lagoon, California newts (*Taricha torosa*), rough-skinned newts (*Taricha granulosa*), Pacific chorus frogs (*Pseudacris regilla*), ensatinas (*Ensatina eschscholtzii*), and slender salamanders (*Batrachaseps attenuatus*) were all seen with some frequency (PWA et al. 1994, Wood 2004). California red-legged frogs were seen regularly, but in low numbers, as discussed in more detail in Section 2.6.3. California giant salamanders have been observed in the upper Redwood Creek watershed, particularly in headwater tributaries to Redwood Creek, both perennial and intermittent (Fong and Howell 2006, Garcia and Associates 2007). Fong and Howell (2006) suggest that giant salamanders could be used as an indicator species for the watershed because (1) they are typically associated with habitat features characteristic of healthy stream conditions (e.g., abundance of larger substrates and undercut banks), (2) they are less mobile than anadromous fish, which means that population trends may be more closely tied to local habitat conditions, and (3) they can be sampled with relative ease. Several reports have been made on western pond turtles (*Actinemys marmorata*) in Redwood Creek (PWA et al. 1994, Fong 2002); however, a lack of sightings has been reported in the last several years (Jones & Stokes 2007). The non-native bullfrog (*Rana catesbeiana*), an invasive species that can potentially prey on and/or outcompete several of the native amphibian species has not been observed in the Redwood Creek watershed, although it is known to occur in the adjacent Tennessee Valley watershed (PWA et al. 1994).

Foothill yellow-legged frogs (a California Species of Special Concern) historically have been found along Redwood Creek (Ely 1993, Fong 1997b). Although suitable habitat still exists for the species, no foothill yellow-legged frogs have been found during surveys conducted over the past 15 years (Ely 1993, PWA et al. 1994). This species presumably has been extirpated from the Redwood Creek watershed.

2.7.2 Aquatic Invertebrates

Aquatic macroinvertebrates are important as food for fish and as indicators of stream conditions. A limited number of aquatic invertebrate studies have been conducted in the Redwood Creek watershed. Much of the research has been to inventory the invertebrate taxa and apply basic metrics to the data to attain biotic indicators of water quality conditions related to fine sediments, organics, and water temperature. Some studies were focused on a single species or specific habitat. Comparisons among these studies are difficult because of differences in sampling methods and study goals.

The SFRWQB (2008a) conducted benthic macroinvertebrate studies as part of the SWAMP between 2001 and 2005, as described in Section 2.6.4, *Current Water Quality Monitoring Efforts*. The NPS conducted invertebrate surveys in mainstem Redwood Creek in 1995 and 1997, at six locations, and found that invertebrate communities differed between the downstream-most site and those upstream (Fong 2002). Specifically, the downstream site below the Pacific Way Bridge exhibited lower species diversity and higher proportions of dominant taxa. This study also found that higher invertebrate abundance was associated with smaller substrate particle sizes, and concluded that reaches that experience higher shear stress (as indicated by larger substrate particle sizes) may result in lower densities of benthic macroinvertebrates.

Additional invertebrate surveys in seasonal and perennial wetlands near the mouth of Redwood Creek have been conducted by the NPS (Fong et al. 2003) and Philip Williams and Associates (PWA et al. 1994). Fong et al. (2003) found that the pasture wetlands in the vicinity of the mouth of Redwood Creek supported higher invertebrate densities and species diversity than Redwood Creek and the other seasonal wetlands adjacent to the creek. Within wetland sites, vegetated margins had higher invertebrate densities and species diversity than open water areas. Mainstem Redwood Creek sites had moderate to low invertebrate abundance and diversity compared to backwater and off-channel habitats. These results are similar to those reported by PWA and others (1994) as part of the Big Lagoon environmental assessment, which found invertebrate abundance and diversity to be greater in habitats outside of the mainstem channel of Redwood Creek, such as perennial ponds, especially in late winter. This study pointed out that during late winter and spring surveys conducted in 1993, reduced density was apparent at sites in the mainstem of Redwood Creek relative to the off-channel habitats, suggesting that high-flow events in winter and spring may displace macroinvertebrates downstream but leave those in off-channel habitats relatively undisturbed. The PWA et al. (1994) study concluded that insect abundance (density) and diversity was positively correlated with the amount of aquatic and emergent vegetation.

Species-focused studies also have been conducted in the Redwood Creek watershed. In 1997 and 1998, the USGS performed a study to determine the abundance and distribution of California giant salamander and the non-native signal crayfish (*Pacifastacus leniusculus*) in the upper Redwood Creek watershed (Fong and Howell 2006). The study found signal crayfish throughout the mainstem of Redwood Creek, but not in first-order streams or upstream of fish barriers. Instances of predation on larval giant salamanders by signal crayfish were recorded, but larval salamanders appeared to prefer different habitat than signal crayfish. This may indicate that competitive exclusion is taking place, but further studies are needed to confirm whether this is the case.

A habitat-focused invertebrate survey was conducted by Kimball and Kondolf (2002) as part of a project to explore the feasibility of riprap removal in Redwood Creek. The goal of the survey was to determine differences in the invertebrate community between two types of banks, natural and rip-rapped. Higher invertebrate diversity and abundance were found along natural banks compared to rip-rapped banks. The study concluded that natural banks in Redwood Creek provide higher quality habitat for invertebrates than rip-rapped banks.

The SFRWQCB (2008a) stated that because of the limited sampling history and geographic extent of existing BMI data, establishing trends that allow assessment of long-term changes in ecological conditions is not possible. However, additional studies may occur in the watershed because Redwood Creek has been selected as a reference site for SWAMP studies based on the relatively high quality of the BMI community (SFRWQCB 2008a). Such additional surveys of macroinvertebrates in Redwood Creek are needed to identify any long-term trends.

2.7.3 Special-Status Aquatic Species

Three aquatic species protected by the state and/or federal Endangered Species Acts occur in the watershed. These are coho salmon, steelhead, and California red-legged frog. Steelhead and California red-legged frog are listed as threatened under the Federal Endangered Species Act. The federal listing status of the coho salmon found in the Redwood Creek watershed was upgraded from threatened to endangered in June 2005 (70 Federal Register 37160). Coho salmon also is listed as endangered under the California Endangered Species Act, and California red-legged frog is considered a Species of Special Concern by California Department of Fish and Game (CDFG). Because these species require a range of habitat types and are especially sensitive to habitat disturbance and degradation, they may serve as indicators of ecosystem health in the watershed.

No sensitive aquatic invertebrates are considered likely to be present in the Redwood Creek watershed. The NPS conducted surveys in the watershed in 1986 and 1997, to document the occurrence of California freshwater shrimp (*Syncaris pacifica*), but recorded no individuals of this species (Serpa 1986, Fong 1997c and 1999). In addition, surveys conducted in the Muir Beach area in 1992 did not encounter the San Francisco fork-tailed damselfly (*Ischnura gemina*), Leech’s Skyline diving beetle (*Hydroporous leechi*), or the Ricksecker’s water scavenger beetle (*Hydrochara rickseckeri*), all of which were considered sensitive species by the U.S. Fish and Wildlife Service (USFWS) (Category 2) at the time of the surveys (Hafernik and Mead 1992).

Coho Salmon

Coho salmon found in the Redwood Creek watershed belong to the Central California Coast ESU (NMFS 1997), which includes (1) coastal drainages from Punta Gorda in northern California south to and including the San Lorenzo River in central California (although coho salmon are occasionally observed further south), and (2) the drainages of San Francisco and San Pablo bays, excluding the Sacramento-San Joaquin River basin. This ESU is listed as endangered under both the federal (NMFS 1996, 2005) and state (CDFG 2002) Endangered Species Acts. Designated critical habitat includes all river reaches and estuarine areas accessible to coho salmon within the ESU’s geographic area (NMFS 1999). Redwood Creek is included in the critical habitat designated for this ESU, which was announced on September 2, 2005, and became effective January 2, 2006 (70 Federal Register 52488). The National Marine Fisheries Service released the draft recovery plan in March 2010 (NMFS 2010.

Coho salmon populations in California have generally declined, and this species no longer occupies many of the streams in California where these fish have historically occurred (Hassler et al. 1991, Brown et al. 1994). Brown et al. (1994) estimated that coho salmon populations in California have decreased to less than 6 percent of the size reported for the 1940s. In the Central California Coast ESU, where historical populations of naturally spawning fish are estimated to have numbered between 50,000 and 125,000, current abundance is estimated to be less than 5,000 fish, with many of these considered being of hatchery origin (Brown and Moyle 1991, Bryant 1994, CDFG 1994).

Similar to the rest of the ESU, the Redwood Creek population appears to be in low abundance since the 1970s, although data describing adult coho salmon abundance and distribution in Redwood Creek before 1995 are sparse. Surveys for adult coho salmon were conducted by CDFG in 1969, 1977–1978, and 1985–1986 (Table 2-15). Since winter 1994–95, the NPS has conducted more comprehensive monitoring of coho throughout the watershed, including documenting adult abundance, spawning distribution (redd surveys), and juvenile abundance and distribution. Early surveys in the watershed (before 1997) used the peak live plus cumulative dead index to estimate adult escapement (Table 2-15). However, this approach does not take into account observer detection error or a protracted spawning period, and is a minimum estimate-based on the peak observations of fish. More recent monitoring has used an "Area Under the Curve" approach, taking into account residency time of spawners, and an observation efficiency for surveyors (assumed to be 50 percent). Since monitoring began, estimated adult abundance has ranged from a low of zero adults in 1999–2000 and 2007-2008 to 171 adults in 2004–2005 (Table 2-15).

Coho salmon in the southern extent of their range have a fixed, 3-year maternal brood year cycle that makes them particularly vulnerable to natural and anthropogenic catastrophic events (Anderson 1995). In most Central Coast watersheds, all brood year lineages are severely reduced and only few streams sustain naturally spawning populations (CDFG 2002). In Redwood Creek, two brood years (2005/2006 and 2006/2007 escapements) are in low abundance but consistently viable. The 2007/2008 brood class was steadily increasing in population size until 2007, when a complete crash was observed. The reasons for the crash are not known, but may be related to extremely poor ocean conditions and subsequent low marine survival of the smolts produced in 2005 (MacFarlene et al. 2008).

Recent genetic analyses have been conducted using coho salmon tissue and scale samples collected from fresh carcasses during the annual NPS spawner surveys. A phylogeographic tree derived from these analyses indicates that coho salmon found in Redwood Creek and Pine Gulch Creek are a distinct subgroup that does not show close genetic relationship with any other coho salmon subgroup in the Central California Coast ESU (Garza and Gilbert-Horvath 2003). Although these results were based on sampling only one fish, they suggest that the Redwood Creek population is not heavily influenced by hatchery introductions. In addition, the results also suggested the population did not suffer the reduced genetic diversity that is a signature of bottlenecks. Overall, this limited information suggests that the current population has the genetic integrity to increase in abundance, in comparison to those populations that are apparently composed mostly of strays from other basins or from hatcheries.

Adult coho salmon return to Redwood Creek as 2- or 3-year-olds and have been observed in the creek from November through February. Life history timing for coho salmon in Redwood Creek is shown in Table 2-16. Peak spawning in Redwood Creek typically occurs from mid-December to mid-January (Reichmuth et al. 2005). In the Redwood Creek watershed, spawning has been observed in the mainstem creek from the Pacific Way Bridge to the upstream boundary of Muir Woods National Monument at river mile (RM) 4.8, and in Fern Creek from its confluence with Redwood Creek upstream to the first impassable falls, at approximately 0.4 mile upstream of the Redwood Creek confluence (Fong 1997b). Juvenile salmonids were also observed in 2010 above Kent Falls in Kent Creek by State Parks and Regional Water Quality Control Board staff (Bjelajac, pers. comm., 2011). Based on observations since 1997, redd densities typically are highest near the main visitor access areas of Muir Woods, approximately RM 3.1–3.7 upstream from the ocean, although the reasons for this are not known (Carlisle et al. 2008).

Table 2-15. Summary of Results of Coho Salmon Spawner Surveys in the Redwood Creek Watershed

Year	Number of Surveys	Survey Length (km)	PLD Index[1]	AUC Range 50% OE RT 8–17 Days[2]	Total Carcasses	Total Redds	Source
1969	1	3.2	24	--	4	--	CDFG, as cited in Del Real et al. 2007
1977–1978	1	3.2	36	--	3	--	CDFG, as cited in Del Real et al. 2007
1985–1986	1	7.2	50	--	--	--	CDFG, as cited in Del Real et al. 2007
1994–1995	5	8.4[3]	58	--	22	--	NPS Fong 1995, as cited in Del Real et al. 2007
1995–1996	5	8.4[3]	27	--	18	--	NPS Fong 1996, as cited in Del Real et al. 2007
1996–1997	6	8.4[3]	57	--	15	--	NPS Fong 1997, as cited in Del Real et al. 2007
1997–1998	7	9.4[4]	65	177–376	30	80	NPS Manning 1999, as cited in Del Real et al. 2007
1998–1999	11	9.4[4]	39[5]	78–167	10	58	NPS CSRP, as cited in Del Real et al. 2007
1999–2000	6	8.4[3]	10	16–35	1	7[10]	NPS CSRP, as cited in Del Real et al. 2007
2000–2001	5	9.4[4]	49	148–314	13	35	NPS CSRP, as cited in Del Real et al. 2007
2001–2002	5	9.4[4]	105[6]	233–494	63	47	NPS CSRP, as cited in Del Real et al. 2007
2002–2003	5	9.4[4]	24[7]	43–92	3	7[10]	NPS, as cited in Del Real et al. 2007
2003–2004	6	9.4[4]	67	86–182	25	43	NPS, as cited in Del Real et al. 2007
2004–2005	7	9.4[4]	171[8]	338–718	76	93	NPS, as cited in Del Real et al. 2007
2005–2006	5	9.4[4]	27[5]	55–117	5	12	NPS, as cited in Del Real et al. 2007
2006–2007	9	9.4[4]	28[9]	46–98	6	21	NPS, as cited in Del Real et al. 2007
2007–2008	7	9.4[4]	0	--	0	0	NPS 2008

1. PLD is the adult population estimate, derived from the combined peak count of live and cumulative dead adult salmon.
2. The Area Under the Curve (AUC) method is dependent on two variables, observer efficiency (OE) and fish residence time (RT) in the freshwater following entry.
3. Includes the main stem of Redwood Creek and Fern Creek.
4. Includes the main stem of Redwood Creek, Fern Creek, and Kent Creek.
5. Includes 2 peaks, 7 weeks apart.
6. Includes 2 peaks, 22 days apart.
7. Includes 2 peaks, 33 days apart.
8. Includes 2 peaks, 25 days apart.
9. Includes 3 peaks, 26 and 24 days apart.
10. Poor survey conditions resulted in low observer efficiency.

(Source: Data compiled by Horizon Water and Environment in 2011)

Table 2-16. Coho Salmon Life History Timing in Redwood Creek

Life Stage	Month											
	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sept	Oct	Nov	Dec
Adult migration and spawning	▨ ▨	▨ ▨									▨ ▨	▨ ▨
Incubation	▨ ▨	▨ ▨	▨ ▨	▨ ▨							▨ ▨	▨ ▨
Rearing	▨ ▨	▨ ▨	▨ ▨	▨ ▨	▨ ▨	▨ ▨	▨ ▨	▨ ▨	▨ ▨	▨ ▨	▨ ▨	▨ ▨
Outmigration			▨ ▨	▨ ▨	▨ ▨							

Sources: Fong 1997a, Manning et al. 1999, and Shapovalov and Taft 1954

Eggs incubate in the gravel for 5–7 weeks before hatching, depending on water temperatures (Shapovalov and Taft 1954). After hatching, the alevins remain in the gravel, surviving on their yolk sacs for an additional 2–4 weeks and emerge from the gravel as fry from March until May (Shapovalov and Berrian 1940, Hassler 1987). Juvenile coho salmon migrate to sea at age 0+ young-of-the year (YOY) or remain in fresh water for up to 15 months and emigrate as age 1+ smolts. Although rearing in fresh water, juvenile coho are typically associated with low velocity pools or off-channel habitats with complex cover, especially that provided by LWD (Shirvell 1990, Bustard and Narver 1975, Bugert 1985, Nickelson et al. 1992).

Rearing juveniles have been reported in Redwood Creek from the Rattlesnake Creek confluence to Big Lagoon, in Fern Creek to the falls, and in Kent Canyon to the falls (located approximately 0.4 mile upstream of the confluence with Redwood Creek) (Fong 1997a; Arnold 1971, as cited in Snider 1984). Outmigrant trapping, conducted in Redwood Creek in 1996 captured YOY coho salmon primarily in March, while smolt outmigrants were captured in late April and early May (Fong 1997a). Analysis of adult coho scales (n=57) found that about 5 percent of returning adults had spent up to 2 years in freshwater (all individuals were female) (Rauber 2000), as observed in other California coastal streams (Bell and Duffy 2007).

Dr. Jerry Smith of San Jose State University monitored juvenile coho salmon at five reference sites in the watershed after 1995 (Smith 1995, 1996, 1997, 1998, 2000, and 2001) (Table 2-17). Linear abundance (fish per 100 feet) of juvenile coho salmon documented in these surveys ranged from a low of 1.1 in October 2000 to a high of 42 in August 1995 (Table 2-18). Smith identified two factors that potentially limit coho salmon production in the watershed: (1) lack of sufficient pool habitat to support oversummering (especially during dry years) and (2) poor overwinter survival during wet years (Smith 2001). Smith concluded that lack of summer habitat provided by deep pools (i.e., greater than 0.5 meter or 1.6 feet) with complex cover combined with low late-summer and fall flows in the lower creek was the primary factor limiting Coho salmon production in the watershed during dry years.

Findings from Smith, Fong and Manning, as well as others support Smith's hypotheses. In the lower watershed, and particularly downstream of the MBCSD well, low flows cause pools to become disconnected during late summer and early fall. The disconnected pools and dry creek areas are downstream of the well and can extend 1.5 miles to the creek's mouth at the Pacific Ocean. During dry year conditions (less than 33 inches of precipitation) juvenile coho salmon densities are significantly lower downstream of the facility than upstream. Under dry year conditions estimated an overall potential for a 10 percent reduction in watershed fish production. (Fong and Manning 2007)

During years with higher than average rainfall, floods may be a more critical limiting factor (see Section 2.3, *Climate*). Smith hypothesizes that high mortality caused by high flows during wet years may have severely reduced the abundance of the 1997 year class, suggesting that redd scour and/or a lack of floodplain connectivity and access to refugia from high flows may limit production during wet years (Smith 2000). Substantial numbers of fry are displaced in the spring from upstream and find their way to the Big Lagoon area in both wet and dry water years (Reichmuth et al. 2006a). This displacement may be a density-dependent response coupled with the absence of velocity refugia (such as floodplains, side channels, and alcoves) upstream (Koski 2009). These findings suggest that the Big Lagoon area may provide important winter habitat because it has extensive secondary channels and floodplains (Fong 2002). In 2009, the NPS initiated a restoration of the channel downstream of the Highway 1 Bridge, to increase winter habitat for juvenile Coho salmon by restoring the channel, allowing natural flooding to occur, and by increasing LWD frequency (Jones & Stokes 2007).

In a study on the likely effects of climate change on salmon habitat, Battin and others (2007) identified three critical hydrologic factors that could affect salmonid species, including changes in: peak flow during egg incubation; stream temperatures during pre-spawning; and minimum flow during spawning. In Redwood Creek watershed, changes in winter flows are not consistently projected (Section 2.3); however, peak flows associated with extreme events are expected to increase in frequency and intensity (Cayan et al. 2006a). Stream temperatures during late summer are expected to increase with increased late summer and early fall air temperatures (TNC 2009). One strategy for addressing the stresses expected with climate change is to build robustness in the populations and redundancy and resilience in their habitats as early as possible, so that the populations (e.g., increase the number and maintain the genetic viability) and their habitat are able to survive the projected changes (Battin et al. 2007).

Table 2-17. Redwood Creek Sites Sampled for Coho Salmon and Steelhead, 1995–2001

Year	Citation	Site and Dates Sampled							
		1	2	3	4	5	6	7	8
1992	PWA et al. (1994) Smith (1994b)		20 Aug			19 Sep	19 Sep 14 Nov	23 Jul 14 Aug 14 Nov	23 Jul 14 Aug 14 Nov
1993	PWA et al. (1994) Smith (1994b)		24 Jun			19 Aug	24 Jun 10 Sep	8 Jun 10 Sep	4 Jun 8 Jun 19 Aug 10 Sep
1994	Smith (1994b) Smith (1994a)	26 Jul	7 Jul 30 Oct	26 Jul 30 Oct	8 Jul	7 Jul 30 Oct	7 Jul 30 Oct[1]	8 Jul 30 Oct[1]	8 Jul
1995	Smith (1995)		22 Aug			22 Aug	23 Aug	23 Aug	
1996	Smith (1996)		2 Nov			2 Nov	2 Nov		
1997	Smith (1997)		27 Sept	5 Oct		27 Sept	27 Sep[1]	27 Sep[1]	
1998	Smith (1998)		9 Oct	30 Oct		30 Oct	9 Oct 30 Oct	9 Oct	
2000	Smith (2000)		18 Oct	14 Oct	14 Oct	14 Oct	14 Oct	14 Oct	
2001	Smith (2001)		23–24 Oct	20 Oct		20 Oct	20 Oct	20 Oct	

Notes:

1 Isolated pools only.

Site Locations

Site 1: Upper Muir Woods—two sites (mi 3.3 and 3.6)
Site 2: Lower Muir Woods—two sites (mi 2.5 and 2.8)
Site 3: 0.35 mi upstream of Kent Canyon (mi 2.1)
Site 4: One-half mi upstream of third bridge (a.k.a. "trail downstream of Kent") (mi 1.65)
Site 5: Upstream of third bridge (mi 1.25)
Site 6: Downstream of diversions (mi 0.85)
Site 7: First bridge (mi 0.35)
Site 8: Pools above delta (mi 0.15)

Source: Smith 2001

Table 2-18. Habitats Sampled and Estimated Mean Number of Coho and Steelhead in Redwood Creek, 1994–1998, 2000, and 2001

Sample Date	Number of Sites	Habitat Types Sampled				Total Length Sampled (feet)	Fish per 100 feet		
							Coho Salmon[1]	Steelhead	
		Pool	Glide	Run	Riffle			0+	1+, 2+
July 1994	7	58	25	12	6	1,287	2	69	14
October 1994	5	83	10	4	3	1,018	2	34	6
August 1995	4	41	30	19	10	796	42	97	4
November 1996	3	51	31	11	7	604	39	33	11
Sept.–Oct. 1997	5	72	18	9	1	984	23	15	5
October 1998	5	58	25	15	1	1,174	32	47	4
October 2000	6	71	27	3	0	1,077	1.1	39	15
October 2001	5	78	15	0	7	956	27	6	6

1. All coho salmon were assumed to be age 0+.

Source: Smith 2001

Steelhead

Steelhead found in the Redwood Creek watershed belong to the Central California Coast distinct population segment (DPS) (NMFS 2006), which includes coastal drainages from the Russian River to Aptos Creek and the drainages of San Francisco and San Pablo Bays, excluding the Sacramento–San Joaquin River watershed. This DPS is listed as threatened under the federal Endangered Species Act (NMFS 2000), but it is not currently listed under the California Endangered Species Act.

Detailed adult abundance estimates are not available for steelhead in Redwood Creek; however, based on opportunistic observations during regular sampling for coho salmon, a consistent run of around 20 adults (assuming two adults per redd) exists in Redwood Creek, with a higher than average abundance observed in 2006/2007 (Carlisle et al. 2008). It is acknowledged that this is likely an underestimate because steelhead adults are elusive, their redds are more cryptic than coho salmon, and their spawning season is longer in duration than the surveys conducted for coho salmon. In general, steelhead stocks throughout California have declined substantially. The most current estimate of the population of steelhead in California is approximately 250,000 adults, which is approximately half of the population that existed in the mid-1960s (McEwan and Jackson 1996).

Throughout their range, steelhead exhibit highly variable life history strategies with large differences in run timing and the amount of time spent rearing in fresh water. Populations are broadly categorized into two reproductive groups, winter-run (or “ocean maturing”) and summer-run (or “stream maturing”). Steelhead in the Central California Coast DPS, including in Redwood Creek, are winter-run. Life history timing for Redwood Creek steelhead is shown in Table 2-19. In Redwood Creek, adult steelhead have been observed from December through May. Unlike most other anadromous Pacific salmon species, steelhead are capable of returning to the ocean and migrating back upstream to spawn more than once, although some die after their first spawning. Because of the late spring spawning of steelhead, flow conditions may preclude access back to the ocean by runback steelhead. Each year, visitors and staff have observed adult steelhead in the deep backwater and mainstem pools by the Big Lagoon pedestrian bridge. It is unclear whether any of these steelhead make it back out to the ocean.

Table 2-19. Steelhead Life History Timing in the Redwood Creek Watershed

Life Stage	Month																							
	Jan		Feb		Mar		Apr		May		Jun		Jul		Aug		Sep		Oct		Nov		Dec	
Adult migration and spawning	▨	▨	▨	▨	▨	▨	▨	▨	▨	▨													▨	▨
Adult (kelts) return to sea	▨	▨	▨	▨	▨	▨	▨	▨	▨	▨											▨	▨	▨	▨
Incubation	▨	▨	▨	▨	▨	▨	▨	▨	▨	▨	▨	▨												▨
Rearing	▨	▨	▨	▨	▨	▨	▨	▨	▨	▨	▨	▨	▨	▨	▨	▨	▨	▨	▨	▨	▨	▨	▨	▨
Outmigration					▨	▨	▨	▨	▨	▨	▨	▨	▨	▨					▨	▨	▨	▨	▨	▨

Sources: Fong 1997a, Manning et al. 1999, and Shapovalov and Taft 1954

After entering the creek, adults migrate upstream to suitable spawning locations. Hofstra and Anderson reported steelhead spawning in Redwood Creek up to the confluence with Rattlesnake Creek (1989). Earlier surveys, however, report juveniles rearing upstream in Spike Buck, Rattlesnake, and Bootjack creeks and in Fern Creek within the Mt. Tamalpais State Park, suggesting that steelhead once spawned further up in the watershed (Arnold 1971, as reported in Snider 1984). Based on surveys conducted for coho salmon since 1997, steelhead redd densities typically are highest near the main visitor access areas of Muir Woods, approximately RM 3.1–3.7 upstream from the ocean, in the same reach where coho salmon spawning is most often observed (Carlisle et al. 2008).

After spawning, fertilized eggs incubate in the gravel for 3–14 weeks before hatching, depending on water temperatures (Shapovalov and Taft 1954). Alevins remain in the gravel substrate for an additional 2–5 weeks before emerging in spring or early summer. After emerging, steelhead fry move to shallow-water, low-velocity habitats, such as stream margins and low gradient riffles (Hartman 1965, Everest et al. 1986, Fontaine 1988). As they increase in size and their swimming abilities improve in late summer and fall, juveniles move to areas with cover and show a preference for higher velocity, deeper mid-channel areas near the thalweg (Hartman 1965, Everest and Chapman 1972, Fontaine 1988).

Juvenile steelhead can rear in fresh water for 1 to 4 years before migrating to the ocean as smolts and spending an additional 1 to 3 years in the ocean, and then returning to their natal streams to spawn (Shapovalov and Taft 1954, Behnke 1992). Analysis of scales collected from juvenile steelhead in Redwood Creek (n=165) documented juveniles ranging in age from 0+ to 3+ years (Rauber 2000). Although the period of fresh water rearing is variable, steelhead typically rear in freshwater for 2 years before smolting. Through the same study, the NPS analyzed scale samples from two adult steelhead from Redwood Creek and determined that one of the adults had spent 1 year rearing in fresh water and 2 years at sea; the other had spent 2 years rearing in fresh water and 1 year at sea, suggesting the potential for successful marine survival of smolts less than 2 years old (Rauber 2000).

Juvenile steelhead typically emigrate to the ocean from April through June. In Lagunitas Creek (just north of the Redwood Creek watershed), steelhead emigration has been reported to begin in early March and end in June (Bratovich and Kelley 1988). The typical peak steelhead smolt emigration period occurs in mid-April in other central and southern coastal California streams (Waddell Creek, Santa Cruz County [Shapovalov and Taft 1954]; Lagunitas Creek, Marin County [Bratovich and Kelley 1988]; Arroyo de la Cruz, San Luis Obispo County [Nelson 1994a]; Gazos Creek, San Mateo County [Nelson 1994b]). In Redwood Creek, the NPS has documented YOY year steelhead moving downstream during large storms as early as March (Fong 1997a).

During 3 years of outmigrant trapping (2005–2007), fewer than 20 steelhead smolts were observed in each year (Carlisle et al. 2008). Low estimates of smolt production would indicate low population abundance, unless production from habitats downstream of the trap is significant, or if steelhead in Redwood Creek can smolt successfully as age 0+ and were therefore underestimated at the trap. Based on the relatively large (greater than 500 in 2007) number of observations of steelhead fry moving downstream during spring, it is possible that rearing occurs in the Big Lagoon habitat downstream of the trap, with smolt production from that habitat undetectable by outmigrant trapping.

Because of their ability to return to the ocean after spawning and their tendency to spawn at a variety of ages, steelhead have not shown pronounced annual variability in abundance in Redwood Creek. Abundance of YOY steelhead, however, was particularly low in 1997 and 2001, and particularly high in 1995 (Table 2-17). Smith attributes low YOY steelhead abundance to loss of suitable rearing habitat and reduced food availability resulting from low summer and fall stream flows, especially at the most downstream sites (1997, 2001). The impacts of low summer and fall flows on steelhead also may be exacerbated by groundwater pumping from the wells that supply the town of Muir Beach and impoundments at Green Gulch Farm. This portion of the watershed has been shown to be used extensively by rearing coho salmon and steelhead when suitable conditions exist, at which time it appears to be important rearing habitat. The effects of low stream flows in this area include reduced availability of rearing habitat and macroinvertebrates for juvenile coho and steelhead, as well as poor water quality (elevated temperature, low DO). This is especially important in dry years, when flows are naturally low. Smith (1994a, 1994c) and Fong and Manning (2007) analyzed the effects on coho salmon and steelhead of streamflow reductions in Redwood Creek caused by drought and groundwater pumping. Smith (1995, 2001) repeatedly noted that groundwater pumping from the wells near the town of Muir Beach can exacerbate the effects of low stream flows in lower Redwood Creek and the upper portion of the tidal lagoon, as was confirmed by the analysis of Fong and Manning.

California Red-Legged Frog

The California red-legged frog is the largest native frog in the western United States. Its range extends along the coast from Mendocino south to northwestern Baja California, Mexico, and inland through the northern Sacramento Valley into the foothills of the Sierra Nevada mountains (Stebbins 2003, Shaffer et al. 2004). A narrow range overlap with northern red-legged frog (*Rana aurora*) occurs in Mendocino County (Shaffer et al. 2004). Habitat loss, habitat fragmentation, construction of reservoirs and water diversions, overexploitation, and introduction of exotic predators and competitors (such as bullfrogs) have contributed to reducing the species’ range by approximately 70 percent compared to historical conditions (USFWS 2002). Critical habitat for this species was established on April 13, 2006 (USFWS 2006); however, it is currently under revision by the USFWS (USFWS 2011). No critical habitat has been designated in the Redwood Creek watershed.

California red-legged frog habitat is generally characterized by still or slow-moving water with deep pools (usually at least 2.3 feet), though frogs have been known to breed in pools less than 2.3 feet deep) and emergent and overhanging vegetation (Jennings and Hayes 1994). Its habitats include wetlands, wet meadows, ponds, lakes, and low-gradient, slow-moving stream reaches with permanent pools. Although some adults may remain resident year-round at favorable breeding sites, others may disperse up to a mile or more (Fellers and Kleeman 2007). Movements may be along riparian corridors, but some individuals move directly from one site to another without apparent regard for topography or watershed corridors (Bulger et al. 2003, Scott and Rathbun 2007).

California red-legged frogs sometimes enter a dormant state during summer or in dry weather (aestivation), finding cover in small mammal burrows, moist leaf litter, root wads, or cracks in the soil. California red-legged frogs typically are active year-round in coastal areas because temperatures are generally moderate (USFWS 2002, Bulger et al. 2003).

Breeding occurs between late November and late April (Jennings and Hayes 1994). Females lay egg masses containing approximately 2,000–6,000 eggs (USFWS 2002, Scott and Rathbun 2007). Eggs hatch within 6–14 days, and tadpoles require approximately 11–20 weeks to metamorphose (USFWS 2002). Metamorphosis occurs from May to September, and individuals become reproductively mature in 2 to 3 years (Bulger et al. 2003).

Introduced species that have been known to prey on California red-legged frogs include bullfrogs, fish (including mosquitofish [*Gambusia affinis*], bass, and sunfish), and crayfish (Hayes and Jennings 1986). Bullfrogs may both prey on and compete with California red-legged frogs (Hayes and Jennings 1986, Cook and Jennings 2001, Cook 2002). Bullfrogs appear more readily adaptable to anthropogenic disturbance, including habitat fragmentation, habitat degradation, and altered hydrology (Hayes and Jennings 1986, D'Amore et al. 2009). During a controlled study, Lawler and others found that only 5 percent of California red-legged frog tadpoles survived in ponds with bullfrogs present (1999).

The NPS, USGS, and contractors have conducted several surveys for California red-legged frogs in lower Redwood Creek; adult frogs have been found in lower Redwood Creek, in the wetlands adjacent to lower Redwood Creek (i.e., the restoration of lower Redwood Creek at Muir Beach), and in an auxiliary pond within the Green Gulch Creek watershed (Ely 1993, Cook 1998, Fong 2000, Wood 2004, Fellers and Guscio 2004, Garcia and Associates 2007). Intensive surveys were conducted by the USGS in 2003 and 2004, as part of the restoration of lower Redwood Creek at Muir Beach (Fellers and Guscio 2004). These included day and night surveys, egg and tadpole searches, and radio-tracking of adult frogs. The results indicated that the California red-legged frog population in the Big Lagoon area is small, with only an estimated 14 adults and three egg masses in 2003 and 2004 (Fellers and Guscio 2004). No successful breeding activity was documented in Big Lagoon during follow-up surveys from 2004 to 2006 (Fong and Campo 2006). One frog was tracked to the lower reaches of Green Gulch Creek, and adults have been tracked moving up lower Redwood Creek (Fellers and Guscio 2004, Fellers and Kleeman 2005). One frog had apparently moved between Big Lagoon and an auxiliary pond in the Green Gulch Creek watershed—in 2007, biologists at Garcia and Associates found the frog at the Green Gulch pond with a pit tag inserted during 2003 surveys by USGS at Big Lagoon (Shoulders, pers. comm., 2007). To date, however, no adults or egg masses have been found in upper Redwood Creek (Fellers and Guscio 2004, Fellers and Kleeman 2005).

In the early 1990s, aggradation of the Redwood Creek channel caused groundwater elevations in the Green Gulch pasture (adjacent to Redwood Creek) to increase by about a foot. A malfunctioning culvert under a levee kept surface water ponded in the pasture, which was subsequently the area where California red-legged frogs were most typically found breeding. Removal of some of the sediment in 2002 from one of the most obstructed portions of the channel caused a slight lowering of the water table, which then caused the ponded area to dry sooner than in previous years, thereby unintentionally preventing tadpoles from metamorphosing. The NPS has since replaced the metal floodgate that backs water up into the Green Gulch pasture with a flashboard structure that prevents water from draining into Redwood Creek in the spring, resulting in extended ponding that allows California red-legged frog tadpoles to complete their metamorphosis (Jones & Stokes 2007). As part of the restoration of lower Redwood Creek at Muir Beach—a 38-acre project aimed at restoring a functional, self-sustaining ecosystem at Muir Beach—riparian and aquatic habitat restoration measures were designed to improve conditions for the small population of California red-legged frogs that appeared to have declined precipitously in the previous 15 years. Measures proposed for lower Redwood Creek attempted to restore the hydrological conditions that create and maintain habitat for California red-legged frogs in the watershed, as opposed to maintaining habitat that relies on the continuing existence of a constructed levee that itself inhibits ecosystem functions, as well as ongoing human intervention (Jones & Stokes 2007).

2.7.4 Aquatic Habitat

In addition to the limited aquatic habitat data collected as part of several of the above fish investigations, a comprehensive stream habitat inventory was conducted in 1995 by GGNRA staff (Fong 2002). This inventory includes data on channel morphology, substrate, water temperature, habitat types, LWD, residual pool volume, streamside cover, riparian canopy density, and benthic macroinvertebrates for approximately 5 miles of Redwood Creek to Bridge 4 in Muir Woods. Geomorphology (channel form) aspects of this study are summarized in Section 2.5.3, *Channel Morphology*. In a separate study, woody debris abundance and distribution in Redwood Creek from 1994–1996 were reported by Vore (1996) for reaches in and immediately downstream of Muir Woods, and PWA (2000) includes data on LWD frequency in portions of the watershed.

The results of the numerous fish surveys performed between 1992 and 2002 are summarized in Appendix D. Survey data have indicated that coho salmon and steelhead year class success in Redwood Creek may be highly dependent on habitat and flow conditions (Smith 1997, 2001). By dewatering shallow habitats and reducing pool volume, low flows can reduce food availability by lowering benthic macroinvertebrate production and delivery, and can limit the area of suitable rearing habitat. Conversely, high winter flows can damage redds, reconfigure the stream channel, and displace rearing salmonids from preferred rearing habitat. The availability (i.e., distribution and abundance) of valuable instream cover, especially LWD in upper stream reaches, is largely responsive to high flows. Vore (1996) found that woody debris in Redwood Creek appeared to be recruited to upstream reaches during the winter of 1994–1995 and redistributed downstream in 1996 in response to storm events (see also Section 2.5.3).

Portions of Redwood Creek in Muir Woods were channelized in the 1930s to prevent flooding (see Section 2.2.3, *Watershed History*). Effects of channelization have included channel widening and a relatively homogeneous, plane-bed channel morphology, with little connection between the channel and its floodplain. The lack of floodplain connectivity may limit the availability of velocity refuge habitat that can be important for coho salmon during high winter flows. Several grade control structures in the creek within Muir Woods have limited channel incision, and rock revetment lines much of both banks in this reach. Until 1986, the NPS removed woody debris from the creek. Woody debris is now left in the creek, aiding the formation of pools that provide important rearing habitat for juvenile coho salmon and steelhead. Stillwater Sciences (2009a) found that winter habitat for juvenile coho salmon under current conditions is limited in availability, but that restoration of lower Redwood Creek at Muir Beach (Jones & Stokes 2007) has the potential to dramatically increase winter rearing habitat by restoring the connection to floodplain and off-channel rearing habitat, and by increasing LWD frequency.

Although only limited data apparently are available on LWD frequency in Redwood Creek, this habitat feature is known to be of key importance for rearing salmonids. In 2003, the NPS implemented a restoration project at the Banducci site in lower Redwood Creek, which included LWD additions, levee removal, and floodplain regrading. Inundation of the lowered floodplain was documented during monitoring at the expected flows, and formation of pools and bars at several of the engineered log jams. As discussed above, restoration of lower Redwood Creek at Muir Beach (Jones & Stokes 2007) also has the potential to increase LWD frequency.

Although features such as LWD jams may provide some value as winter refuge for salmonids, cover consisting of interstitial spaces in cobble or boulder substrate is the key attribute defining winter habitat suitability for juvenile steelhead (Hartman 1965, Chapman and Bjornn 1969, Meyer and Griffith 1997). Filling of coarse substrate interstices by fine sediment can severely reduce the amount of cover available for overwintering juvenile salmonids. Measures to reduce fine sediment delivery, especially in upstream reaches (e.g., Muir Woods) where YOY steelhead densities are typically high (Smith 2000), may improve winter habitat quality for juvenile salmonids.

2.8 Terrestrial and Wetland Vegetation and Habitats

Existing vegetation and terrestrial habitats in the Redwood Creek watershed are a product of pre-settlement era vegetation and Native American management, overlaid with 150 years of Euro-American management and associated impacts. Thus, although the ancient redwoods in Muir Woods have been protected as a National Monument since 1908, important changes in natural processes that maintain the ancient forest and other natural areas in the rest of the watershed have caused, and in some cases are continuing to cause, shifts in plant community structure and composition. For example, historical changes in land use, including intensive eighteenth and early nineteenth century grazing, timber harvesting, road and rail road construction, and subplanting of the Native American burning regime with twentieth century fire suppression have resulted in large conversions of native grasslands to annual grass and shrub lands, increased accumulation of wildfire fuels and associated increases in wildfire hazard, and changed riparian and wetland extent and distribution. Proliferation of invasive non-native species, particularly in highly trafficked roadsides and trails, require ongoing eradication and prevention efforts. Relatively new threats, including the spread of SOD and local effects of climate change on existing vegetation, make managing the evolving landscape even more complex.

2.8.1 Vegetation Classification and Mapping

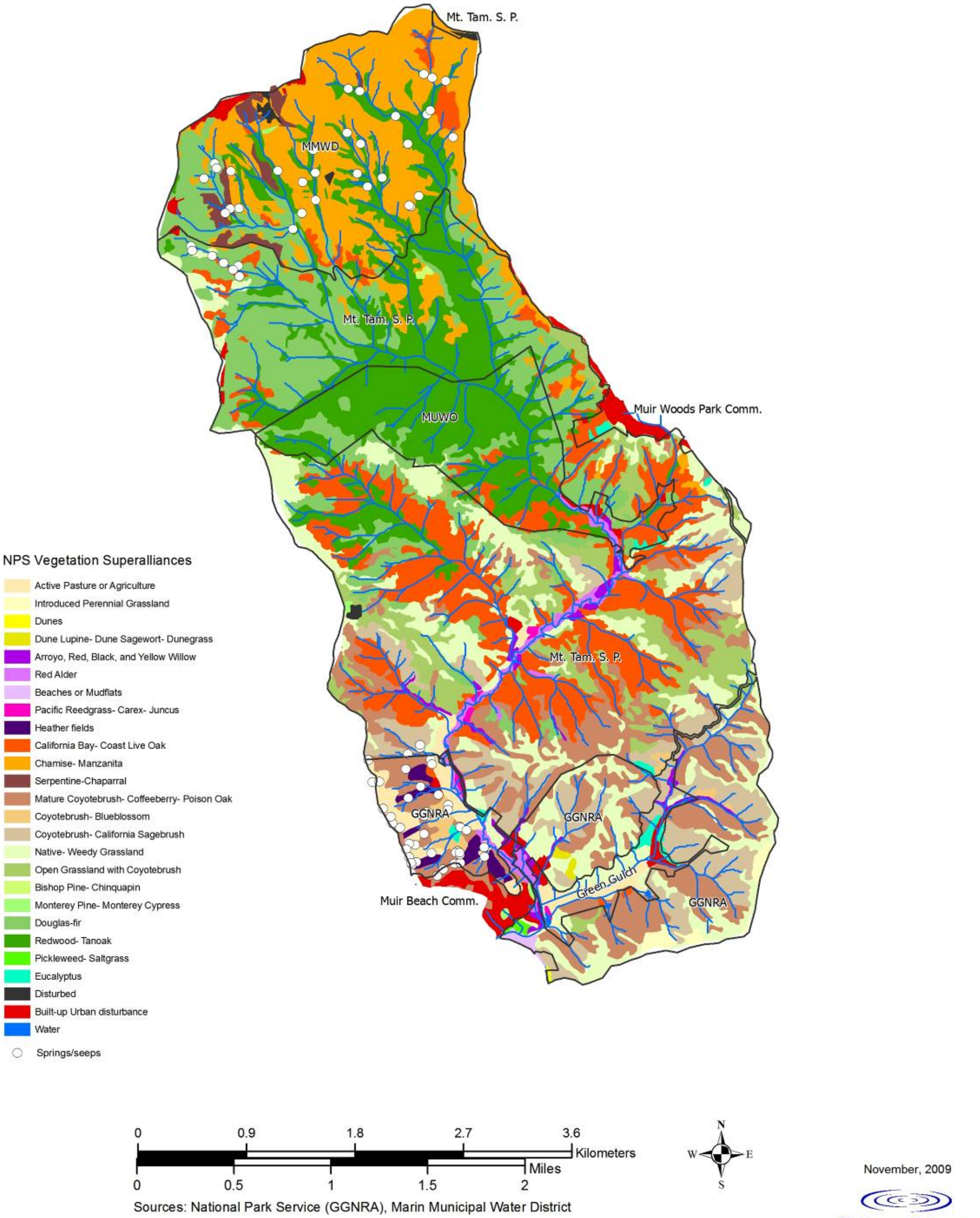
During the 1995 Vision Fire in Point Reyes, the NPS realized that not having a map of vegetation types severely limited their ability to predict and more effectively combat fire. As a result of this experience, constructing a vegetation type classification and map became an agency priority. A vegetation map and classification also can provide an important foundation piece for other management concerns, such as monitoring wildlife habitat use, and monitoring rare plant species populations and community types. The NPS contracted the mapping software company ESRI and GIS production and environmental company Aerial Information Systems, Inc. (AIS) to map vegetation cover types in the watershed using interpretation of aerial photography combined with ground truthing of sample plots (Moritsch et al. 1998). The NPS mapping effort, which covers the central and southern portion of the Redwood Creek watershed, is based primarily on interpretation of 1:24,000-scale, true color aerial photographs taken in 1994. Aerial photo-interpretation, based on ground truthing to check signature photo-textures by type, was performed to the alliance level for all polygons, and to the vegetation association level where possible (Moritsch et al. 1998). Three to seven sample plots representative of each vegetation type, for a total of 360 plots, then were field surveyed using a modified releve method (plot size: 400 mi^2 for shrub and herbaceous types; 1,000 mi^2 for forested types) (Moritsch et al. 1998). Based on this field data, vegetation was classified to the association level (as defined by Sawyer and Keeler-Wolf [1995]), using multivariate techniques (Moritsch et al. 1998). A field accuracy assessment of the draft vegetation map was performed by NPS personnel in 1999, and a low level of accuracy (42.5 percent) at the alliance level was measured.

A coarser level of classification, termed the superalliance, was found to provide a more accurate representation of field conditions (accuracy of 71.4 percent), and it is presented in Figure 2-30 with several minor modifications including altering two superalliance names to better fit the Redwood Creek watershed community composition. Because the original vegetation map and the superalliances were created for a much greater area than the Redwood Creek watershed (including Point Reyes), the names of two superalliances include species that are not found in this watershed; therefore, their titles falsely imply that these two species are fairly dominant. These include the Open Grassy Coyote Brush–Yellow Bush Lupine and Introduced Perennial Grassland-Deschampsia superalliances. Because yellow bush lupine (*Lupinus arboreus*) does not occur in the watershed and Deschampsia, as discussed below, has not been observed or reported in the watershed, these species names were dropped from the superalliance titles. Also, the Pacific Reedgrass-Carex Juncus superalliance is only represented in the Redwood Creek watershed by disturbed plant communities that include species of that superalliance (8.9 acres). Similarly, the Dune Lupine-Dune Sagewart-Dunegrass superalliance refers to the more diverse dune communities in Point Reyes, but in the Redwood Creek watershed is represented by depauperate dune communities that include a few common dune species intermixed with non-native invasive plants. Another important modification to the superalliance classification is that the upper Redwood Creek watershed includes areas supporting serpentine chaparral; these areas are included in the Redwood Creek vegetation map based on polygons that are delineated in a MMWD vegetation map and overlaid on the NPS classification layer (MMWD 2004). The MMWD vegetation map is not shown in its entirety because, other than the serpentine types, the MMWD polygons and vegetation types were largely in agreement with the NPS vegetation map.

The final vegetation map for the Redwood Creek watershed identifies 26 distinct superalliances under the NPS vegetation mapping scheme, including areas classified as “Built-up Urban Disturbance,” ‘Disturbed,” “Water” and “Active Pasture or Agriculture,” and the MMWD vegetation category on serpentine chaparral. These various community types can be lumped into seven general cover types for the watershed—Redwood-Douglas-fir- forest, mixed hardwood forest, chaparral/evergreen scrub, grassland, riparian woodland, and coastal communities—and a sixth category of dominantly human-altered cover types referred to as “Other.” A cross-walk of these general cover types, the 26 NPS superalliances, and the extent of the superalliances in the watershed are summarized in Table 2-20.

Table 2-20. Crosswalk of General Vegetation Cover Types to NPS-Mapped Vegetation Types

General Cover Types	NPS Superalliances	Hectares	Acres
Redwood-Douglas-fir forest	Redwood-tan oak	380.3	939.7
	Douglas-fir	323.3	799
Mixed hardwood forest	Bishop pine-giant chinquapin	0.9	2.3
	California bay-coast live oak	313.0	773.5
	Eucalyptus	9.8	24.3
Chaparral/evergreen scrub	Mature coyote brush-coffeeberry-poison oak	256.2	633.2
	Chamise-manzanita	247.2	610.9
	Coyote brush-California sagebrush	150.7	372.3
	Serpentine-chaparral	19.8	48.9
	Coyote brush-blueblossom	10.4	25.8
	Open grassland with coyote brush	249.4	322.4
Grassland	Native weedy grassland	130.5	616.4
	Introduced perennial grassland	13.0	32.1
Riparian woodland	Red alder	26.5	65.4
	Arroyo, red, black, and yellow willow	17.8	44
Coastal communities	Pacific reedgrass-carex-juncus	3.6	8.9
	Beaches or mudflats	2.9	7.2
	Dune lupine-dune sagewort-dunegrass	2.0	5
	Pickleweed-saltgrass	1.4	3.4
Other	Built-up urban disturbance	47.7	117.8
	Active pasture or agriculture	41.0	101.3
	Heather fields	11.5	28.4
	Disturbed	4.7	11.5
	Monterey pine-Monterey cypress	2.1	5.3
	Dunes	0.3	0.8
	Water	0.9	2.2
Total	**Grand total**	**2,267.0**	**5,601.90**



Sources: National Park Service (GGNRA), Marin Municipal Water District

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Figure 2-30. Vegetation cover types in the Redwood Creek watershed. (Sources: NPS and MMWD, unpubl. data; Faden 2005)

2.8.2 Upland and Riparian Vegetation Types

Brief descriptions of the general upland and riparian vegetation types are provided below.

Redwood-Douglas-Fir Forest

The Redwood-Douglas-fir forest cover type includes the Redwood-Tan oak and Douglas-fir superalliances mapped by the NPS. This forest type covers approximately 1,700 acres on steep slopes and deep canyons of the watershed (Figure 2-30). This type represents a central range of coast redwood forests extending from San Francisco to southern Humboldt County, where Douglas-fir (*Pseudotsuga menziesii*) is co-dominant with redwood (*Sequoia sempervirens*), and tan oak (*Lithocarpus densiflorus*) grows as a mid-canopy species. Further north, both redwood stands and Douglas-fir forests generally occur in wetter areas, where other conifer species such as western hemlock (*Tsuga heterophylla*) are co-dominant; further south to Monterey, redwoods are genetically distinct and occur with less understory shrubs and more mid-canopy hardwoods (Howell 1970, Sawyer et al. 2000).

The redwoods occupying the canyon floor of Muir Woods National Monument are the only remaining old growth redwood forest in the Mt. Tamalpais area (Fairley and Heig 1987). This forest is somewhat isolated compared to other areas to the south and north, where old growth redwood stands are more extensive. Some redwood trees in Muir Woods may be as much as 1,000 years old. Other tree species occurring in the forest subcanopy include big leaf maple (*Acer macrophylum*), California bay laurel (*Umbellularia californica*) and, along Redwood Creek, red alder (*Alnus rubra*). Species composition on the slopes differs from the alluvial valley floor, with some redwood, Douglas-fir, bay laurel, tan oak, and madrone (*Arbutus menziesii*) being more common on slopes than on the valley floor.

The redwood trees in Muir Woods were the focus of most conservation efforts in the decades following establishment of the site as a national monument in 1908. Based on analysis of age distribution in Muir Woods, the number of redwood seedlings and sprouts in Muir Woods is sufficient to continue the dominance of redwoods well into the future (McBride and Jacobs 1978). The understory and ground cover, however, were quickly eliminated because of extensive use of the forest floor for picnicking, camping, ballgames, vehicle access, and even collection of ferns and rhododendrons by early twentieth century visitors. Soil compaction associated with frequent human trampling also is associated with reduced vegetation cover (Krenzelok 1974).

By the 1950s, Muir Woods prohibited collection of all vegetation and fungi by visitors, and rangers began revegetation efforts (Fairley and Heig 1987; Hall 2008). Revegetation efforts accelerated in the 1980s and 1990s, and were supported by NPS management actions to restrict visitor access to trails. Understory cover today is probably the most extensive that it has been in a century, but one redwood ecologist has observed that the subcanopy is far less dense than would be expected in an undisturbed old growth forest (Russell, pers. comm., 2002). For instance, huckleberry (*Vaccinium ovatum*) typically is extensive in an old growth forest, but it is scarcely found at Muir Woods (Russell, pers. comm., 2002). Additional challenges remain for managing these forests to develop more old growth characteristics; these challenges include allowing for more natural disturbance regimes, allowing for increased frequency of tree-fall gaps created by fallen trees, and preventing or reducing compaction which can stress the redwood shallow root systems, possibly making the trees more prone to disease (Krenzelok 1974; Russell, pers. comm., 2002), and managing the forest to minimize negative effects associated with SOD (see Section 2.8.5).

Mixed Hardwood Forest

The mixed hardwood forest cover type is dominated by the California Bay-Coast Live Oak superalliance mapped by the NPS (although it also includes the Eucalyptus and Bishop Pine-Chinquapin superalliances). This forest type covers approximately 800 acres, primarily on the slopes of drainages in the lower portion of the watershed (Figure 2-30). California bay laurel, tan oak, and coast live oak (*Quercus agrifolia*) dominate the mixed hardwood forest, and madrone, chinquapin (*Chrysolepis chrysophylla*), and canyon live oak (*Quercus chrysolepis*) contribute to the relatively dense canopy of the forest. The brushy understory includes species such as poison-oak (*Toxicodendron diversilobum*), toyon (*Heteromeles arbutifolia*), and sword fern (*Polystichum munitum*). The mixed hardwood forest typically grades into the coyote-brush-dominated chaparral scrub community on the upper slopes.

Chaparral/Evergreen Scrub

Coyote brush chaparral near Dias Ridge

The chaparral/evergreen scrub cover type is comprised of the Serpentine Chaparral type mapped by the MMWD, and the following superalliances mapped by the NPS: Chamise-Manzanita, Coyote brush-Blueblossom, Coyote brush-California Sagebrush, Mature Coyote brush-Coffeeberry-Poison Oak, and Open Grassy Coyote brush. Altogether, the chaparral superalliances cover approximately 2,150 acres of the watershed, typically occupying the upper hill slopes (Figure 2-30). The chaparral habitat is characterized by a dense, closed canopy of evergreen shrubs and a paucity of herbaceous vegetation in the dark understory. Dominant species include coyote brush (*Baccharis pilularis*), Eastwood manzanita (*Arctostaphylos glandulosa*), hoary manzanita (*Arctostaphylos canescens*), chamise (*Adenostoma fasciculatum*), buckbrush (*Ceanothus cuneatus*), wavyleaf ceanothus (*C. foliosus*), blue blossom (*C. thyrsiflours*), interior live oak (*Quercus wislizeni*), and yerba santa (*Eriodictyon californicum*). Other less common shrub species include bush poppy (*Dendromecon rigida*) and wavyleaf silktassel (*Garrya elliptica*). Species composition of the chaparral cover type is fairly consistent throughout the watershed, although considerable variation exists in regard to species' relative dominance. Herbaceous species are largely restricted to gaps within the canopy and sunny openings created by service roads and trails. Among the more noticeable herbaceous to marginally woody species are wooly Indian paintbrush (*Castilleja foliosa*), milkwort (*Polygala californica*), tall star lily (*Zigadenus fremontii*), and bear grass (*Xerophyllum tenax*). Many rare, threatened, or endangered plant species (e.g., CNPS lists 1 and 2) occur within the chaparral habitats of the watershed, including Marin manzanita (*A. virgata*), Mt. Tamalpais thistle (*Cirsium hydrophilum* var. *vaseyi*), and Santa Rosa thin-lobed horkelia (*Horkelia tenuiloba*).

On serpentine substrates, which occur along the upper hillslopes of Mount Tamalpais (Figure 2-21), chaparral gives way to a mosaic of balds, barrens, and vegetated islands dominated by prostrate shrubs and bunch grasses. This serpentine chaparral community is highly diverse in both structure and species composition. Dominant shrubs include Mt. Tamalpais manzanita (*A. hookeri* ssp. *montana*), Jepson's ceanothus (*Ceanothus jepsonii*), and leather oak (*Quercus durata*). Dominant bunch grasses include serpentine reed grass (*Calamagrostis ophitidis*), squirreltail grass (*Elymus elymoides*), and Sandberg blue grass (*Poa secunda*). Among the profusion of annual and perennial forbs that thrive on the margins of these shrubs and bunch grasses are serpentine onion (*Allium falcifolium*), Oakland star tulip (*Calochortus umbellatus*), serpentine spring beauty (*Claytonia exigua*), pink baby's breath (*C. gypsophiloides*), and serpentine morning glory (*Calystegia collina*). Many endemic, and numerous rare, threatened, or endangered plant species occur in these serpentine chaparral habitats, including the aforementioned Mt. Tamalpais Manzanita as well as Tiburon buckwheat (*Eriogonum luteolum* var. *caninum*), Marin County navarretia (*Navarretia rosulata*), Mt. Tamalpais jewelflower (*Streptanthus glandulosus* ssp. *pulchellus*), and Mt. Tamalpais thistle.

Grassland

The grassland cover type is comprised of the Native-Weedy Grassland and Introduced Perennial Grassland superalliances, mapped by the NPS. Perennial and annual grasslands cover approximately 650 acres and occur along ridgetops and slopes, primarily in the southern half of the watershed (Figure 2-30).

Today, less than 0.1 percent of California's native grasslands remain (Barry 1972). As in the rest of the state, many grasslands in the Redwood Creek watershed have been almost completely converted to plant communities, dominated by non-native annual grasses introduced from the Mediterranean region. However, approximately 616 acres of Native-Weedy Grassland persist in the Redwood Creek watershed and represent important remnants of these severely diminished native grasslands. In the Native-Weedy Grassland superalliance, native perennial bunchgrasses co-exist with a subtle, but rich diversity of native forbs (e.g., blue-eyed grass [*Sisyrinchium bellum*] and footsteps of spring [*Sanicula arctopoides*]). The successive blooms of native grassland flora in early spring create one of the spectacular natural events of the watershed.

The locations of these remnant native grasslands in the watershed have not been thoroughly inventoried or accurately mapped because their sizes are generally far below the minimum 5-acre mapping unit used for the NPS vegetation map (Moritsch et al. 1998), making it difficult for resource managers to prioritize protection measures, such as non-native invasive species removal and prescribed burns. The MMWD has mapped grasslands within their purview (Stillwater Sciences 2005c). Some locations of native grassland that have been informally noted in the watershed by resource managers include:

- a dense stand of the feathery red fescue (*Festuca rubra*), with a diverse mix of other native grassland species, stretching across the ridge near the intersection of the Coastal Trail and the Deer Park Fire Road;
- a forest opening along Panoramic Highway near the Bootjack Trail, which supports very large bunches of California fescue (*F. californica*);
- dense stands of California oatgrass (*Danthonia californica*) and purple needlegrass (*Nassella pulchra*) found on slopes near the Miwok trail and mixed stands of these species on Diaz Ridge;
- small pockets of native meadow barley (*Hordeum brachyantherum*) occurring at limited locations, such as on Diaz Ridge just west of Panoramic Highway;
- native junegrass (*Koeleria macrantha*) along with other native grasses occurring on slopes at the base of Coyote Ridge near the Green Gulch Farm trail to Muir Beach;

- a dense blend of red fescue, California brome (*Bromus carinatus*), and California oatgrass occurring east side of Panoramic Highway at Four Corners (French broom [*Genista monspessulana*] that has been removed repeatedly at this site throughout the past decade to protect the native grassland);

- mixed stands of purple needlegrass common at the Three Sisters site, which extends to the Sun Trail above Muir Woods (Stillwater Sciences 2005c); and

- remnant patches of native grassland along the Coast View trail (Stillwater Sciences 2005c).

Some native species that would be expected to occur in the Redwood Creek watershed, such as tufted hairgrass (*Deschampsia caespitosa* spp. *holciformis*), have not been documented by any recent vegetation surveys.

Non-native annual grasses dominating most of the watershed's grasslands include wild oats (*Avena barbata*), soft chess (*Bromus hordeaceous*), ripgut brome (*Bromus diandrus*), ryegrass (*Lolium multiflorum*), and other common annual grasses. These grasses are so extensive as to be considered permanent members of the grassland community (Heady 1977). Several non-native invasive perennial grass species also occur, including Harding grass (*Phalaris aquatica*), tall fescue (*Festuca arundinacea*), and kikuyu grass (*Pennisetum clandestinum*). Panic veldt grass (*Erhata erecta*) has become more common in recent years and persists in the riparian corridor through Frank Valley. Invasive plant species are discussed in more detail in Section 2.8.6.

Riparian Woodland

The riparian woodland cover type is comprised of the Arroyo/Red/Black/Yellow Willow and Red Alder superalliances mapped by the NPS, but arroyo willow (*Salix lasiolepis*) is by far the single most dominant willow species in this watershed. Riparian woodland covers approximately 110 acres of the watershed and occurs along Redwood Creek and its tributary channels (Figure 2-30). Riparian vegetation along the mainstem creek and tributary drainages downstream of Muir Woods is dominated by native species, including red alder, which generally grows very close to bankfull elevations, and arroyo willow (*Salix lasiolepis*). Other tree species that occur more infrequently in the riparian corridor include buckeye (*Aesculus californica*), bay laurel, and coast live oak. The only cottonwoods (*Populus* sp.) that are known to occur in the watershed were planted by residents along the Green Gulch tributary, and they are not native to the watershed (Johnson, pers. comm., 1999; as cited in GGNRA 2003). Common shrubs occurring in the riparian corridor include red elderberry (*Sambucus racemosa*), dogwood (*Cornus sericea*), and twinberry (*Lonicera involucrata*). The native California blackberry (*Rubus ursinus*) is probably the single-most common native understory species. Other native understory species include thimbleberry (*Rubus parviflorus*), stinging nettle (*Urtica dioica*), wild cucumber (*Marah fabaceous*),

Dense riparian vegetation in lower Redwood Creek

gooseberry (*Ribes divaricatum* and *Ribes sanguineum*), sword fern, lady fern (*Athyrium filix-femina*), and false solomon's seal (*Smilacina racemosa*). Two locations of the relatively uncommon bleeding heart (*Dicentra formosa*), a summer deciduous plant, are known—one on the east bank of the Redwood Creek mainstem near Heather Horse Camp, and one on the west bank of the Redwood Creek mainstem at the Banducci site. Non-native species that occur in the watershed include cape ivy (*Delairea odorata*), English ivy (*Hedera helix*), and morning glory (*Calystegia silvatica* ssp. *disjuncta*). Non-native riparian species are discussed in more detail in Section 2.8.6.

The extent of riparian vegetation in Frank's Valley today is somewhat greater compared to the mid-1900s. Dairy ranchers and farmers living in the valley from the late 1800s through the mid-1900s typically cleared trees along the creeks and used adjacent floodplains for grazing and row crop agricultural (Banducci, pers. comm., multiple conversations, May 15, 1998–2000; and Brazil, pers. comm., 1999; both as cited in GGNRA 2003). Aerial photographs, taken in 1947, show significant portions of the creek without tree cover. Where trees did occur, the width of the riparian vegetation was often no more than that of a single tree. Fields and floodplains adjacent to the channel were either heavily grazed or farmed to the edge of the channel bank.

Although likely still limited in its lateral extent because of channel incision and consequent narrowing of the effective floodplain, the riparian corridor through Frank's Valley has widened significantly during the over 30 years since ranching ended there. Alders and willows form a generally contiguous canopy, and native understory species occur throughout the corridor. A large number of California bay laurel saplings, a very slow-growing species, are scattered throughout the alluvial valley, noticeably in locations where mature California bay laurels do not occur (Shoulders, pers. obs., 2002; as cited in GGNRA 2003). This suggests a successive wave of recovery following that of the fast-growing, pioneer alders and willows that quickly re-established when ranching ended. Because agriculture at the Banducci site ended much more recently (in 1995), the riparian corridor there is generally characterized by a single line of alder trees at the creek's edge, with little shrubby understory. The NPS implemented restoration actions in 2003 to expand the width of the riparian corridor by 80 feet along 1,300 linear feet in this reach. After grading to reconnect a portion of the channel with its historic floodplain, this area is now extensively covered by alder seedlings and saplings, some planted and most naturally recruited.

Full recovery of native riparian vegetation appears to be limited in some areas where particularly aggressive, non-native species have become established. A good example of this is at the confluence of the Kent Canyon tributary and Redwood Creek. Historic maps (U.S. Coast Survey 1853) show an extensive wooded area at this confluence. In photographs taken in 1947, this area appears to have been cleared and was probably grazed by cattle; tree cover is limited to the immediate channel banks. Today, the riparian corridor is somewhat wider at this site than it was in 1947, but the grazed area is dominated by the persistent perennial invasive grass, tall fescue, and the noxious biennial poison hemlock (*Conium maculatum*), which produces large quantities of seed and establishes monocultures in wet areas. At this site, as with numerous other areas adjacent to the creek, the recovery of native species is probably not likely without active restoration efforts.

Riparian vegetation at Muir Beach has followed a transition opposite to that of Frank Valley. In this area, the extent of woody riparian vegetation has expanded over the last 150 years. The riparian forest became established along the present course of lower Redwood Creek only during the last 30–40 years. The expansion of riparian vegetation extent at Muir Beach appears to be correlated with the human-made alterations to the creek channel and floodplain that began in the 1960s, which apparently changed the hydraulic and sediment deposition patterns, creating conditions appropriate for recruitment and establishment of riparian trees. Aerial photographs from 1946 and 1952 show the diverted creek course running through close-cropped agricultural lands, a setting consistent with observations of residents at the time. By 1965, photos show the double row of Monterey pines, reportedly planted along the road in the

1930s, adjoining riparian trees, and some riparian trees or shrubs extending upstream. By then, the dense willow forest adjacent to the present parking lot was established in the area previously occupied by roads and buildings. Restoration of lower Redwood Creek at Muir Beach will replace much of this riparian forest with emergent wetlands (Jones & Stokes 2007).

Herbaceous Wetland

Herbaceous wetlands include emergent wetlands found in lower Redwood Creek as well as seeps and springs found in the upper reaches of the watershed. Both of these vegetation types are described in greater detail in the following Section 2.8.3. Wetlands and Seeps. These are not included in the cross-walk presented in Table 2-20 because there is significant but inconsistent overlap between the delineated wetlands described below and the NPS mapped vegetation types.

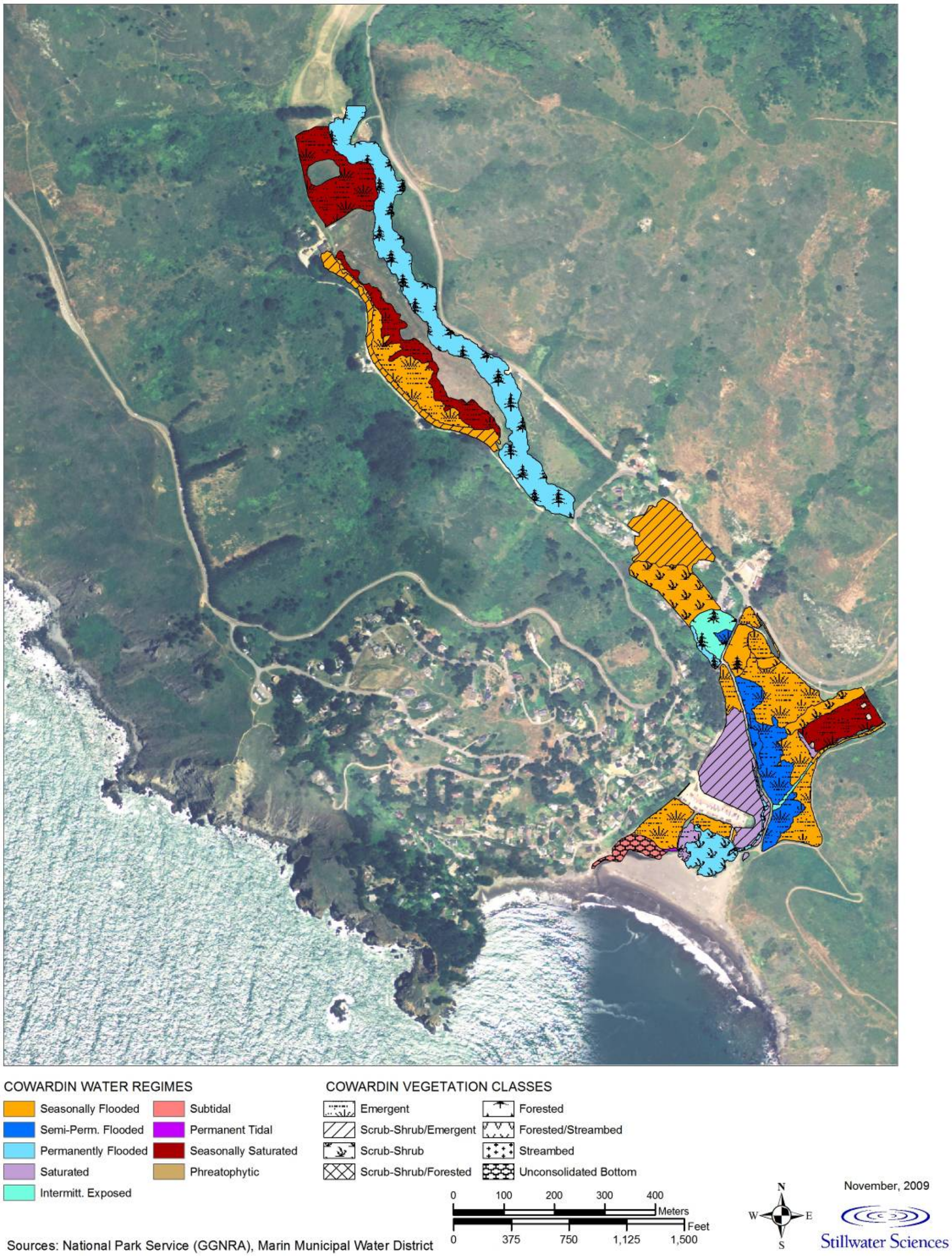
Coastal Communities

The Coastal Community cover type includes the Pacific Reedgrass-Carex-Juncus, Pickleweed-Saltgrass, Beaches or Mudflats, and the Dune Lupine-Dune Sagewort-Dunegrass superalliances. The first two superalliances are emergent wetlands and are described in Section 2.8.3. Beaches and mudflats are mostly unvegetated areas where sand is deposited by wind and/or water at Muir Beach. These areas can be colonized with very low cover by several native annual plant species such as California salt bush (*Atriplex californica*), yellow sand verbena (*Abronia latifolia*), and coast strawberry (*Fragaria chiloensis*).

Areas along the steeper slopes of Muir Beach to the north and south of the mouth of Redwood Creek are mapped as the Dune Lupine-Dune Sagewort-Dunegrass superalliance. As mentioned above, these polygons support communities that include several of the superalliance native indicator species, such as dune sagewort (*Artemsia pycnocephala*), beach morning glory (*Calystegia soldanella*), beach evening primrose (*Camissonia cheiranthifolia*), beach burr (*Ambrosia chamissonis*), California bee plant (*Scrophularia califonica*), yellow sand verbena, and native dune grasses. However, these native dune grasses, such as American dunegrass (*Leymus mollis* ssp. *mollis*) and Pacific wildrye (*Leymus pacificus*), cover less area than European annual grasses, such as ripgut brome (*Bromus diandrus*) and European beachgrass (*Ammophila arenaria*). Although large amounts of iceplant (*Carpobrotus edulis*) were removed from the south beach in the 1990s, these dunes are still riddled with non-native forbs such as European sea rocket (*Cackile maritime*) and kikuyu grass (*Pennisetum clandestinum*).

2.8.3 Wetlands and Seeps Found in the Lower Redwood Creek Watershed

Wetlands have been mapped several times in lower Redwood Creek, including the reach from the Banducci restoration site downstream as well as the lower Green Gulch tributary area (Figure 2-31). Caltrans initially delineated CWA Section 404 jurisdictional wetlands in the lower Redwood Creek watershed in 1993 (PWA et al. 1994). In 2002 and again in 2003, the NPS updated this wetland mapping and classification, following Cowardin et al. 1979 (Schirokauer 2003). Most recently in July 2006, Section 404 wetland delineations were checked for development of an EIR in support of the Lower Redwood Creek Restoration at Muir Beach project (Jones & Stokes 2007). Based on a methodology adapted from Cowardin and the U.S. Army Corps of Engineers Delineation Manual that uses vegetation, soils, and hydrology as indicators of wetland conditions (Castellini et al. 2006; USACE 1987), 62 acres of wetlands in lower Redwood Creek were mapped. Plant species were considered indicative of wetland conditions if they were classified as Obligate Wetland Species (OBL) or Facultative Wet Wetland (FACW) (Reed 1996), but not if they were classified as Facultative Wetland (FAC), unlike the USACE (1987) criteria. Team members from GGNRA and Point Reyes National Seashore made this decision based on the observation that in the coastal fog belt, the distribution of many FAC plant species includes uplands as well as wet areas, and thus these species are not indicative of wetland conditions (Castellini et al. 2006). The 2006 mapping confirmed the previous wetland mapping efforts and is presented in Figure 2-31. Although these mapped wetlands overlap with the NPS superalliance vegetation types described in Table 2-20, little specific agreement in the wetland types exists between the two efforts (Figures 2-30 and 2-31, respectively). Because the 2006 wetland mapping was a more focused and high-resolution effort, based on multiple field investigations as well as aerial photo-interpretation, it offers a more precise representation of wetland types and boundaries within the lower Redwood Creek than the NPS superalliance map. It is also important to note that resource management activities being implemented as part of the lower Redwood Creek restoration at Muir Beach will alter the spatial extent and classification of wetlands in that area.



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Sources: National Park Service (GGNRA), Marin Municipal Water District

Figure 2-31. Wetland Delineation and Classification in Lower Redwood Creek Watershed based on methodology adapted from Cowardin et al. (1979).

Emergent Wetland

Before restoration at lower Redwood Creek, a brackish marsh west of the Muir Beach parking lot was dominated by salt rush (*Juncus leseurii*), salt grass (*Distichlis spicata*), and silverweed (*Potentilla anserine*). Native salt marsh species formerly observed in these areas in 1992–1993 also included jaumea (*Jaumea carnosa*), alkali heath (*Frankenia salina*), and grindelia (*Grindelia stricta*). These areas fall under the two coastal emergent wetland superalliances Pacific Reedgrass-Carex-Juncus and Pickleweed-Saltgrass.

Pre-project freshwater emergent wetlands were dominated by cattails (*Typha latifolia*), with spikerush (*Eleocharis macrostachya*), water plantain (*Alisma plantago-aquatica*), silverweed (*Potentilla anserine*), and water parsley (*Oenanthe sarmentosa*), bulrush (*Scirpus* spp.), tall cyperus (*Cyperus eragrostis*), dotted smartweed (*Polygonum punctatum*), and baltic rush (*Juncus balticus*). Many non-native weeds also were common, especially along the levee roads and trails; the most common of these were ox-tongue (*Picris echioides*) and knotgrass (*Paspalum spp*.).

The Lower Redwood Creek Restoration at Muir Beach project includes creation of a backbarrier lagoon and seasonally brackish to freshwater marsh near the creek mouth (Jones & Stokes 2007). Revegetation goals include establishing species that are tolerant of variable fresh to saline conditions and capable of rapid re-establishment after scouring and accretion events. Species selected for this include rushes (*Juncus lesuerii* and *J. phaeocephalus*), bulrush (*Scirpus pungens*), saltgrass, sedges (*Carex obmupta*, *C. praegracilis*), and forbs (*Aster chilensis*, *Cicuta douglasii* and *Rumex occidentalis*) (Friedel 2009).

Climate projections for northern coastal California indicate that mean sea level rise could inundate large portions of the planned wetland complex at Muir Beach. Landward migration of the shoreline and the brackish freshwater marsh along lower Redwood Creek could occur, along with increasingly frequent and intense winter storm flows from upstream (Bay 2008). Plant species that are adapted to frequent disturbance, such as willow, alder, and bulrush, have high resilience because they reproduce readily on newly deposited substrate and are likely to survive such climatic stresses (Bay 2008). Rhizomaceous species and other species with dense rooting structures also will provide additional bank stability as resistance to effects of increased storm intensity and frequency. Redundancy in multiple willow and herbaceous species in the riparian zone will provide strength against potential species vulnerabilities.

Freshwater wet meadows are being replanted along the alluvial fan of Green Gulch and the un-named tributary to its southwest as part of the Lower Redwood Creek Restoration at Muir Beach project during the fall and spring of 2009 and 2010 (Jones & Stokes 2007, Friedel 2009). The intent of these replantings is to establish diversity of freshwater wetland communities for upper, mid, and lower elevations that can withstand yearly variations in groundwater levels fed by Green Gulch creek and the un-named tributary. Species included in the planning plan, many of which have already been planted, include sedges (*Carex praegracilis*, *C. barbarae*), rushes (*Juncus balticus* and *Eleocharis macrostachya*), and native grasses and forbs (*Leymus triticoides*, *Hordeum brachyantherum*, *Equisetum arvense*, and *Artimisia douglasiana*). Several areas are designed to be permanently saturated or inundated, such as the “frog pond.” With the intent of precluding establishment of cattail monocultures while allowing for establishment of a diverse native plant community, these areas are planted with bulrushes and other hydrophytes (e.g., *Scirpus* spp., *Sparganium eurycarpum*, and *Juncus effusus*).

Scrub-Shrub Wetland

Scrub-shrub wetlands are dominated by arroyo and shining willow (*S. lucida*), with an understory of thimbleberry, blackberry (*Rubus ursinus* and *R. discolor*), and red elderberry with patches of herbaceous species such as stinging nettle, non-native water parsley (*Oenanthe sarmentosa*), and hedgenettle (*Stachys ajugoides*). Non-native species include cape ivy and English ivy. Before implementation of the Lower Redwood Creek Restoration at Muir Beach project, scrub-shrub wetlands were located west of parking lot (permanently flooded and saturated), north east of parking lot (saturated), and between the Pacific Way and Highway 1 bridges (seasonally flooded). Revegetation plans combine shrub and forested riparian community types into a single "riparian" plant palette (Friedel 2009), discussed next.

Forested Wetland

This type is the same as described above in Section 2.8.2 and is dominated by red alder, several willow species, blackberry and elderberry shrubs. Riparian woodlands occur along the transport and depositional reaches of Redwood Creek and its tributaries. Before implementation of the Lower Redwood Creek Restoration at Muir Beach project, red alder and willow riparian communities occupied the banks and floodplains adjacent to lower Redwood Creek between the Pacific Way and Highway 1 bridges.

Implementation of the Lower Redwood Creek Restoration at Muir Beach project involves moving sections of the lower Redwood Creek channel to the lowest point on the floodplain and replanting adjacent banks and several floodplain areas with native species (Jones & Stokes 2007, Friedel 2009). The proposed planting palette includes red alder, willow, California wax myrtle (*Myrica californica*), dogwood (*Cornus sericea*), twinberry honeysuckle, red elderberry, rhododendron (*Rhododendron occidentale*), grasses and forbs (e.g., *Leymus triticoides*, *Artemsia douglasiana*, *Carex obnupta*, *Scirpus macrocarpus*, *Equisetum arvense*, *E. hyemale*, and *Lilium pardalinum*) (Friedel 2009).

Streambed and Unconsolidated Bottom Wetland

Subtidal, unconsolidated stream bottom occurs at the mouth of Redwood Creek as it drains into the ocean at Muir Beach. Areas classified as streambed include lower Redwood Creek, Green Gulch, and unnamed tributary channels, which are intermittently exposed during the dry season. Sparse cover of ruderal species occurs in these areas late in the season, but these plants are regularly scoured out during high flow events. No revegetation plans exist for these areas.

Seeps and Springs

In 2003, the NPS hired private contractor Mike Faden to survey seeps and springs along the northwestern portions of upper Redwood Creek as well as along Dias Ridge, Camino del Canon, Kent Canyon, and parts of Muir Woods. In 2005, Faden extended this survey to include Stinson Beach and the bluffs above, Green Gulch, and Muir Beach. Over both surveys, 48 springs and seeps were documented within Redwood Creek watershed (Faden 2003a, 2005). Areas were designated as springs only when standing or flowing water was present, or when a film of surface water was observed (Faden 2005). Besides location, field data recorded as part of these surveys included water temperature, conductivity, dominant plant species, and surface substrate. Large springs (flow rate over 1 gallon per minute) were documented near—and are used by—the Green Gulch Farm. Characteristic seep vegetation within grasslands and chaparral include lady fern (*Athyrium felix-femina*), Pacific reedgrass (*Calamagrostis nutkaensis*), slough sedge (*Carex obnupta*), giant horsetail (*Equisetum telmateia* ssp. *braunii*), and California wax-myrtle; within forested areas, lady fern and giant chain fern (*Woodwardia fimbriata*) were consistent indicators, and redwoods and arroyo willow were common to springs but also were often found in areas without springs (Faden 2003a, 2005).

2.8.4 Vegetation Changes and the Role of Fire

Fire History

Fire has played an important role in shaping vegetation communities in coastal California. Although lightening-induced fires were historically unusual in northern coastal California because of infrequent lightening strikes during the dry season (approximately one strike every 5 years; Sunget and Martin 1984), the native Coastal Miwok people lived with frequent, low intensity fires for over 8,000 years before Euro-American occupation (Levy 1978). Coastal Miwok used fire to drive game, facilitate the collection of acorns and seeds, kill insects and small mammals for food, promote growth of seed-bearing annuals, increase the extent of grazing areas, and maintain open areas for temporary shelter and travel.

Early Euro-American settlers continued to use fire through the 1900s to increase grazing lands for livestock. As more people settled in southern Marin, fire suppression became the prevailing practice. Fires were often ignited, but they were generally suppressed and confined to small areas. As a result, fire frequency in the watershed has been greatly reduced. McBride and Jacobs (1978) evaluated fire history at Muir Woods and concluded that, before the earliest recorded fire in 1850, the Muir Woods area probably burned on the order of once every 22 to 27 years. Fire suppression can affect redwood regeneration, forest succession, and ultimately forest structure and composition. It also can lead to increased fuel loads that can cause more intense burns when fires occur. The recorded fire history of Mt. Tamalpais and associated Redwood Creek watershed is shown in Table 2-21. Changes in fire frequency and intensity have affected fuel loads, plant community structure and composition in the watershed, particularly in the grasslands, chaparral, and Redwood–Douglas-fir forests.

Table 2-21. Recorded Fire History of Mt. Tamalpais

Year	Location	Comment
1859	Mt. Tamalpais	Burned for 3 months.
1881	Mill Valley through NE portion of Redwood Creek watershed	65,000-acre wildland fire. Accidentally spread from a brush pile fire in Mill Valley.
1891	From Ross over to the extreme northern portions of the watershed	12,000 acres of Mt. Tamalpais burned. Fire started near Ross.
1913	Mt. Tamalpais Summit, Blithedale and Cascade canyons, most of Fern Canyon	2,600 acres burned. Fire started near West Point Inn, probably ignited by railroad sparks.
1919	From Pipeline Reservoir to Muir Woods	Undocumented extent.
1929	Mill Valley to Fern and Cascade canyons	“Great Tamalpais Fire” burned 2,500 acres.
1931	Muir Woods	Illegal campfire charred redwoods in Cathedral Grove.
1932	Panoramic Highway to Muir Woods	60 acres (24 ha) burned, including 2 (0.8 ha) ac within the Muir Woods boundaries
1959	Kent Canyon	50 acres burned near logging operations on Brazil Ranch.
1965	One-quarter mile from Muir Woods southeast boundary	150 acres burned.

Source: MMWD 1995

Grassland to Shrubland Conversion and Fire Suppression

Increased urbanization, fire suppression, and decreased grazing in the watershed have all contributed to the gradual conversion of grasslands to shrublands. Leonard Charles & Associates compiled historical photographs taken in the watershed and took current photographs from those same locations. Qualitative observations of these photographs, which are presented in the *Mount Tamalpais Area Vegetation Management Plan* (MMWD 1995), reveal a sharp reduction in grassland area and an increase in shrubland area since the 1920s. The Humboldt State University's study of prehistoric vegetation for the California Department of Parks and Recreation provides the best information available to date on historical grass and shrubland composition in the watershed and changes from historical to current conditions (Bicknell et al. 1993). The study area included State Park lands in the lower portion of the watershed (i.e., downstream of Muir Woods National Monument) and to the north. The study relied on a combination of (1) review of historical accounts, (2) interpretation of aerial photography, and (3) analysis of phytolyths to document pre-historic and current vegetation conditions at the study sites. For this study, prehistoric vegetation was defined as "that which existed prior to occupation of the Mt. Tamalpais State Park area by Euro-American settlers." Current and pre-historic vegetation composition for the study's "Site A," approximately half of which is within the Redwood Creek watershed, is shown in Figure 2-32. This analysis indicates that grassland area has been reduced by approximately 64 percent since Euro-American settlement caused by conversion of grasslands to shrubland and shrubland/grassland mosaic. Although many ranchers practiced burning to maintain grasslands for forage following displacement of native populations, subsequent cessation of deliberate burning has likely allowed for shrubland conversion (Bicknell et al. 1993, Blackburn and Anderson 1993, Evett 2000).

Fuel and Fire Hazard Management

A fire hazard map for Marin County, developed by the Marin County Fire Department and based on fuel, slope and aspect, shows that most of the upper portions of the Redwood Creek watershed have high to very high fire hazard (Marin County Fire Department 2005). Fire management issues throughout the watershed include fuel loading (especially as a result of SOD in Muir Woods), control of invasive species, visitor safety, and access/egress routes for adjacent residential communities. Fuel and fire management in the watershed is implemented separately by the three major public agencies (the MMWD, GGNRA, and state parks through the county); each agency has their own guiding fire/vegetation management plan. Marin County has identified priority action areas based on the primary goal of reducing fire risk along the wildland-urban interface (Leonard Charles & Associates and Wildland Resources Management 2008). The GGNRA's *Fire Management Plan* (FMP) identifies ten goals (GGNRA 2005), which include public safety as well as protection of private property and structures, and protection of natural resources. Similarly, the MMWD's *Fire Hazard Management Plan* includes "maintaining existing significant biological resources" alongside "minimizing risk to life and property from wildfire" as primary goals (Leonard Charles & Associates and Wildland Resources Management 2008). For the Muir Woods Fire Management Unit, GGNRA also identifies preservation of the "pristine character" of Muir Woods as a priority. Three objectives are to be pursued by GGNRA to attain this goal: (1) restore the role of fire in the relevant vegetation communities; (2) reduce fuel loading and the threat of catastrophic wildfire; and (3) further study fire effects in old-growth coast redwood forest. These objectives are being pursued through a mix of prescribed fire and mechanical fuel reduction. Prescribed fire is planned to restore the fire regime in the redwood/Douglas-fir forest and for control of non-natives in the Conlin Avenue area near the maintenance yard (GGNRA 2005).

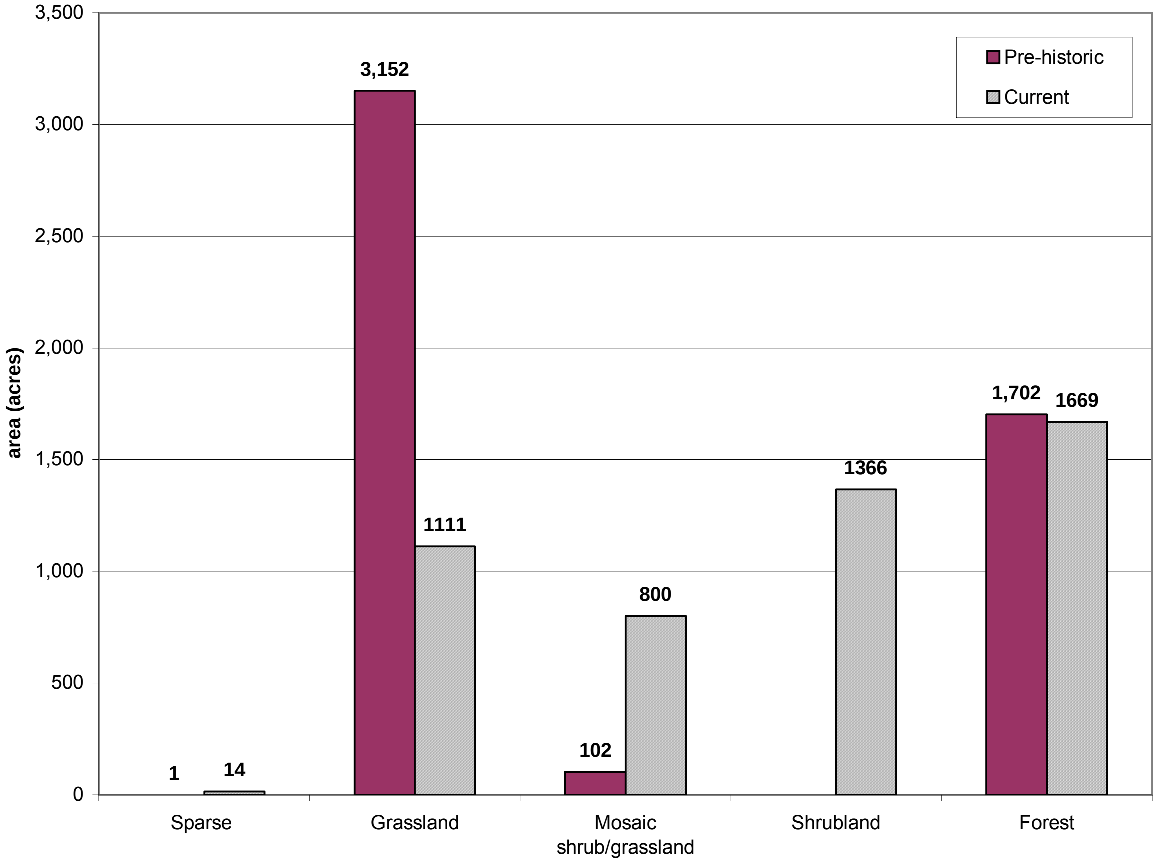


Figure 2-32. Current and pre-historic (i.e., pre-European) vegetation composition for Bicknell et al. "Site A", approximately half of which is within the Redwood Creek watershed. (Adapted from Bicknell et al. (1993))

Institutional differences in emphasis result in slight variations on the types of activities implemented under the three jurisdictions in the watershed. Marin County resources are focused on fuel reduction, creation and maintenance of fuel breaks, and outreach to residents about creating and maintaining defensible space and evacuation plans. Although the MMWD and GGNRA emphasize human safety and evacuation routes, they also integrate prescribed burns with mechanical fuel management as a means of reducing wildfire risk and restoring some of the natural disturbance processes to the forest, grasslands, and shrublands. GGNRA goals also include using fire management to sustain and restore natural resources and improving understanding of fire through research and monitoring (NPS 2005a). The range of activities include creation and maintenance of fire/fuel breaks and brush removal, prescribed burns in targeted areas, fire suppression, and ensuring safe access and evacuation in case of wildfire (Stillwater Sciences 2005c; Leonard Charles & Associates and Wildland Resource Management 2008).

Fuel Breaks

The MMWD maintains a 30-foot fire break on its property along Panoramic and East Ridgecrest Boulevard (Leonard Charles & Associates and Wildland Resources Management 2008). Marin County picks up responsibility for maintaining a fuel break along Panoramic Highway down to the intersection with Highway 1 (Leonard Charles & Associates and Wildland Resources Management 2008). Similarly, GGNRA maintains fire roads to allow for safe access by emergency vehicles in Muir Woods. The MMWD has found that when French or Scotch broom (*Genista monspessulas* and *Cytisus scoparius*, respectively) invade areas opened as fuel breaks, maintenance requires annual rather than every 3- to 5-year weed control, which substantially increases the cost of maintaining the fuel breaks (Leonard Charles & Associates and Wildland Resources Management 2008).

Fuel Reduction Projects and Prescribed Burns

Marin County has identified priority action areas for reducing fire risk along the wildland-urban interface, including clearing fire-prone trees at two locations along Panoramic Highway along the northwestern border of the watershed (Marin County Fire Department 2005). The MMWD and GGNRA also have identified critical areas in need of fuel reduction to reduce wildfire hazard. Prescribed burns have been used in the watershed, for fuel load reduction and management of non-native invasive plant species.

Since executing the 1993 GGNRA *Fire Management Plan*, several prescribed fires were conducted in Muir Woods between 1993 and 2001, including three burns in redwood/Douglas-fir forests (9-acre upper Dear Park, 52.5-acre Dear Park 2 burn, and 35-acre Johnson prescribed fire), and two burns to control non-native broom species at the lower end of Camino del Canon. In the 1990s, Mount Tamalpais State Park and Marin County executed a number of burns to control non-native plant species and coyote brush invasion in grasslands along Panoramic Highway, north of Three Sisters, and along Muir Woods Road (above the Sun Trail) (Boyd, pers. comm., 2005).

Although these prescribed burns were successful and provided vital information on controlling invasive species such as French and Scotch broom, few burns have been possible since 2000. During this time, the use of prescribed burning in the Redwood Creek watershed has become increasingly constrained by associated high costs in relation to available funding, complexity of logistical issues such as appropriate weather conditions, constraints related to smoke management, and coordination among various agencies (Stillwater Sciences 2005c). In spite of these logistical challenges, the 2005 GGNRA Fire Management Plan Environmental Impact Statement, as well as the Marin County and the MMWD FMPs all call for continuation/renewal of strategies involving prescribed burns in the future.

Fire Suppression

Fire suppression is still an important component of fire management practices in the area (Stillwater Sciences 2005c). According to the GGNRA FMP FEIS (2005), the current policy for all considered alternatives is to suppress all unplanned ignitions aggressively and with human safety as a top priority. GGNRA and the Marin County Fire Department have a cooperative agreement to work together to control wildfires (Marin County Fire Department 2005).

2.8.5 Special-Status Plant Species

GGNRA natural resources staff have provided Stillwater Sciences with a list of special-status plants that have been observed or could potentially occur in the Redwood Creek watershed (NPS 2005b, unpubl. data). Additionally, a list of potentially occurring special-status plant species was generated using the California Natural Diversity Database (CNDDB) (CDFG 2009), and CNPS Inventory of Rare and Endangered Plants (CNPS 2009), based on records for the two USGS 7.5-minute topographic map quadrangles covering the Redwood Creek watershed (Point Bonita [467D] and San Rafael [467A] quadrangles]. The list of potentially occurring, special-status plant species include those species that have been documented to occur, either historically or recently, and have the following status designations: state or federally threatened, endangered, candidate, proposed threatened, or proposed endangered; species listed as rare by the state; and species listed as CNPS 1A, 1B, 2 and 4. The 2005 NPS special-status plant list and the 2009 database-generated list were reviewed and combined into one table. Table E-1 of Appendix E provides the compiled list and includes species habitat associations, locations of occurrences within the watershed, and potential threats.

Many of the special-status plant species that occur in the watershed are serpentine-endemic species or found in coastal habitats (i.e., coastal bluff, dunes, scrub, marshes and swamps), although a few special-status plant species occur in valley and foothill grassland, broadleaf upland forest, and coniferous forest.

Special-status plant surveys and monitoring have been conducted within sections of the Redwood Creek watershed by the following groups: NPS (1998–2004; 2008-present), M. Faden (2002, 2003b) and J. Taylor (2003) for the NPS, and the MMWD. The 2009 database queries contain all reported special-status plant occurrences within the watershed’s boundaries.

Results from the 1998–2004 special-status plant surveys conducted by the NPS within the GGNRA are compiled in GGNRA’s *Special-Status Vascular Plant Inventory and Monitoring Report* (Speith and Taylor 2009). During these surveys, six special-status plants (California bottlebrush grass [*Elymus californicus*], Oakland star tulip, hooker’s Manzanita [*Arctostaphylos hookeri* ssp. *montana*], serpentine reed grass, Tiburon buckwheat, and Mt. Tamalpais jewelflower) were identified in the Redwood Creek watershed within the Muir Woods National Monument, Four Corners, and the Mill Valley Air Force Station, located along the west peak of Mt. Tamalpais and the very upper reaches of the Redwood Creek watershed.

California bottlebrush (*Elymus californicus*; CNPS list 4) perennial grass is widely distributed in riparian forests throughout Muir Woods (NPS 2009). Monitoring recommendations include a survey every 3 years to ensure threats of invasive species do not impair the population. Patches of Oakland star tulip were located at Four Corners on non-serpentine soils, atypical for this species because all other populations located within Golden Gate National Parks inhabit serpentine soils (Speith and Taylor 2009). Surveyors noted that the population may be under threat by French broom invasion, and monitoring is recommended every 3 years. Six special-status plants are located within the Mill Valley Air Force Station, many with multiple populations (Hooker’s manzanita, Tiburon buckwheat, Mt. Tamalpais jewelflower, Oakland star tulip). No special-status plant species located at this site are considered under immediate threat and monitoring intervals of 2 or 3 years is recommended. The results and survey recommendations for all special-status plant populations is provided in Table E-2 of Appendix E.

Additional surveys were conducted in the Redwood Creek watershed for the NPS by Michael Faden (2002, 2003b) and Jeanne Taylor (2003). Faden's 2002 surveys targeted the following special-status plants: tower mustard (*Arabis glabra*), San Francisco wallflower (*Erysimum franciscanum*), California bottlebrush grass, and Lobb's aquatic buttercup (*Ranunculus lobii*) in Green Gulch, Diaz Ridge, Big Lagoon, and the Banducci Site, with no findings. Taylor's 2003 special-status plant surveys were conducted at Big Lagoon (Muir Beach) for the following special-status plants: pink sand verbena (*Abronia umbellata* ssp. *Breviflora*), swamp bellflower (*Campanula californica*), San Francisco spineflower (*Chorizanth cuspidata* var. *cuspidate*), Point Reyes bird's-beak (*Cordylanthus maritimus* ssp. *Palustris*), Marin knotweed (*Polygonum marinese*), and Lobb's aquatic buttercup. No special-status plants were located during these surveys. Three special-status plant occurrences of rose rock cress (*Arabis blepharophylla*), Oakland star tulip, and San Francisco wallflower were documented in Faden's 2003 surveys of Green Gulch, Four Corners, Mill Valley Air Force Station, Coyote Ridge, Big Lagoon and Muir Beach and are listed in Table E-3 of Appendix E (Faden 2003b).

The MMWD surveyed for special-status plants along a number of trail and road sections along Mt. Tamalpais and the upper Redwood Creek watershed for their finalized *Comprehensive Roads and Trails Management Plan* (Leonard Charles & Associates 2005). As part of baseline studies for the plan, the MMWD conducted special-status plant surveys in May 2004, along trails in the Redwood Creek watershed. Results from the surveys are provided in Table E-4 of Appendix E and include the following species: Mt. Tamalpais manzanita, Mt. Tamalpais jewelflower, Carlotta Hall's lace fern (*Aspidotis carlotta-halliae*), Shreve oak (*Quercus parvula* var. *tamalpaiensis*), Mt. Tamalpais thistle, serpentine reed grass, Marin County navarretia, and Oakland star tulip. The MMWD manages lands supporting every population of Mt. Tamalpais thistle in the watershed (this taxon is endemic to Mt. Tamalpais). John Herr of the U.S. Department of Agriculture has monitored this plant in the watershed for 10 years as part of a larger study on the effects of introduced biocontrol agents (introduced to control non-native thistles) on native thistles (Stillwater Sciences 2005c). The two populations that occur in the Redwood Creek watershed are in decline (Stillwater Sciences 2005c).

The *Biodiversity Management Plan for Marin Municipal Water District Lands* (Garcia and Associates 2009), a supplement to the 2009 *Vegetation Management Plan Update*, includes special-status plant occurrence maps and data within the MMWD lands, including areas within the Redwood Creek watershed. The special-status plant occurrences located within the MMWD lands are based on a 1990 inventory by Charles Patterson and personal observations by Doreen Smith, the Rare Plant Coordinator of the Marin Chapter of CNPS (Garcia and Associates 2009), and they can be downloaded from the MMWD Web site. Goals and objectives to maintain, enhance, and restore special-status plants and habitats for future management for the MMWD lands is presented in the 2009 *Vegetation Management Plan Update* (Leonard Charles & Associates 2009a)

2.8.6 Non-Native Invasive Plants

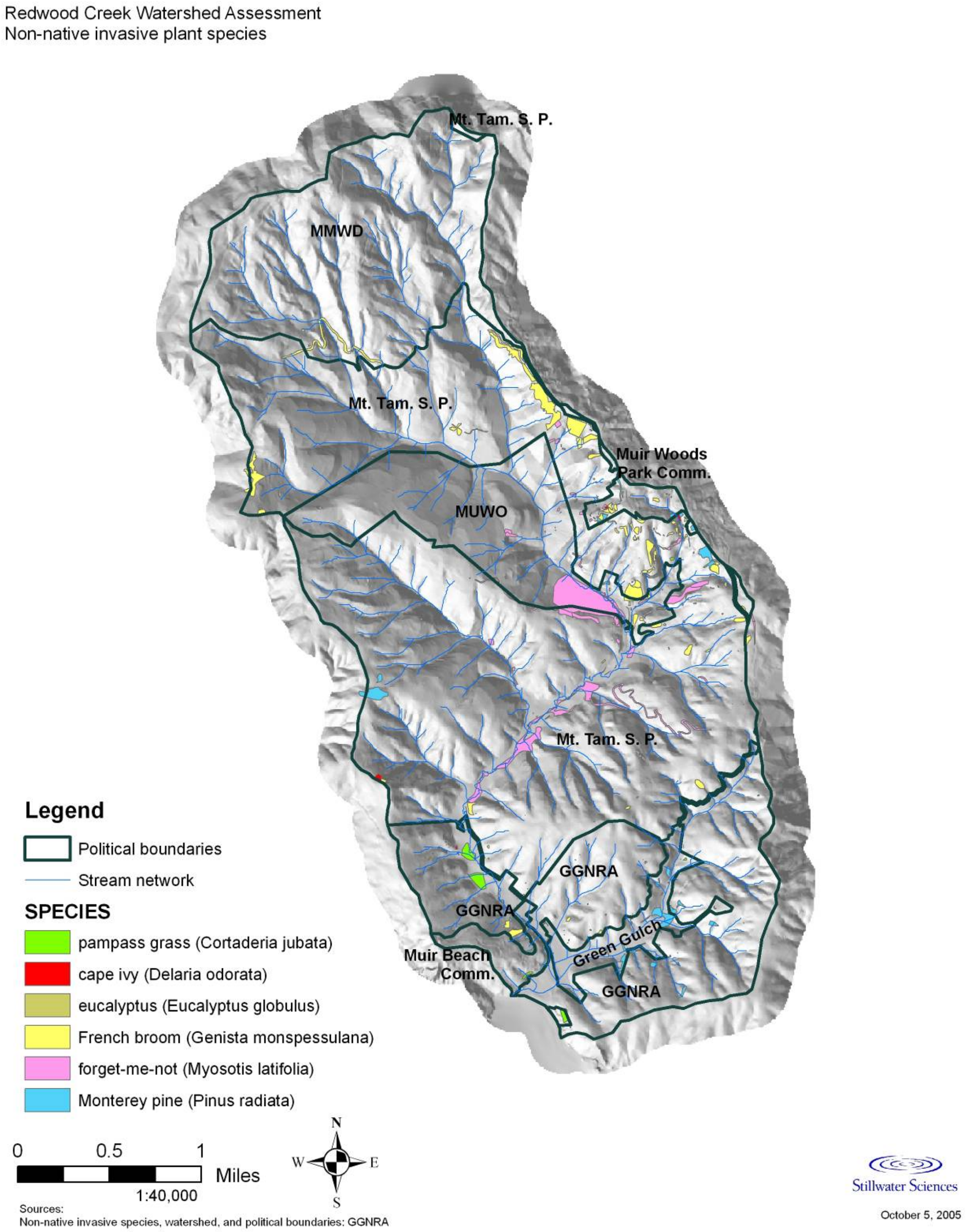
Non-native invasive plants pose a significant threat to the quality of native plant communities in the Redwood Creek watershed. Invasive species displace native vegetation, alter the structure and function of plant communities, and dominate species composition, thereby reducing biodiversity.

Invasive Plant Survey and Mapping Efforts

The distribution and spread of non-native invasive plant species are being surveyed and mapped in various locations throughout the watershed. However, no consistent or coordinated ongoing efforts occur on a watershed-wide basis. The NPS identified and mapped locations of invasive plant species throughout the entire watershed in 1999 (GGNRA, unpubl. data). This survey identified a total of 39 invasive species occupying 921 acres in the watershed, or 16 percent of its total area (Figures 2-33 through 2-35). A list of invasive plant species documented in these surveys is provided in Table E-5 of Appendix E. Of the area dominated by invasive species, 16 percent is in riparian habitat, 24 percent is in grassland, and 27 percent is in scrub/grassland (Appendix E, Table E-6). Invasive species occurred primarily along roads and trails, which provide disturbed, exposed soil where these species can easily become established. Roads and trails also function as conduits for the spread of invasive species, particularly those with wind-dispersed propagules. Reconnaissance surveys have since occurred within portions of the watershed, providing an updated status of the documented invasive plant species as well as of new populations. Two resources providing current material on non-native invasive plant populations in the Redwood Creek watershed include the *Long Term Invasive Species Management Plan for Muir Woods* (Baxter et al. 2009) and Weed Watchers, the NPS volunteer-based invasive plant early detection program, (available: http://science.nature.nps.gov/im/units/sfan/vital_signs/Invasives/weed_watchers.cfm).

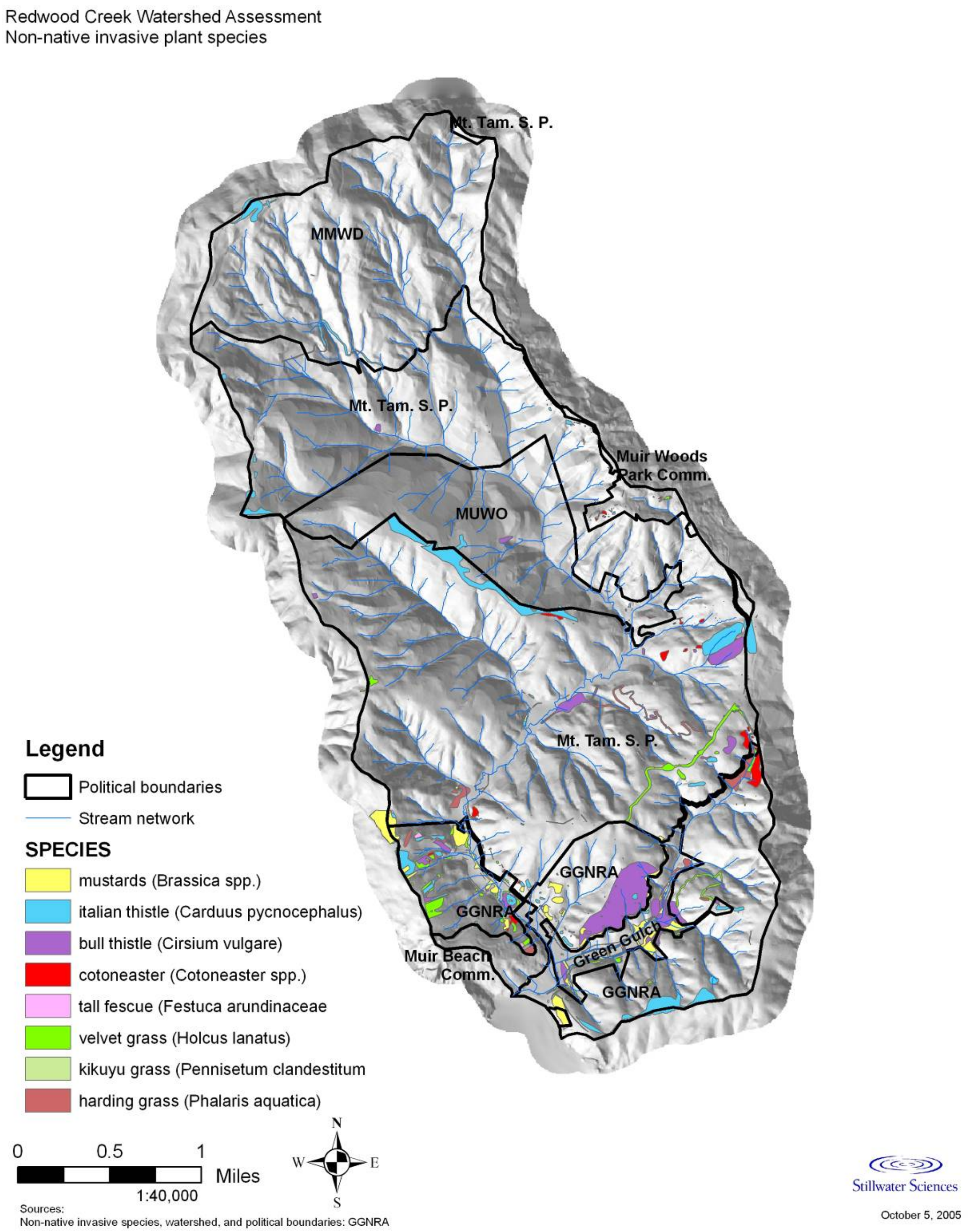
Recent results for non-native invasive plant surveys conducted by the NPS within Muir Woods (560 acres) and bordering area within the Redwood Creek watershed (124 acres) are documented within the *Long Term Invasive Species Management Plan for Muir Woods* (Baxter et al. 2009). Surveyed locales were divided into five management areas with priority ranking for each. Management area descriptions, priority ranking decisions, and the approximate area of invasive mapped plants for each are provided in Table 2-22. During these surveys, mapped locations of the following six non-native invasive plants were updated: licorice plant (*Helichyrisum petiole*), Himalayan blackberry (*Rubus discolor*), Cotoneaster (*Cotoneaster* sp.), English ivy, forget-me-nots (*Myosotis latifolia*), and French broom (Baxter et al. 2009).

English ivy and panic veldt grass were recently located within Muir Woods National Monument and extensively mapped within the management areas because of their rapid spread since the 1999 surveys (Baxter et al. 2009). The *Long Term Invasive Species Management Plan for Muir Woods* provides detailed invasive plant findings per management area and discusses methods for future control and eradication per site location, based on GGNRA’s Best Management Practices, as shown in Table E-7 in Appendix E.



Sources:
Non-native invasive species, watershed, and political boundaries: GGNRA

Figure 2-33. Distribution of non-native invasive plant species that have been the target of recent control efforts in the Redwood Creek watershed.
(Source: NPS unpublished data.)



Sources:
Non-native invasive species, watershed, and political boundaries: GGNRA

October 5, 2005

Figure 2-34. Distribution of non-native invasive plant species that occupy a significant area of the Redwood Creek watershed, but have not been the target of extensive control efforts.

(Source: NPS unpubl. data.)

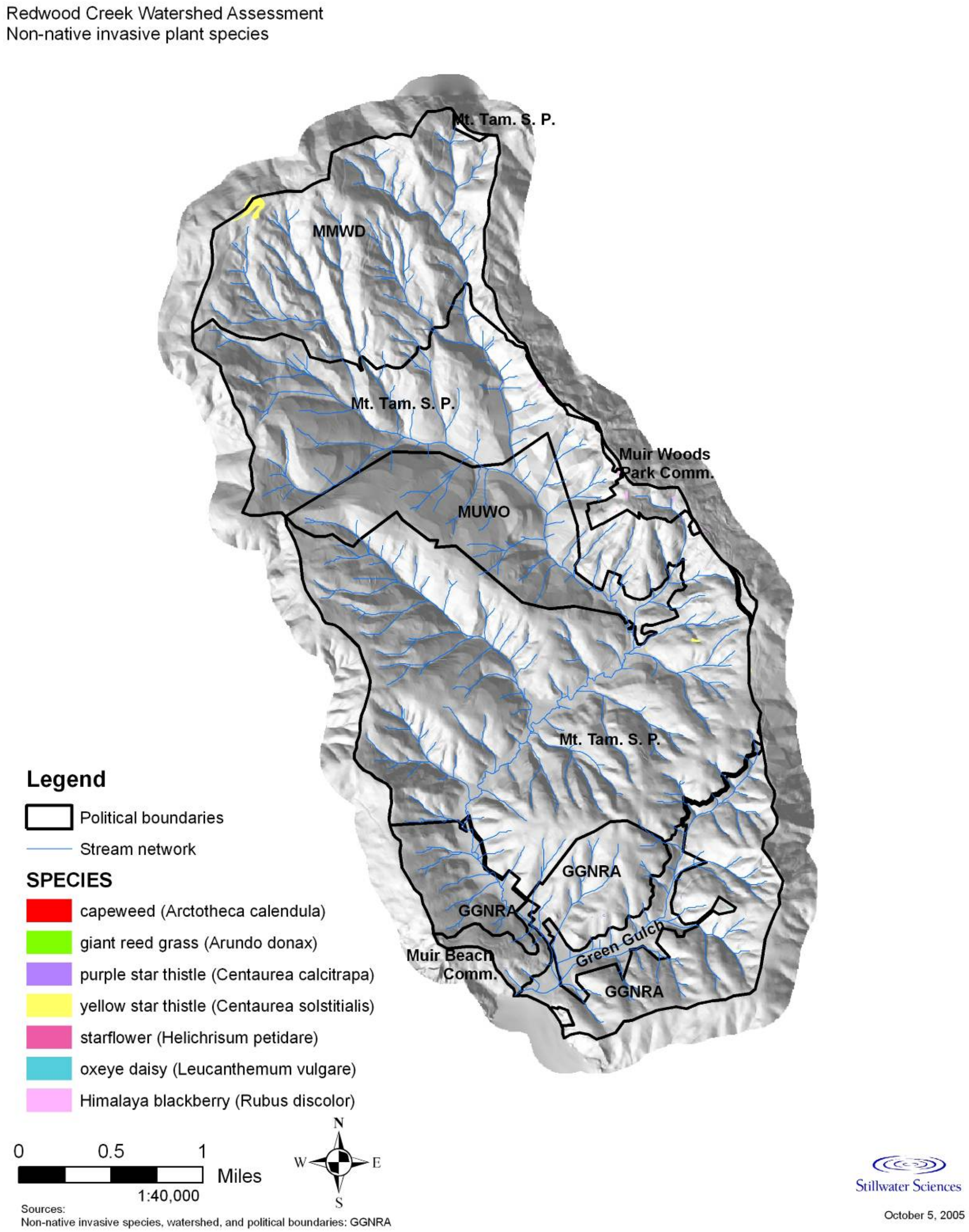


Figure 2-35. Distribution of non-native invasive plant species that are highly invasive, but currently occupy only limited areas within the Redwood Creek watershed. (Source: NPS unpubl. data.)

Table 2-22. Management Areas Surveyed in 2009 for Non-Native, Invasive Weed Assessment for Muir Woods and Bordering Areas within the Redwood Creek Watershed

Priority Ranking	Management Area	Management Area Location	Total Area (acres)	Approximate Area with Invasive Weeds (acres)
1	Redwood Forest and Riparian	Main Forest paved paths, Fern Creek, Hillside, Bootjack, and Ben Johnson trails. Ranked highest priority for maintaining the integrity of the core riparian and old growth redwood habitat, endangered species habitat and importance as a major National Park visitor viewshed.	382	≤6.81
2	Entrance Area	Main and Annex parking lots, Education Lab/ Old Inn, Dipsea trail, Old Service Road, Redwood Creek Nursery, and the Concrete bridge. Ranked second for its role as a central hub of species introduction (past and present) and significance for visitor viewshed among facilities.	49	≤22.03
3	Upper Deer Park Fire Road	Upper Deer Park Fire Road, Dipsea, and Ben Johnson trails. Ranked second for protection of intact redwood plant community in the uppermost section of the watershed from invasion along exposed ridgeline.	138	1.25–12.25
4	Camp Eastwood/ Oceanview Trail	Camp Alice Eastwood, Fern Creek, and Oceanview trails. Ranked fifth as a management priority due the ecological significance of the endemic Marin manzanita and historic management by NPS on State Park property up gradient of the main forest.	78	6.5–13.58
5	Camino del Canon	Druid Height steps, Conlon Rd and Camino del Canyon Road. This section, with its historic residential land use impacts, is identified for habitat enhancement and control of spread of established invasives in the mixed coniferous forest.	68	≤40

Source: Baxter et al. 2009

The NPS also provides updated mapped locations of non-native invasive weeds within the GGNRA priority subwatersheds (including Redwood Creek watershed [GGNRA 12-1–12-9]), as a part of the volunteer-based invasive plant early detection program, Weed Watchers. Updated mapped locations of non-native invasive plants in the Redwood Creek watershed can be viewed on the Weed Watchers Web site. The collective efforts of volunteers and NPS staff involved in the Golden Gate Weed Watchers program continue to annually (2007–2009) detect, map, control and eradicate invasive weeds throughout San Francisco Bay Area Network, which includes many of the Redwood Creek watershed trails and roads. Through the Golden Gate Weed Watchers program, many invasive species in the watershed are now mapped and managed using the methods from *Early Detection of Invasive Plant Species in the San Francisco Bay Area Network, a Volunteer-Based Approach* (Williams and Speith 2008). Annual reports and maps documenting the end of the year results are provided on the NPS Weed Watchers Web site.

The MMWD also is mapping non-native invasive plant species within its purview and actively managing invasive plants throughout its watershed lands (Stillwater Sciences 2005c). Invasive plants on MMWD lands typically are found along pipelines, power lines, tanks, roads, and trails. Invasive species of concern on MMWD lands include French broom, Scotch broom, Monterey pine, Monterey cypress (*Cupressus macrocarpa*), jubata grass, yellow star thistle (*Centaurea solstitialis*), and purple star thistle (*Centaurea calcitrapa*). Broom species infest approximately 1,000 acres of MMWD lands (Redwood Creek sites are "outliers" to the main infestations [Figures 2-33 through 2-35]).

Invasive Non-Native Plant Control Efforts

The MMWD, the NPS and State Parks are all engaged in ongoing efforts to control non-native invasive plants on their lands. Invasive species that have been the target of NPS GGNRA control efforts through the Habitat Restoration Team include: cape ivy (*Delaria odorata*), French broom, Scotch broom, pampass and jubata grass (*Cortaderia selloana and C. jubata*), Tasmanian blue-gum eucalyptus (*Eucalyptus globulus*) (although the species is not considered to be a major issue in the watershed), Monterey pine (*Pinus radiata*), and forget-me-not. The distribution of these species in 1999 is shown in Figure 2-33. The NPS identified cape ivy as a control priority in 1998, after witnessing its extremely rapid proliferation in native riparian vegetation communities. Alvarez conducted a field study to determine the effects of cape ivy invasion on plant communities within the GGNRA (1999). In the Redwood Creek vicinity, Alvarez reported that plots where cape ivy was dominant (greater than 70 percent cover) had lower plant species diversity, altered species composition in favor of non-native species, and reduced abundance and diversity of seedlings. In plots where cape-ivy was removed, a significant increase was seen in plant species richness, predominantly caused by increases in seedling recruitment of grasses and forbs. Cape ivy invasion also was found to alter the riparian terrestrial invertebrate community within Redwood Creek (Fisher 1997). Fisher reported that plots invaded by cape-ivy had significantly decreased abundance of flies (*Diptera*) and beetles (*Coleoptera*), and increased abundance of springtails (*Collembola*), than plots that were devoid of the ivy.

In 1999, cape ivy occupied up to 40 acres along Redwood Creek from Muir Beach almost to Muir Woods; whereas during the late 1980s it was recorded at infrequent locations with such a low rate of cover that it was not considered an imminent threat. Since 1998, approximately 5 acres of cape ivy have been removed from the Redwood Creek riparian corridor by the NPS at the Banducci site, reducing its cover in that area from approximately 40 percent to less than 1 percent in the first year after removal, with a quantified increase in cover by native species 4 years after removal. The labor-intensive removal cost an average of about $15,000 per acre. An estimated total of 9.7 acres of cape ivy is planned for removed in the Redwood Creek riparian corridor. The NPS removed 4.6 acres of cape ivy upstream of Pacific Way and plans to remove additional acres of cape ivy downstream in later phases. Furthermore, in Muir Woods, the steady work of hundreds of volunteers over two decades has nearly eliminated forget-me-nots from the Monument.

The MMWD completed a broom eradication project at Throckmorton Fire Station in 2004, and it considered the project to be a major success, although broom management was noted to be very labor intensive. The Throckmorton project involved brush removal in conjunction with the licensed application of herbicide, which was applied to recently cut stems between June and October ("whack-and-spray" method). Brush removed during cutting was stacked for subsequent pile burning during winter. Maintenance is required at least 1–2 times annually, and MMWD crews have observed a 98-99 percent broom mortality rate. The MMWD has tested various control methods for broom species in the last 10 years, with varied success. Treatments have included handpulling, annual mowing, annual mowing with follow-up herbicide application, periodic prescribed burn with annual mowing, and periodic prescribed burn with annual mowing and follow-up herbicide application. A summary of broom control techniques is provided in *Chemical Weed Control Techniques* for the MMWD (Leonard Charles &

Associates et al. 2008). As part of the 2009 *Vegetation Management Plan Update*, the MMWD reviewed all potential methods and techniques for future application.

State Parks began broom eradication on about 100 acres at the Three Sisters site below Panoramic Way, near the Muir Woods Park neighborhood, in 1994. The site extends to the Sun Trail above Muir Woods. The use of controlled burning (completed annually for a 3-year period) was successful at this location because it was a large site with good road access, allowing the fire to burn hot enough to kill the broom (Stillwater Sciences 2005c). Maintenance, however, will be required in perpetuity to prevent re-infestation, which was noted to be significant at the site in 2005 (Stillwater Sciences 2005c). Another successful invasive species control project in the watershed was conducted by Mt. Tamalpais State Park west of Panoramic Highway near Muir Woods Road. This project eliminated a 10-acre stand of French and Scotch broom through a series of prescribed burns, conducted since 1994, with follow-up spot application of herbicides. These operations cost approximately $95,000. State Parks also has implemented an eradication plan for pampass and jubata grass on their lands (Stillwater Sciences 2005c), including infested areas along Highway 1 near Green Gulch.

Invasive species that occupy significant area in the watershed but generally have not been the target of extensive control efforts (except in the Muir Woods National Monument and bordering areas and those sections mapped by the Weed Watchers program) include cotoneaster, velvet grass (*Holcus lanatus*), tall fescue (*Festuca arundinaceae*), harding grass, kikuyu grass (*Pennisetum clandestitum*), bull thistle (*Cirsium vulgare*), Italian thistle (*Carduus pycnocephalus*), and mustards (*Brassica nigra* and *Brassica rapa*). Cotoneaster, spread by birds, has been observed to be fairly widespread in the understory of scrub on the hillside at the Banducci site. It can be difficult to control, since a cut stem will yield multiple new sprouts, and it threatens to become a significant control issue in the future. Panic veldt grass has become well-established in the riparian areas in recent years, extending recently into Muir Woods National Monument, where year-round hand removal and chemical treatment as well as seasonal mechanical treatment are scheduled to occur by NPS staff, hired contractors, volunteer groups, and Muir Woods docents, interns, and interpretive staff (Baxter et al. 2009). This species is hard to control because it grows well in shade and also survives periodic inundation. The distribution of these species in the watershed is shown in Figure 2-34.

Highly invasive species that occur in the watershed, but still occupy very limited area, include yellow star thistle, giant reed grass (*Arundo donax*), starflower (*Helichrisum petidare*), ox-eye daisy (*Leucanthemum vulgare*), capeweed (*Arctotheca calendula*), purple star thistle, and Himalaya blackberry. The distribution of these species in the watershed is shown in Figure 2-35. Starflower has claimed extensive areas on nearby Bolinas Ridge and is likely to become more common in the watershed in upcoming years.

Sudden Oak Death

Since 1995, an epidemic referred to as Sudden Oak Death (SOD) has claimed tan oak, coast live oak, and black oak (*Quercus kellogii*) in coastal areas from Monterey to Humboldt County in California, and Curry County in Oregon (California Oak Mortality Task Force 2005). Large numbers of trees have died quickly from a fungal-like infection, drawing the attention of scientists, task forces, and the state of California in a race to identify the pathogen and curb its rapid spread. A fungus-like organism, *Phytopthera ramorum*, a relative of the organism that caused the Irish potato famine, was identified as the culprit.

Tan oak die-off was first observed in Muir Woods in 1995, at the earliest stages of the epidemic, when tan oaks on canyon slopes showed the late-stage symptoms of yellowed and dead, brown leaves dominating the canopy foliage. Maps of affected tan oaks in Muir Woods prepared in 2000 showed greater die-back in areas adjacent to trails, particularly those east of Oceanview Trail, between Oceanview Trail and Redwood Creek Trail, along Hillside Trail on the west side of Redwood Creek, and along the Ben

Johnson Trail. Fewer trees with SOD symptoms occurred in more remote areas with less exposure to visitors (Hooten 2000). The disease is creating openings in the forest canopy that may increase the risk of Douglas-fir encroachment and non-native plant invasion into Muir Woods. The resulting levels of dead foliage, branches and mid-canopy trees are substantially increasing fuel loads and associated wildfire risk in the affected forests.

In research conducted by the California Oak Mortality Task Force, numerous other species have been identified as *Phytopthera* host plants. Many of these species, such as huckleberry, California bay laurel, madrone, California buckeye, bigleaf maple (*Acer macrophyllum*), California coffeberry (*Rhamnus californica*), and toyon occur in or near Muir Woods, but SOD symptoms have not been observed on species other than tan oak there. However, most species can be sources of infection and spread by releasing SOD spores from infected foliage (Rizzo and Garbelotto 2003). Redwood also has been identified as a host plant (Davidson et al. 2003). SOD also can be spread during the rainy season on the soles of shoes or tires.

2.9 Terrestrial Wildlife

2.9.1 Species Occurrence and Distribution

The Redwood Creek watershed provides habitat for a diverse assemblage of terrestrial invertebrates, amphibians, reptiles, birds, and mammals. Numerous wildlife surveys have been conducted in portions of the watershed over the last 15 years that provide both qualitative and quantitative information about species composition, distribution, and abundance in the watershed. In addition to species documented during these surveys, known habitat associations and species distribution information can be used to infer potential occurrence of a number of additional species in the watershed (CDFG 2008).

Vertebrate species documented in the watershed include at least eight reptile species (Appendix C), approximately 200 bird species (Appendix F, Table F-1), and about 34 mammal species (Appendix F, Table F-2). Bird species include year-round residents, seasonal visitors, and migrants. Species that have been documented or are predicted to occur in the watershed are shown in Appendices C and F, which also include typical habitat associations for each species. Terrestrial animals that may be found in the Redwood Creek watershed are discussed below, organized by habitat types found in the watershed. Amphibians and aquatic reptiles are discussed in Section 2.7, *Aquatic Species and Habitats*.

Although the majority of terrestrial wildlife studies in the Redwood Creek watershed have focused on vertebrates, a few surveys also have been conducted for rare or unique terrestrial invertebrates. Muir Beach used to support large numbers of overwintering monarch butterflies (*Danaus plexippus*); habitat restoration and management has been recommended for this species (Monroe 2003). Few monarchs appear to use the area for overwintering at present, and it is likely that the region is now used primarily as foraging habitat (Jones & Stokes 2007). A preliminary survey for the federally endangered Myrtle’s silverspot butterfly (*Speyeria zerene myrtleae*), which has been recorded in Marin County, was conducted in 1992 at Muir Beach (Hafernik and Mead 1992); however, neither the species nor its larval host plant, western dog violet (*Viola adunca*), were observed. The mission blue butterfly (*Icaria icarioides missionensis*) is the only other special-status invertebrate that has been documented to occur in close proximity to the Redwood Creek watershed, as indicated by a CNDDB search of the San Rafael and Point Bonita 7.5-minute quadrangles. Mission blue butterflies are known to currently inhabit Fort Baker and the Marin Headlands (Merkle, pers. comm., 2011). A robust population of mission blue butterflies was found in nearby Oakwood Valley, which makes it the northernmost population documented (Arnold and Lindzey 2003).

2.9.2 Wildlife Habitat Relationships

Redwood-Douglas-Fir Forest

Redwood-Douglas-fir forest covers over one-third of the Redwood Creek watershed and provides habitat for approximately 11 reptiles, 49 bird species, and 20 mammal species (Appendix C, Appendix F). Special-status animal species that have been detected in redwood-Douglas-fir habitat include northern spotted owl (federally threatened and state endangered), olive-sided flycatcher (state Species of Special Concern), and two bat species (western red bat and Townsend's big-eared bat, both state Species of Special Concern).

Redwood-Douglas-fir habitat supports an average-to-high bird diversity and low bird abundance compared to other habitats in the watershed. Bird species most commonly encountered include chestnut-backed chickadee (*Parus rufescens*), Pacific-slope flycatcher (*Empidonax difficilis*), spotted towhee (*Pipilo maculates*), Wilson's warbler (*Wilsonia pusilla*), and winter wren (*Troglodytes troglodytes*). Hermit warbler (*Dendroica occidentalis*), red-breasted nuthatch (*Sitta canadensis*), and pileated woodpecker (*Dryocopus pileatus*) also use these habitats. Most notable is the presence of the northern spotted owl and the apparent absence of the federally threatened and state endangered marbled murrelet. Muir Woods is designated critical habitat for the marbled murrelet; protection for the species is enforced in the park despite its unconfirmed presence.

Marin County, including the Redwood Creek watershed, may support the highest known densities of northern spotted owls in the western United States (Stralberg et al. 2008). Throughout most of their range, northern spotted owls are found in mature or old-growth forests characterized by dense, multi-layered canopies. However, northern spotted owls use a variety of habitats and may use forests with different characteristics for nesting, roosting, and foraging, providing the habitat has a multi-layered structure and dense canopy cover (Adams et al. 2004). In Marin County, they have been observed in second-growth Douglas-fir, coast redwood, bishop pine, mixed conifer-hardwood, and evergreen hardwood forests, as well as old-growth stands of coast redwood and Douglas-fir (Hatch et al. 1999, Adams et al. 2004). Between 1998 and 2005, 195 northern spotted owl nests were found during surveys in Marin County at Muir Woods, Point Reyes National Seashore, and Golden Gate National Recreation Area (Jensen et al. 2006). Both logging and fire have resulted in younger forests in Marin County (Adams et al. 2004). Nest type, whether an open platform or cavity, appears to depend on the age of the forest (LaHaye and Gutierrez 1999). A very high percentage of nests in Marin County are open platforms (91 percent), while a small percentage are in cavities (9 percent). Most nests in older forests tend to be in cavities; the ratio of nest types in Marin is similar to the ratio observed in other younger-aged forests (Buchanan and Irwin 1993).

Marin County populations, including those at Muir Woods, represent the southern limit of northern spotted owl distribution. The local population in Marin is relatively isolated, resulting in minimal gene flow with northern spotted owl populations to the north along the coast (Barrowclough et al. 2005, Jensen et al. 2006). If northern spotted owls in Marin are or become genetically isolated, the local population could be at increased risk of extinction from catastrophic events (e.g., fire) or by long-term reductions in productivity or survivorship. For this reason, protection and management for northern spotted owl populations in Marin County is of particular importance (Jensen et al. 2006). All native evergreen forest habitats in Marin County should be considered potential northern spotted owl habitat, and management activities should focus on reducing impacts to habitat quality and/or nesting success of northern spotted owls (Jensen et al. 2004).

Additional threats to northern spotted owls include urban development along open space boundaries, disturbance caused by recreational activities, potential for catastrophic wildfires along the urban/wildland interface, wildland fuel management, continued range expansion of barred owl (*Strix varia*), and West Nile Virus, which was confirmed in Marin County in 2004 (Jensen et al. 2006). Also of concern is the die-off of tree and shrub species because of SOD, occurring throughout spotted owl habitat in Marin County, which may have long-term impacts on nesting habitat and prey populations (Adams et al. 2004, Jensen et al. 2006).

In its updated *Revised Recovery Plan for the Northern Spotted Owl*, the USFWS considers competition from barred owls as posing a significant threat to the northern spotted owl (USFWS 2011). Barred owls have been recorded in Marin County, including Muir Woods, for 6 consecutive years. In 2007, NPS biologists documented the first confirmed breeding of barred owls in Marin County; a barred owl pair and two fledglings were observed in historical northern spotted owl territory in Muir Woods (Jensen et al. 2008).

Marbled murrelet surveys, including intensive censuses, eggshell surveys, and shore-based surveys, were conducted from 1995 through 1998, but no confirmed sightings were reported (Chow 1996, Gardali and Geupel 2000). At least two studies assessing offshore distribution and abundance reported no marbled murrelets in waters adjacent to Muir Woods during the breeding season (Briggs et al. 1987, Ralph and Miller 1995), nor have surveys detected murrelets in the nearshore waters off of Muir Beach (Gardali and Geupel 2000). The absence of marbled murrelets in the watershed may be explained by the fact that relatively few trees in the area appear suitable for marbled murrelet nesting (Hamer and Nelson 1995; Gardali and Geupel 2000; T. Gardali, pers. obs.).

Mammals including opossums (*Didelphis marsupialis*), shrews (*Sorex* spp.), moles, coyotes (*Canis latrans*), gray fox (*Urocyon cinereoargenteus*), raccoons (*Procyon lotor*), skunks, mountain lions (*Puma concolor*), and bobcats (*Lynx rufus*) have been detected in redwood-Douglas-fir forest in the watershed. Deer mice (*Peromyscus maniculatus*) were found to prefer this habitat over others in the watershed (Howell et al. 1999). Vagrant shrews (*Sorex vagrans*) were detected exclusively in redwood stands (Howell et al. 1998, Howell et al. 1999). Several bat species utilize redwood hollows in Muir Woods as day roosts, night feeding roosts, or maternity roosts (Heady and Frick 2004).

Grasslands

Grasslands in the Redwood Creek watershed provide habitat for at least three reptile species, 12 mammal species, and 36 bird species (Appendix C, Appendix F). Special-status species that have been detected in grasslands on or near the watershed include northern harrier (*Circus cyaneus*), olive-sided flycatcher, and loggerhead shrike (*Lanius ludovicianus*), all of which are state Species of Special Concern.

Common reptiles that have been documented in grassland habitats in the watershed include northern alligator lizard (*Elgaria coerulea*), western terrestrial garter snake (*Thamnophis elegans*), and western fence lizard (*Sceloporus occidentalis*). Reptiles such as these provide an important prey species for birds and mammals.

In a landbird inventory study of all San Francisco Bay area national parks, habitats dominated by non-native annual grasses supported nearly the lowest species diversity and abundance of birds (Flannery et al. 2001). Species commonly found in annual grassland habitats include turkey vulture (*Cathartes aura*), western bluebird (*Sialia mexicana*), American kestrel (*Falco sparverius*), killdeer (*Charadrius vociferous*), house sparrow (*Passer domesticus*), savannah sparrow (*Passerculus sandwichensis*), white-crowned sparrow (*Zonotrichia leucophrys*), and song sparrow (*Melospiza melodia*). House sparrows (a non-native species) and savannah sparrows are more abundant in this habitat compared to others in the watershed (Flannery et al. 2001). Grassland bird species are in decline in most parts of the country because of the continuing loss of native grasslands (Sauer et al. 1995). Unfortunately, little information is available regarding bird abundance and distribution in California grasslands (California Partners in Flight 2000).

Mammal species found in annual grasslands of the watershed include coyote, gray fox, striped and spotted skunk (*Mephitis mephitis* and *Spilogale gracilis*, respectively), bobcat, black-tailed deer (*Odocoileus hemionus*), deer mouse, western harvest mouse (*Reithrodontomys megalotis*), and California meadow vole (*Microtus californicus*). Three introduced mammals that may pose a threat to native wildlife have been documented in the watershed: domestic dogs (*Canis familiaris*), feral cats (*Felis catus*), and black rats (*Rattus rattus*) (Takegawa et al. 2003). Non-native introduced game birds may pose a threat to native bird and animal species. Turkeys have become more abundant in recent decades and chukar, a Eurasian upland game bird species, has been released into the watershed in the past (Merkle, pers. comm. 2011).

Mixed Hardwood Forest

Mixed hardwood forest provides habitat to at least six reptile species, 61 bird species, and 17 mammal species (Appendix C, Appendix F). Mixed hardwood forest provides an important food source, acorns, to birds and mammals. Special-status species that have been detected in mixed hardwood forest on or near the watershed include: northern spotted owl (discussed previously), loggerhead shrike (a state Species of Special Concern), and western red bat (also a state Species of Special Concern).

Mixed hardwood forests support average to above-average bird species diversity and average to high species abundance in the San Francisco Bay area (Flannery et al. 2001). Species of greatest abundance in mixed hardwood forests include chestnut-backed chickadee, song sparrow, dark-eyed junco (*Junco hyemalis*), Wilson's warbler, Pacific-slope flycatcher, and acorn woodpecker (*Melanerpes formicivorus*). Less frequently encountered are belted kingfisher (*Ceryle alcyon*), black-throated gray warbler (*Dendroica nigrescens*), pileated woodpecker, and hermit thrush (*Catharus guttatus*).

Reptiles using mixed hardwood types that have been documented in the watershed include western fence lizard, rubber boa (*Charina bottae*), and sharp-tailed snake (*Contia tenuis*).

Mammals associated with mixed hardwood forests in the watershed include shrew, coyote, gray fox, skunk, bobcat, black-tailed deer, deer mouse, mountain lion, western gray squirrel (*Sciurus griseus*), and dusky-footed woodrat (*Neotoma fuscipes*). Although not often seen, bobcats and mountain lions play an important role in the food web as top carnivores. Dusky-footed woodrats are found in greater abundance in coast live oak-California bay habitat, compared to redwood-Douglas-fir and grassland habitat types, and may rely on oaks for food and cover (Howell et al. 1998). The dusky-footed woodrat is important as a primary prey species, in both frequency and biomass, for the northern spotted owl (Barrows 1980).

Coastal Scrub and Chaparral

Coastal scrub and chaparral covers approximately one-third of the Redwood Creek watershed and provides habitat for at least three species of reptiles (Appendix C), 31 species of birds, and 14 species of mammals (Appendix C, Appendix F). Special-status species that have been detected in coastal scrub or chaparral on or near the watershed include yellow warbler, a state Species of Special Concern.

This habitat supports low bird diversity and abundance compared to other habitat types in the watershed (Flannery et al. 2001). In fact, the southern ridge of the watershed, Coyote Ridge, had the lowest bird diversity index in this habitat type compared to all other surveyed sites in the GGNRA (Gardali and Geupel 1997). The most abundant bird species documented in coastal scrub habitats include white-crowned sparrow, wrentit (*Chamaea fasciata*), and spotted towhee.

Although several mammal species may be found using scrub and chaparral habitats, brush rabbit (*Sylvilagus bachmani*) is the only species found in the Redwood Creek watershed that is mainly associated with this habitat type (Jameson and Peeters 1988, Howell et al. 1999).

Riparian Woodland

Riparian woodlands are extremely valuable for wildlife because they provide water, favorable microclimates, and important movement corridors. Although these areas comprise less than 5 percent of the Redwood Creek watershed, they provide breeding, foraging, and cover resources for at least six reptile, 72 bird, and 22 mammal species (Appendix C, Appendix F). Special-status species that have been documented in riparian woodland within the watershed include willow flycatcher (*Empidonax traillii*) (state-listed as endangered) yellow warbler (*Dendroica petechia*) (a state Species of Special Concern), and dusky-footed woodrat (a state Species of Special Concern), which has been observed in riparian areas as well as dense scrub on hillsides (Merkle, pers. comm., 2009).

Riparian woodland supports above-average to high bird species diversity and abundance compared to other habitat types in the watershed (Flannery et al. 2001). Species commonly encountered in this habitat include song sparrow, Swainson's thrush (*Catharus ustulatus*), and Wilson's warbler. Black-headed grosbeak (*Pheucticus melanocephalus*), black phoebe (*Sayornis nigricans*), orange-crowned warbler (*Vermivora celata*), song sparrow, warbling vireo (*Vireo gilvus*), western wood-pewee (*Contopus sordidulus*), Wilson's warbler, ash-throated flycatcher (*Myiarchus cinerascens*), yellow warbler, northern oriole (*Icterus galbula bullockii*), and common yellowthroat (*Geothlypis trichas*) are more abundant in this habitat compared to others in the watershed.

From 2000 to 2002, White et al. (2005) examined the habitat use of Swainson's thrush, particularly post-fledging juveniles, within the Redwood Creek and Lagunitas Creek watersheds. Swainson's thrush nests were found only in riparian areas, but adults with broods and independent juveniles were more often found in habitats adjacent to the riparian forests. Adults with broods and independent juveniles were located in upland vegetation 38 percent and 56 percent of the time, respectively. Key habitats for independent juveniles were determined to be mixed-hardwood forests, north-slope coastal scrub, and riparian vegetation, all of which overlapped areas of fruiting shrub thickets. Swainson's thrushes were never found in annual grassland, grazed annual grassland, or Eucalyptus (*Eucalyptus* spp.) habitats. The study concluded that land management should be focused not only on improving nest success, but also should consider habitat selection and use by juvenile birds.

Nest predation and brood parasitism have been well-documented in the Redwood Creek watershed. Michaud et al. (2004) studied its effects on nesting success of Wilson's warbler. Nest predation appeared to be the biggest cause of nest failure for Wilson's warbler, but a high incidence of brood parasitism by brown-headed cowbirds also was noted. The effects of nest predation and brood parasitism combined resulted in low rates of nesting success. Other research has indicated that brood parasitism by brown-headed cowbirds on Swainson's thrushes (4 percent) is much lower than on Wilson's warblers (33 percent), despite their nesting in similar habitats (White and Gardali 2004). The nests of Swainson's thrushes appeared better concealed, which may make them less susceptible to parasitism. Additionally, Swainson's thrushes are partially frugivorous, which may not be optimal for cowbird nestlings, possibly reducing the rate of nest parasitism because cowbirds may prefer to parasitize the nests of other species, or by reducing cowbird nestling survival. Although differences in Wilson's warbler and Swainson's thrush nesting behavior were not addressed in this study, they may contribute to the disparity in brood parasitism rates.

In the mid-1990s, researchers determined that nearly one-third of the riparian shrub and herbaceous species in the Redwood Creek riparian corridor was non-native (PWA et al. 1994). Because understory plant density and diversity are important habitat characteristics for nesting riparian birds, efforts have been made to remove the invasive non-native plant species Cape ivy from almost 6.2 acres of streamside habitat. Following Cape ivy removal, nesting bird species diversity and abundance substantially increased (Scoggin et al. 2000) (also see Section 2.8.6 *Non-native Invasive Plants*).

River otters (*Lontra canadensis*) have made a return to Redwood Creek, which may indicate that riparian habitat conditions are improving (Merkle, pers. comm., 2009). The shrew-mole (*Neurotrichus gibbsii*) and broad-footed mole (*Scapanus latimanus*) were only detected in this habitat type (Howell et al. 1998, Howell et al. 1999).

Wetlands

Seasonal wetlands provide habitat for six reptile species, 83 bird species, and eight mammal species (Appendix C, Appendix F). Special-status species that have been documented in seasonal wetlands near Big Lagoon include northern harrier, tricolored blackbird (*Agelaius tricolor*), and yellow-headed blackbird (*Xanthocephalus xanthocephalus*), each of which is a state Species of Special Concern. Historical reductions in wetland habitat may have decreased wildlife abundance, diversity, productivity, and distribution in the Redwood Creek watershed.

Reptile species that utilize wetlands within the watershed include common garter snake (*Thamnophis sirtalis*) and western pond turtle. Commonly encountered bird species include mallard (*Anas platyrhynchos*), American wigeon (*Anas americana*), American coot (*Fulica americana*), killdeer, black phoebe, marsh wren (*Cistothorus palustris*), and red-winged blackbird (*Agelaius phoeniceus*) (Stallcup 1995). Mammal species include western harvest mouse (Takekawa et al. 2003), deer mouse, California meadow vole, and river otters; river otters are likely increasing and spreading in the watershed due to the prohibition of trapping and harvest as well as possible improvements to riparian habitat conditions (Merkle, pers. comm., 2011).

2.10 Watershed Characterization Synthesis

The Redwood Creek watershed offers a unique opportunity to practice and demonstrate integrated watershed management. The watershed is near San Francisco (a major metropolitan center which heightens public interest in its management), has over 95 percent of its area in public ownership, and possesses one of the last groves of ancient redwoods in the San Francisco Bay area. It hosts native habitats for four listed animal species (northern spotted owl, steelhead and coho salmon, and California red-legged frog) as well as numerous endemic serpentine and dune plant species. Furthermore, although many watershed biophysical processes are recovering from various historical impacts and continue to be affected by some current land uses, many of the natural processes that support the watershed's native habitats are intact or moving along a trajectory towards greater functionality. This Watershed Assessment is aimed at improving the understanding and ability to respond to the evolving processes in ways that support and promote the health and recovery of the watershed, its habitats, its native species, and the lives of its human inhabitants.

Although the watershed supports numerous native ecosystems, many are in some stage of recovery from historical impacts associated with Euro-American settlement. For example, the balance between sediment input and transport was profoundly altered during the late nineteenth and mid-twentieth centuries. The removal of native trees through logging and conversion of perennial native grasslands to annual European grasslands increased tributary sediment inputs at the same time that increases in grazing and impermeable surface area from roads and trails within the watershed led to increased peak runoff. These changes promoted incision of the mainstem along Frank Valley, subsequently disconnecting the mainstem channel from its floodplain and increasing sediment delivery downstream to Big Lagoon. In the mid-twentieth century, levee construction, channel straightening, and removal of riparian vegetation and large in-stream woody debris exacerbated these changes in channel processes and morphology. Recovery from these alterations has been underway for at least the past 20 years, through improved upland vegetation management, improved road and trail design and management, reintroduction of large wood into the stream channel, removal of bank hardening structures, and restoration efforts at Big Lagoon and Frank Valley. However, the mainstem channel remains disconnected from its historical floodplain along much of its length.

Stress on the aquatic ecosystem resulting from these historical changes remains as the system slowly recovers and is compounded by other changes including subsurface channel water pumping in Frank Valley, changes in regional weather patterns, and anthropogenic nutrient loading to the lower creek reaches that reduce instream dissolved oxygen concentrations. Some part or a combination of all these factors may be affecting the health and recovery of coho salmon and steelhead populations in the watershed. Fish populations generally respond to conditions on a much shorter time scale than do geomorphic processes, and although simply removing the human cause of disturbance may allow natural geomorphic process rates and morphology to recover in decades to centuries, anadromous salmonids may be extirpated from the basin within that time frame. Therefore, restoration actions are required that actively address sediment dynamics, fluvial geomorphology, riparian functions, and the quality and quantity of summer baseflows as they relate to the needs of aquatic habitat in the short term (1 to 5 years). These are further discussed in Chapter 4, *Issues and Associated Indicators*.

Additionally, infrastructure (such as roads, bridges, parking lots, culverts, and channel revetment) directly affects natural hydrologic and geomorphic processes as well as wildlife movement at several important points in the watershed. Some of these infrastructure constraints are well understood; plans that address some of these issues, such as those related to the current configuration of the Pacific Way Bridge and the Muir Beach parking lot, have been developed but require significant funding for implementation. The impacts and potential solutions associated with other aspects of infrastructure are less well understood and need to be better studied and articulated.

Processes that maintain the native vegetation communities in the Redwood Creek watershed also have been impacted by Euro-American settlement. As mentioned previously, grazing in the nineteenth and early to mid twentieth centuries affected grassland species composition, and logging during the same periods affected forest age structure and, to some degree, species composition. Euro-American settlement also brought about a shift from frequent, low intensity wildfires in grassland, shrubland, and forest systems to infrequent and spatially limited fires under a policy of fire suppression in the mid and late twentieth century. Possible effects associated with this change in the fire regime included expansion of shrub (primarily coyote brush) and tree cover into existing grassland habitat (an estimated 64 percent decrease in grassland acreage in the watershed has been reported, relative to use under native American settlement), increased density of mid-canopy trees, and increased forest fuel load. The SOD epidemic in the mid-1990s also has impacted the structure and composition of Muir Woods and the redwood forest in Kent Canyon through the large-scale reduction in tan oak cover, formerly a dominant mid-canopy species in these forests. The effects of this change in forest species composition on wildlife and gap-succession dynamics are unknown. The current die-off of tan oak is likely to substantially increase the fuel load (including ladder fuels) in Muir Woods; however, this has not been quantified or evaluated for its effects on the likelihood of catastrophic wildfire.

Beyond changes to native species, a steady succession of non-native invasive plant species have made their way to the Redwood Creek watershed over the years, including cape ivy, pampass and jubata grasses, French broom and scotch broom, periwinkle, panic veldt grass, capeweed, and Himalayan blackberry, among others. Studies have demonstrated that these non-native invasive plant species can have massive impact on native wildlife and in simplifying native plant communities. Substantial progress has been made in reducing the extent and controlling the spread of these species, and all three of the public agencies with large land ownership in the watershed have active non-native plant management programs, with some degree of cost and data sharing (e.g., the Bay Area Weed Watchers program, available: www.weedwatcher.org). Pest animal species, such as cow birds, corvids, turkey, Chukar partridge, and the barred owl also are suspected or known to be impacting native animal and plant populations in the watershed. For these pest animal and plant species, early detection is critical so that control measures can be undertaken before an infestation worsens and control becomes infeasible.

In Chapter 4, *Issues and Associate Indicators*, 33 issues regarding natural resources ecology and management in the Redwood Creek watershed are articulated, based on the understanding of existing conditions as presented in this chapter.

3 HUMAN USES AND VALUES

This chapter characterizes past and present human uses and interactions with the watershed as well as how humans will likely interact with the watershed in the future. Assessing the human resource component of the Redwood Creek watershed is essential to understanding how the watershed affects and is affected by its residents and visitors. Intensive resource extraction and agricultural uses (described in Chapter 2) are now a part of the watershed's history, with most of the land in public ownership and managed under what could be termed a "resource protection" phase. However, sustaining viable communities and natural ecological systems requires consideration of the human uses and values associated with the watershed. Land managers must understand the potential conflict between stakeholder expectations and behavior, and agency desires to implement resource protection and restoration activities. Thus, the aim of this human use and values assessment is to: (1) inform land management and policy decision makers about human resource factors; (2) provide baseline information about past, current, and expected future activities to be used for evaluating the effects of proposed management actions; and (3) develop a functional means of gaining input and cooperation from the stakeholders who are most affected by watershed management decisions.

Guidance for this chapter is provided in part by *Understanding Human Uses and Values in Watershed Analysis* by Fight et al. (2000). Five topics that address how socioeconomic processes have and will affect a watershed's biophysical processes and conditions are documented, including: (1) residential development, (2) commercial uses, (3) recreation uses, (4) culturally motivated uses, and (5) off-site passive use values. Given the current and expected future importance of recreational visitation to the watershed, this chapter also considers the effects of recreational activities on watershed resources. Carrying capacity decision-making frameworks often are employed by land managers seeking to balance recreation visitation with the protection of natural and cultural resources and maintenance of high quality visitor experiences (NPS 1997).

3.1 Residential Development

Land ownership in the watershed is described in Section 2.2.1, *Public Land Ownership*, and Section 2.2.2, *Private Land Ownership*. Human residential development within the watershed occurs principally in three locations:

- **Muir Beach Community**: Located near the mouth of Redwood Creek, this community, which began in the 1920s, includes approximately 300 people and 129 houses (some are located outside the watershed) (Muir Beach Improvement Association 1978). A small portion of this community lies in the Redwood Creek floodplain, and flooding of the Pacific Way access road and floodplain homes have necessitated periodic dredging to remove accumulating sediments from the Redwood Creek channel.

- **Green Gulch Farm and Zen Center**: Located a short distance up a side valley from Muir Beach, this Soto Zen Buddhist community is one of three branches of the San Francisco Zen Center (Larsen 1984). The community was established in 1972, on land now operated as an organic farm and a Zen learning center, offering public lectures and classes on gardening, meditation, and Buddhist philosophy and practices. A residential staff of up to 70, assisted by 10–20 guest students, serves class and conference groups of 25–50 people on weekdays and groups of 200-300 on Sundays. A residential apprenticeship program in organic gardening and farming assists with operation of the organic farm, including 2 acres of flower gardens and up to 20 acres of vegetable crops.

- **Muir Woods Park Community**: Located high in the watershed along the Panoramic Highway, this neighborhood that dates to the 1920s includes 590 parcels, 318 of which are developed, and has approximately 1,000 residents (some are located outside the watershed) (Marin County 1992).

A small number of additional residences for park staff are located on NPS and State Park lands and a few residences remain in a small community on NPS lands at Camino del Canon. This community once included several residences but is being phased out through life leases.

Several important issues with relevance to watershed planning are associated with human habitation in the watershed: septic systems, accelerated runoff and soil erosion, congestion on area roads, water use, and introduction of non-native plants and animals. All houses in the watershed, excepting those in Muir Woods National Monument, currently operate on septic systems, and problems with overloaded or poorly sited septic fields are noted in community plans. Further development, including redevelopment to larger residences, is expected to exacerbate these problems. Similarly, increasing development, home sizes, paving of roads and driveways, and removal of native vegetation also are expected to increase water runoff and the potential for soil erosion and water pollution. NPS water quality monitoring occasionally has found Redwood Creek bacteria levels to exceed state standards for human contact and elevated nitrogen levels. Problems with traffic congestion also are exacerbated by full-time residents in the watershed, caused by the area's narrow and winding road system. Watershed residents make numerous daily trips, but what proportion of total traffic they represent is unknown. A traffic study is warranted.

The water needs for all residents and agricultural uses are accommodated through extraction from surface or subsurface water resources in the watershed. In particular, water extraction from Redwood Creek is a significant issue as low summer flows have been identified as the primary limiting factor for the endangered coho salmon (Smith 2001). As described in Section 2.4.8, *Flow Diversions*, water is diverted from Redwood Creek and its tributaries by the Muir Beach and Green Gulch communities, and also by the Marin Municipal Water District and Mt. Tamalpais State Park (Muir Woods receives water from outside the watershed).

3.2 Commercial Uses

This section describes past and current commercial uses in the watershed and characterizes the extent to which commercial entities in areas such as Mill Valley, Stinson Beach, and San Francisco are visitor- or tourism-dependent. The Redwood Creek watershed has supported a diverse array of commercial uses over time, beginning with cattle and dairy ranching and timber harvesting, transportation of tourists via the railroads, and associated tourist hotels and restaurants (see Section 2.2.3). Crop farming, including the former Banducci flower farm (Section 2.4) and the Green Gulch organic farm (Section 2.5.2), represent less common commercial uses. Extractive land uses have been associated with the greatest environmental impact to watershed resources. For example, the construction of railroads, roads, and harvesting of timber contributed sediments to watershed creeks and triggered landslides. Similarly, cattle grazing required conversion from forest and shrub cover to grasslands and introduction of non-native forage species. However, the era of extractive land use is over, replaced by a small number of mostly tourism-oriented services that have less impact on the watershed's natural and cultural resources.

Only six commercial businesses are located in the watershed and, with one exception, they are related to tourism services. The Mountain Home Inn (10 rooms) along the Panoramic Highway and Pelican Inn bed and breakfast near Muir Beach (7 rooms) are the only two businesses that offer lodging and restaurants. The largest commercial business in the watershed is the gift shop and café at Muir Woods Monument, operated by the International Aramark Corporation, an authorized concessionaire of the National Park Service. Two businesses are visitor-oriented membership clubs. The California Alpine Club, founded in 1913, is an outdoor and social organization whose purpose is to explore, enjoy, and protect natural resources and lands. The Club has approximately 850 members and offers a variety of hiking and outdoor activities. It also operates the Alpine Lodge, a small structure with dormitory accommodations and three private rooms, acquired in 1925 and located along the Panoramic Highway. The Tourist or “German” Club, established in 1912, owns several properties and structures in the Muir Woods Park subdivision, including a Bavarian style lodge with a kitchen, dining room, and dance floor. The Tourist Club has 430 members that organize frequent hikes and social events, including large festivals.

The Green Gulch Farm and Zen Center is a residential Buddhist retreat center that combines spiritual practice with land stewardship (Harvard University 2004). Started in 1972, the community cultivates environmental awareness and ethics in part through operation of an organic garden and farm that sells flowers and produce. The farm is open to the public and offers organic gardening classes and a farmer apprenticeship. The Zen Center also offers training in the Japanese Soto Zen tradition, through a variety of educational classes and conferences.

Further development of commercial businesses within the watershed, particularly lodging or restaurants, are not expected because of land ownership patterns, public land management objectives and planning guidance, and the expressed desires of local residents. Existing commercial businesses possibly could expand, though recent trends do not suggest such an occurrence. The economic impact of these businesses on the economy of the watershed and region is fairly small; most residents and visitors spend money on goods and services outside the watershed. The environmental impacts associated with these businesses appear to be relatively low but similar to those of the watershed’s residential communities (see Section 2.5.2). These include the use of in-ground septic systems, runoff and soil erosion from roads and parking lots, water use, and the possible introduction of non-native plants and animals.

Commercial businesses are more numerous outside the watershed in the Mill Valley area. Most of the general businesses and stores selling manufactured items are oriented primarily to residents. A search identified 37 businesses that included nine restaurants, two gas stations, two hotels, three groceries, three tourism-related businesses, 13 stores selling manufactured items, and five general businesses. Phone calls to representative businesses revealed that tourism-related visitors account for approximately 15–40 percent of the customers of the hotels, restaurants, gas stations, and grocery stores. Even apparent tourism-related businesses, including two surf shops, estimated non-resident customers at only 20–30 percent. Other commercial businesses in the Stinson Beach, Sausalito, and San Francisco areas also are partially dependent on visitation to the Redwood Creek watershed. These include various tourism infrastructure entities such as transportation services (e.g., bus companies and tour operators), lodgings, and restaurants.

3.3 Recreational Uses

From near the 2,571-foot panoramic summit of Mt. Tamalpais, through towering groves of redwood trees to the rugged Pacific Ocean shoreline, the Redwood Creek watershed has long provided a diverse array of scenery that has attracted a variety of recreational activities. Though the watershed is small, more than 95 percent of it is publicly owned, and it is situated in close proximity to Mill Valley, with 14,000 residents, and the San Francisco Bay Area, with approximately 800,000 people. As such, the watershed provides a diverse but relatively intact natural ecosystem that is highly accessible to local, regional, national, and international visitors.

3.3.1 Recreation Infrastructure

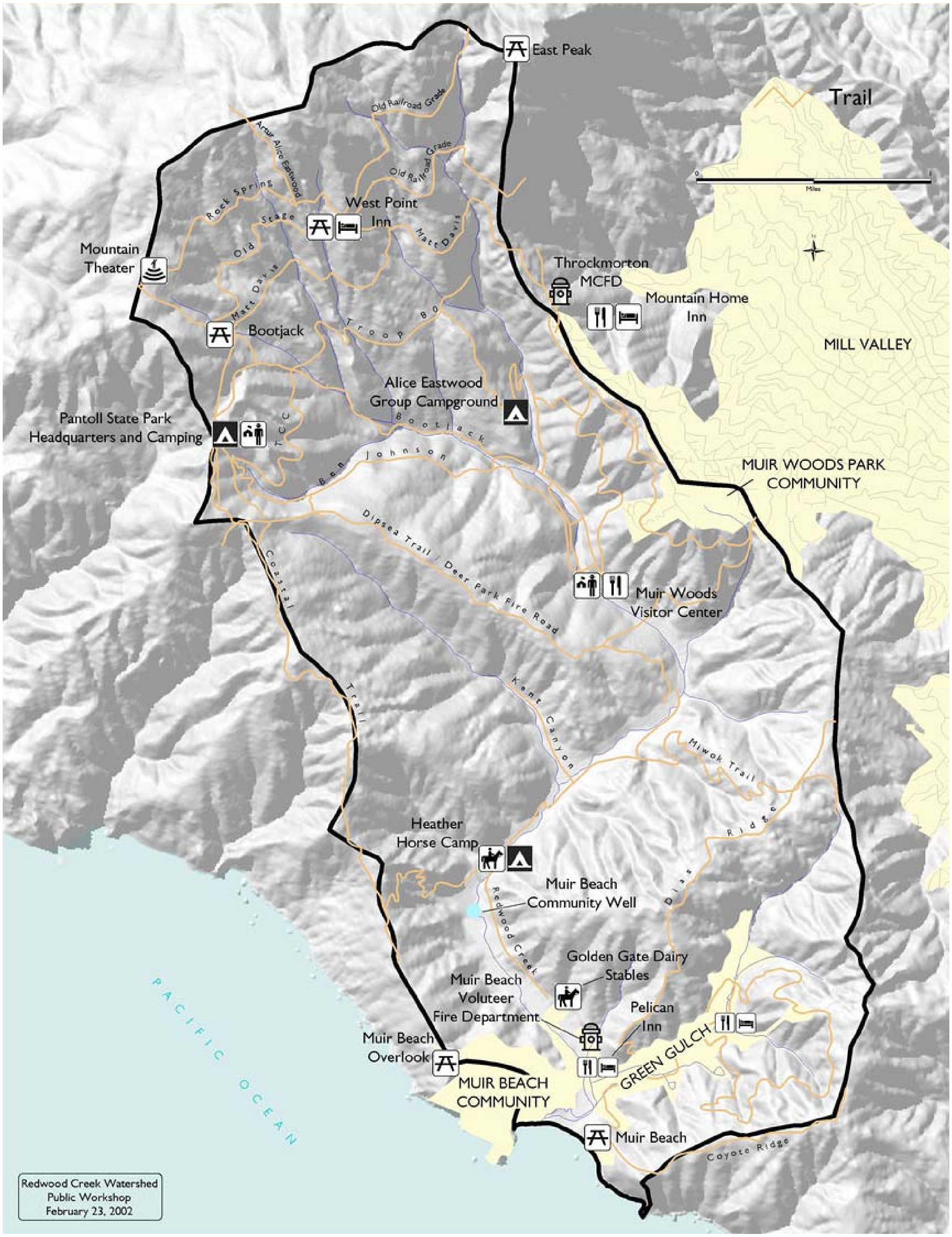
Recreational infrastructure for the watershed is provided entirely on public lands (Figure 3-1). This includes the roads that visitors use to access the watershed and its recreational facilities, including visitor centers, campgrounds, picnic areas, parking lots, and trails that support such uses. A comprehensive inventory of roads and trails in the watershed, conducted in 2002 (PacWA 2002), identified 40 miles of trails and 27 miles of roads (16 paved miles). Roads used by visitors are owned and managed by the California Department of Transportation and Marin County. Land uses for the three primary public land management agencies (GGNRA, Mt. Tamalpais State Park, and the MMWD) revolve around resource protection and recreation. As discussed in Section 2.2.1, the MMWD is primarily oriented to maintaining open space and protecting natural resources and water quality, with limited recreation developments. The GGNRA is similar, though more elaborate recreation facilities are provided in areas that receive intensive visitation, such as the developed areas of Muir Woods and Muir Beach. The Mt. Tamalpais State Park has the largest land base and a greater variety of recreation developments, including campsites and cabins to accommodate overnight visitation. The recreation infrastructure managed by these agencies is summarized as follows:

- **Muir Woods National Monument**: Recreational facilities within the Monument’s 560 acres include 6 miles of hiking trails, a visitor center, café, gift shop, rest rooms, and parking lots. The trails include 1.5 miles of paved or boardwalk trail that are mostly flat and handicapped accessible, and 4.5 miles of unpaved trails that connect with trails leading into Mt. Tamalpais State Park.

- **Other GGNRA lands**: GGNRA also manages 929 acres in Frank Valley, at Muir Beach, and along Coyote Ridge. Recreational facilities at Muir Beach include a parking lot, picnic area, restrooms, and trail to a sand beach. Other facilities in the watershed include an extensive network of trails and the Golden Gate Dairy, occupied by the Muir Beach Volunteer Fire Department, and the Ocean Riders, a local equestrian group. Mountain biking is restricted to 4–5 miles of trails located on old roads: Coastal Trail south, Middle Green Gulch (uphill only), Upper Green Gulch, and portions of Coyote and Miwok. Work was recently completed to realign portions of the Dias Ridge and Coast View Trails, allowing them to be opened to bicycle use.

- **Mt. Tamalpais State Park**: This park occupies 2,915 acres in the watershed. Park recreational facilities include 45 miles of trails, the East Peak Visitor Center/Gardner Outlook, Pantoll State Park Headquarters and campground with 16 campsites and 10 cabins, West Point Inn, Alice Eastwood group camping area, Frank Valley Horse Camp, Bootjack Picnic Area, and the Mountain Theater (a stone amphitheatre providing a venue for performances and events). The trails include old ranch roads, fire roads, and primitive, single-track trails that provide recreational opportunities for hikers, runners, mountain bikers (4-5 miles), and equestrians (limited to 15 miles). California State Parks are implementing trail projects to reduce eroion and sedimentation (e,g., Bootjack and Diaz Ridge trails). Pets are not permitted on the trail system.

- **Marin Municipal Water District**: The MMWD has 969 acres in the upper watershed, managed as open space to protect water quality and natural resources. Passive, nature-based recreation uses that require little or no development or facilities are permitted (MMWD 2010). Recreation facilities include roadside parking areas, trails, and unpaved roads (open to hikers, equestrians, and mountain bikers) (MMWD 2005a and 2005b).



Redwood Creek Watershed
Public Workshop
February 23, 2002

Figure 3-1. Redwood Creek watershed map illustrating the recreation infrastructure of recreation sites, primitive roads and trails.

A number of other facilities in the watershed that support recreational or natural and cultural resource protection objectives are noteworthy. Historic buildings on GGNRA lands include the Hillwood School and the Golden Gate Dairy, the latter housing the Muir Beach Volunteer Fire Department, which is unrelated to recreational use or resource protection objectives. Non-historic buildings include the Cameron House, used by a Chinese-American group for summer day-camp activities, and the Education Lab, a Muir Woods building used for NPS and partner education and office meetings. A number of NPS buildings also are associated with park maintenance functions, administrative and concession facilities, ranger residences, and a plant nursery. Mt. Tamalpais State Park also has park administrative and maintenance buildings, a park ranger shooting range, and staff housing in Frank Valley, at the mouth of Kent Canyon.

3.3.2 Historical Recreation

An in-depth review of the watershed's historical recreation uses are described in Section 2.2.3, *Watershed History*, which also is briefly summarized here. Early visitation was minimal until improved transportation via a ferry service to Sausalito (1868) and roads, including the Elridge Grade from San Rafael to Mt. Tamalpais (1879), were developed. Hunting was the most popular activity from the 1870s until it was prohibited in 1917, following conflicts with and political pressure by a growing number of hikers. Numerous hiking clubs developed and began to offer hikes, establish camps, and build and maintain trails, many of which still exist today. By the 1920s, thousands of hikers visited Mt.Tamalpais each weekend; many camped overnight on the slopes in several club tent campgrounds (Eastman 2004). The annual Dipsea Race, run along the Lone Tree Trail from Mill Valley to the Dipsea Inn in Bolinas, began in 1904.

Commercial developments supporting recreational visitation began in 1896, with the construction of the Mt. Tamalpais Scenic Railway that carried tourists up Mt. Tamalpais, where the Tavern of Tamalpais was built on the East Peak. Visitor access to the mountain's redwood groves was enhanced by construction of a railroad spur in 1907, along with a luxury hotel, the Muir Inn (at the present-day site of Camp Alice Eastwood) and the tiny West Point Inn, built in 1904 (Eastman 2004). Other hotels include the Mountain Home Inn, opened in 1912, and Joe's Place, the Muir Woods Inn, Muir Beach Tavern, and the Pelican Inn bed and breakfast.

Public developments include infrastructure for the Muir Woods Monument (established in 1908) and Mt. Tamalpais State Park (established in 1928), constructed by the Civilian Conservation Corps from 1933–1941. A considerable amount of stonework, including bridges, rock revetments, and construction of the Mountain Theater, date to this period. Completion of the Golden Gate Bridge in 1937 tripled annual visitation to the Muir Woods, to more than 180,000 visitors per year. Approximately 58 miles of roads and trails existed in the watershed in 1947, increasing by only 5 miles by 1965, and by 4 miles by 1982.

3.3.3 Current Recreation

The diverse mountain, valley, and coastal resource settings of the Redwood Creek watershed provide an attractive resource base for numerous recreational and educational activities. Most visitors access the watershed by vehicle or bus from San Francisco via Highway 101 through Marin City to Highway 1 (Shoreline Highway) and the Panoramic Highway and Muir Woods Road. Increasing traffic congestion on these two-lane roads and limited parking in the watershed are prompting a shift to greater reliance on buses. Visitation, described next, is largely day-use because few options are available to accommodate overnight stays in the watershed.

- **Muir Woods National Monument**: Visitation at Muir Woods was estimated at 778,368 visits in 2004 and on July 4th weekend in 2011, saw record-breaking number of visits totaling over 10,000 (NPS 2004; pers. comm. Monroe). Hiking, sightseeing, and nature observation/study are the most popular activities. The following activities are not permitted: picnicking, camping, mountain biking, dogs (except service dogs), and horses (except on fire roads). Visitor use surveys and traffic counts were conducted in 2003 (Manning and Budruk 2003). Visitors to Muir Woods are from the U.S. and many other countries, and only 37 percent are from California. The predominant form of transportation to the Monument is by personal vehicle (92.5 percent), followed by bus (7 percent). Most groups are comprised of family and/or friends (98 percent) and arrive in groups of 2–4 (80 percent); only 5 percent were members of a commercial tour. Nearly half (57 percent) have visited Muir Woods previously, on an average of 6.1 times (median = 2).

- **Muir Beach**: Visitation at Muir Beach was estimated at approximately 440,000 visits in 2004 (NPS 2004). The most popular activities are beach activities—swimming, picnicking, hiking, bird-watching, beach fires, beachcombing, and dog-walking. Leashed pets are permitted. Visitor use surveys (Manning and Budruk 2003) indicate that visitors to Muir Beach also are mostly from the U.S. (94 percent), and a majority (74 percent) are from California, including 14 percent who are local residents from the Muir Beach community or Green Gulch Farm and Zen Center. The predominant form of transportation to the beach is by personal vehicle (92.5 percent), followed by walking or biking (5 percent). Most groups are comprised of family and/or friends (83 percent), who arrive in groups of 1–2 (65 percent). Nearly half (62 percent) have visited Muir Beach previously, on an average of 188 times (median = 15).

- **Mt. Tamalpais State Park**: Visitation at Mt. Tamalpais was estimated at approximately 1.6 million visits in 2001 (California Dept. of Parks & Recreation 2002). Visitation to MMWD lands, some of which lie outside the Redwood Creek watershed, was estimated to be greater than one million visits per year (MMWD 2005a). Popular activities include hiking, mountain biking, horse riding, camping, picnicking, sightseeing, and nature observation/study. Although pets are not permitted on the Mt. Tamalpais State Park trail system, leashed pets are permitted on MMWD lands. The State Park has 16 developed walk-in campsites, group campsites for hikers and equestrians, the West Point Inn (hike-in, seven rooms), and 10 rustic cabins. Visitor use survey data are unavailable but visitation to Mt. Tamalpais State Park and MMWD lands is estimated to be similar to the characterization for Muir Beach visitors, perhaps with a greater proportion of Californians.

- **Green Gulch Farm and Zen Center**: Beyond offering long-term visitors for the Zen study program, Green Gulch Farm Zen Center is also open to daily visitors to enjoy their planted gardens and grounds at the organic farm, as well as a guest house, conference center and a trail that runs along the Green Gulch tributary links the Zen Center to Muir Beach.

Some key events also attract substantial visitation to the watershed. These included the Dipsea and Double Dipsea races, the Mountain Theatre, the Muir Beach Volunteer Fire Department annual picnic, Winter Solstice and Earth Day events.

3.3.4 Future Recreation

The Redwood Creek watershed contains resources that are a national, regional, and local draw for recreational visitation of over three million people annually. Though visitation is likely to continue to grow, relatively few changes in the types of recreation activities are expected. Over 95 percent of the watershed’s lands are in public ownership and the management policies for the principal land management agencies generally emphasize resource protection over recreational visitation. These management policies are summarized as follows:

- **National Park Service (GGNRA)**: National Park Service management policies (NPS 2001; NPS 2006a) direct the agency to err on the side of resource protection, "…when there is a conflict between conserving resources and values and providing for enjoyment of them, conservation is to be predominant." Existing trails may be realigned or reconstructed but significant trail expansion or camping opportunities at Muir Woods seem unlikely. Mountain biking and equestrian use likely will continue to be largely restricted to old roads.

- **California State Parks**: State Parks management policies are more likely to promote recreation visitation, although its policy states that: "Recreation areas should be planned and carefully managed to provide optimum recreation opportunities without damaging significant natural or cultural resources" (California State Parks 2005). The development of further recreational facilities and opportunities could occur on Mt. Tamalpais State Park lands, including additional trail development, changes in trails uses, additional camping or cabin development, and other facilities such as new or expanded picnic areas. However, public opposition might limit some changes. In 2003 a coalition of local groups (including the Tamalpais Conservation Club, Marin Conservation League, the Marin Chapter of the Sierra Club, the Marin Horse Council, and the Bay Area Trails Preservation Council) was formed to prevent opening a portion of the historic Dipsea Trail to mountain biking and the narrowing of two fire roads, which they felt would become by default bikes-only trails (Tamalpais Conservation Club 2005). California State Parks and NPS have continuing examination of vehicle parking and driving practiced along Muir Woods road and are developing pilot program for pedestrian safety and reduction of vehicle impacts to the watershed due to parking practices.

- **Marin Municipal Water District**: The MMWD notes in its road and trail management plan, "Consistent with District policy, the Plan's goal, in general, is to reduce the road and trail network in the Watershed to help protect water quality and its natural resources" (MMWD 2005b). New trails are not expected and existing trails might be closed or realigned, reconstructed and maintained to limit the erosion of soil. Uses that contribute most greatly to soil erosion are anticipated to be further regulated, limited or prohibited in the future. Management policies are likely to limit the expansion of facility-intensive recreational activities, such as camping and picnicking. Increasing concern and control actions related to the introduction and spread of non-native plants also could lead to further trail-use restrictions. Trail users are one of many possible agents for the introduction and spread of non-native invasive plants (see Section 2.8.6).

Historic trends of increasing recreation visitation are likely to continue in the future, an issue of significant concern among watershed residents and close neighbors. Agency resource protection objectives and budget limitations could restrict infrastructure development needed to accommodate increasing visitation or develop public transportation alternatives. This inevitably would lead to problems with traffic congestion on the watershed's narrow two-lane roads, insufficient parking at attraction sites and trailheads, and crowding at popular sites and trails. A draft report by Manning and Budruk (2003) revealed that the majority of surveyed visitors feel somewhat crowded at Muir Woods but not at Muir Beach. At Muir Woods, the percent of visitors stating that they felt some degree of crowding was 77 percent along the trails, 86 percent at the parking lot, and 79 percent along the road. At Muir Beach, the percentages were 39 percent along the trail, 58 percent at the parking lot, 49 percent along the road, and 47 percent at the beach. Muir Woods visitors reported that they preferred to see about 6–7 visitors in their immediate vicinity along the main trails, but they reported actually seeing about 10 visitors in their immediate vicinity. However, 6 percent of visitors stated that seeing even 30 people nearby would not be sufficient to justify restricting use, and 13.3 percent reported that visitor use should not be restricted at the Monument.

The draft report and additional research conducted by Manning and Budruk in 2004 and 2005 was aimed at developing further information on visitor's standards of quality related to crowding. This information could be employed by the NPS in carrying capacity decision-making. The NPS also has funded a study to survey residents within and adjacent to the watershed regarding their opinions about watershed values and visitation management issues.

Traffic congestion appears to be the most salient public issue in the watershed. According to an article in the Marin Independent Journal, traffic congestion has been a long-term persistent problem for area residents and visitors (Brenner 2005). The *Southwest Marin Comprehensive Transportation Management Plan* (CTMP), initiated in 2000, included a coalition of government agencies working together to conduct a regional evaluation of traffic and visitor access alternatives to address some of the traffic problems. Following planning studies in 2000–2001, and NEPA scoping in 2002, draft alternatives were developed in 2003–2004, but public opposition caused the project to stall. In early 2005, Marin County decided to end their involvement with the project, and the project was effectively terminated. Since the end of the CTMP effort, the former coalition members have proceeded to work both independently and together on smaller pilot transportation projects, to test possible solutions to specific problems. No large scale planning effort to address the range of traffic issues encompassed in the CTMP effort has been proposed. Traffic planning studies have been conducted, along with public scoping meetings, to produce proposals ranging from closing the Muir Woods Road, building a transit intercept facility, and constructing a new parking lot at Muir Beach. Four plan alternatives were presented in December 2004, but public opposition has delayed continued progress and caused Marin County to pull out of the joint effort.

3.3.5 Visitor Experience and Resource Protection Framework

Increasing numbers of visitors to protected natural environments such as the Redwood Creek watershed inevitably contribute negative effects to natural and cultural resources that also can degrade the quality of visitor experiences. For example, erosion from heavy trail use can contribute to sedimentation and turbidity in streams, create rutted trails that are aesthetically displeasing, make travel difficult or unsafe, and degrade the quality of visitor experiences. Similarly, increasing numbers of visitors, particularly at popular attraction sites, can lead to visitor crowding and conflict that also diminish visitor satisfaction. Such concerns are a common and a recurring challenge for land management agencies such as the National Park Service. "Providing opportunities for public enjoyment is an important part of the Service's mission; but recreational activities and other uses may be allowed in parks only to the extent they can take place without causing impairment or derogation of a park's resources, values, or purposes" (NPS 2001). This statement from the NPS Management Policies recognizes the legitimacy of providing opportunities for public enjoyment of parks. However, the Management Policies also acknowledge that some resource degradation is an inevitable consequence of visitation and direct managers to "ensure that any adverse impacts are the minimum necessary, unavoidable, cannot be further mitigated, and do not constitute impairment or derogation of park resources and values" (NPS 2001).

The NPS has developed the Visitor Experience and Resource Protection framework to guide carrying capacity decisions needed to protect park natural and cultural resources while maintaining the quality of the visitor experiences (NPS 1997, Manning 2001). Based on management objectives that prescribe desired resource and social conditions for an area, measurable indicators and standards of quality are selected that reflect desired conditions. Standards of quality define minimal acceptable conditions. These "limits" define the critical boundary line between acceptable and unacceptable conditions, establishing a measurable reference point against which future conditions can be compared through periodic monitoring. When conditions for resource or social indicators exceed standards, carrying capacity has been exceeded and corrective management actions are needed. Such actions may involve visitor education or regulation, site management, or use limits.

3.4 Culturally Motivated Uses

The Redwood Creek watershed has a rich human history, beginning with the Coast Miwok native Americans who lived in the area for an estimated 7,000 years before Euro-American settlement in the late 1700s. The watershed's human history, described Section 2.2.3, is summarized here as it relates to culturally motivated recreation uses and values. Many Native Americans died from diseases introduced by white settlers; those who survived generally remained in the region and intermarried. Indian reservations were not established nor are there commemorative cultural sites in the watershed, although early midden sites have been located and several place names are derived from Miwok terms (Duncan 1989). No structures remain in the watershed from the early cattle grazing era that began in the 1830s, or from the timber harvesting that began in the late 1800s, although Kent Canyon retains its strong legacy of logging. Many railroad lines constructed during this time frame were converted to trails and roads, some that remain in use today.

Several structures from the early 1900s, the era of Portuguese dairy farming, can be found in the watershed, although none are well-known or frequently visited as cultural landmarks. The earliest include the Golden Gate Dairy ranch house, constructed around 1900 near Muir Beach, and the West Point Inn, constructed by the railroad on the upper slopes of Mt. Tamalpais in 1904 and accessible today only by trail. Two other early structures, located along the Panoramic Highway, include the Tourist Club, built in 1912, and the Mountain Home Inn, constructed in 1912 and extensively renovated in 1985. Other historic structures exist in Muir Woods, Camino del Canon, and the Mt. Tamalpais State Park, but these also are not widely known among visitors or featured as cultural landmarks. A cultural feature that is well-known and visited in the watershed is the Sidney B. Cushing Memorial Amphitheater (a.k.a. the "Mountain Theater"), built by the Civilian Conservation Corps in 1939, in the Mt. Tamalpais State Park. Since 1913, the Mountain Play Association has hosted plays on the upper slopes of Mt. Tamalpais, originally in a natural hillside depression, but shifted to the stone amphitheatre on its completion.

The 170-acre Banducci farm, located in the lower watershed 0.5 mile upstream from Pacific Way, also is a noted, long-time residence and business. This farm is a remnant of the culturally significant Portuguese farming era. A 28-acre portion of this land within the floodplain of Redwood Creek was farmed from the mid-1930s to 1995 as a commercial wholesale flower farm (Livingston 1994). During its operation, water was extracted for irrigation and the fields were protected from flooding by drainage ditches along the sides and a berm along Redwood Creek. California State Parks personnel have relocated structural features of several of the ranches and homesteads in the watershed and are currently (as of July 2011) preparing a report in which these cultural features are described; the cultural features include house foundations, dairy barns, and hay barns. In addition California State Parks personnel are transcribing interviews with individuals related to the dairy ranching in the watershed (Bjelajac, pers. comm., 2011).

Given the watershed's current and future recreational significance, early recreational uses are likely to retain some cultural interest. Recreation uses began with hunting (1850s-1917), but shifted to hiking and sightseeing as access to the watershed improved in the early 1900s. The Sierra Club held many of its first hikes on Mt. Tamalpais in the early 1900s (Spitz 1997). As previously noted, the annual Dipsea Trail Run follows a historic route between Mill Valley and the Pacific Ocean at Willow Camp (7 miles). The first race was run between the San Francisco Olympic Club and a local Marin hiking group in 1905 (Spitz 2010). A number of watershed trails date from the late 1800s, including the Lone Tree (a portion of today's Dipsea Trail), Cataract, Kent, Throckmorton, Bootjack, and West Point (now Rock Spring) trails.

Preservation of the watershed's most famous feature, the old-growth redwood grove, also has important cultural significance and values. Under the Antiquities Act of 1906, President Theodore Roosevelt designated the Muir Woods National Monument in 1908, from 295 acres donated by William and Elizabeth Kent (Sears 2005). Kent requested that it be named Muir Woods to honor John Muir, the noted wilderness preservationist whom he admired. Kent, like Muir, saw contact with nature as a fundamental human need and a means of physical and spiritual recovery from the destructive effects of urban life. The qualities of strength, endurance, quietness, and courage he found in the redwoods seemed to him to represent the ideal American virtues, "An American Wordsworth will one day come to sing these noble trees as teaching the ideal of the social and individual life of the American" (Sears 2005).

The cultural values held by watershed residents require consideration in any watershed planning and land management decisions. These values are captured in the *Muir Beach Community Plan* (Muir Beach Improvement Association 1978). The stated goals of this plan include preservation of a semi-rural community and setting where nature is protected, commercial development is largely absent, and recreational access is provided while protecting the coastal environment and preserving the natural environment. The plan stresses the maintenance of wild beauty and isolation: "Large numbers of cars, not to mention commercial establishments designed to serve them ranging from gas stations to motels and restaurants, can spell an end not only to the unique geography of this area, but also to the true recreational potential which a large undeveloped area can offer to an urban area." The implications for GGNRA development projects are clearly described: "…parking facilities be provided at the outer boundaries of the GGNRA, with facilities for purchasing food and gas located there; that existing roads within the park lands remain slow-speed, scenic roads, narrow and winding, and be so posted that pollution-free modes of transport be used to carry travelers; a minimum of future commercial development be allowed, placed in presently used commercial zones where it complies with local community plans." The plan encourages such recreational development as horse trails, bicycle paths, hiking trails, and access trails to small coves and beaches.

A similar plan for the Muir Woods Park Community, the *Tamalpais Area Community Plan* (Marin County 1992) also includes objectives that stress the preservation of the "semi-rural character of the community as defined by its residential neighborhood character and the quality of the surrounding natural environment." Plan guidance emphasizes constraints on the construction of large "mega houses," overloading of the area's leaching capacity, and the need for a visitor center and parking lot along Highway 101, where tourists going to Muir Woods and Muir Beach could leave their cars and take public transit.

3.5 Off-Site Passive Use Values

Natural and cultural resources can have substantial passive use values, based on economic, psychological, or spiritual benefits (Krutilla & Fisher 1985). Off-site passive uses are the enjoyment, appreciation, or contemplation of a resource that a person experiences without actually visiting the place (Fight et al. 2000). These values include:

- **Existence value**: the worth one places on the existence of a resource, regardless of their intention to ever visit it
- **Option value**: the value one would be willing to pay to ensure the option of potential future use
- **Bequest value**: the worth one places on the assurance that a resource will continue to available for future generations to enjoy

- **Memorial value**: the worth one associates with places where important events have occurred (e.g., historic events, marriages)

- **Stewardship value**: the worth one attaches to keeping a special place in good condition (e.g., volunteers who have made a long-term commitment to an area's preservation, maintenance, or interpretation)

- **Educational value**: the worth one places on learning about natural and cultural resources or historic events

Little direct documentation of these values has been made specifically for the Redwood Creek watershed. Although several visitor surveys have been conducted for areas in the watershed, surveys of residents in the region or nation regarding passive values are not available. Visioning workshops conducted by the National Park Service for the watershed have acknowledged and documented some passive values. Participants noted various scenic and inspirational values, including the area's unique old-growth redwood forest, original undisturbed natural conditions, scenic qualities, authenticity, and unique combination of landscapes (National Park Service 2003). Other sources of documentation include direct feedback from visiting groups, students, and volunteers.

Although difficult to document, off-site passive use values for the nationally and internationally acclaimed redwood groves in the watershed are perceived to be exceptionally high. The redwood trees at the Muir Woods Monument grow up to 250 feet tall, with the oldest tree at least 1,100 years of age, prompting naturalist John Muir to call this place, "...the best tree-lovers monument that could possibly be found in all the forests of the world." These ancient old-growth redwood groves have high scenic values that can be inspirational even for individuals who only experience them through photographs, videography, and writings. The preserved redwood groves within the Monument and adjoining Mt. Tamalpais State Park also provide an important "living" example of what the surrounding Marin County land must have resembled before its transformation and development by Euro-American settlers.

The watershed's high ecological values also contribute to strong passive-use values. The watershed lies within the internationally designated Golden Gate Biosphere Reserve and is included as one of 25 global biodiversity "hot spots" recognized by The Nature Conservancy. As noted in the preceding chapter, the watershed provides critical habitats for some of the West Coast's most imperiled rare species, including the coho salmon, steelhead, northern spotted owl, and California red-legged frog. The area's extensive human history (i.e., inhabitation by the Coast Miwok native people, colonization by Euro-American settlers, the intensive resource extraction phase, and the most recent resource preservation phase) also provide a basis for significant passive-use values.

Redwood Creek watershed values were specifically addressed through facilitated workshops involving the collaboration of land management agency staff and the public in 2002 (see also http://www.redwoodcreek.org/vision_wksp.htm). A vision team comprised of technical experts and community organization representatives helped frame watershed issues and define desired future conditions for the watershed vision (Vick 2002):

> *The Redwood Creek watershed exists as an intact natural ecosystem that offers opportunities for people to learn about, experience, and protect a rich blend of nature, rural character, and cultural history in an urbanized area.*

Some of the agency and public meetings focused on identifying watershed values, defined as special watershed attributes that should be preserved or restored. These included:

- **Rich Biodiversity**: a wide range of relatively undisturbed natural environments
- **Inspirational/Scenic Values**: Unique combination of scenic coastal landscapes including pristine stands or old growth forests
- **Rural Quality/Openness**: Lands that promote a rural and open space feeling
- **Human Enjoyment**: Easy access for many forms of recreation use
- **Stewardship and Conservation**: Education, sustainability, and historical perspectives on preservation

A principle output of this process is eight guiding principles, several relating to human values:

- The watershed is managed as a model of interdependency of all resources and beings, acknowledging the presence and activities of people historically and currently.
- Education is provided as a foundation for future watershed protection and stewardship.
- Opportunities for human and cultural experiences and interaction with the natural environment are fostered.
- People are active stewards of the watershed, and land management agencies provide an example for and promote stewardship of the watershed's resources by watershed residents and visitors.

Clearly the Redwood Creek watershed's natural resources are of national and international prominence and significance; thus, the "community of interest" holding off-site passive-use values should be considered to be global in scope. Land managers should acknowledge that their decisions could affect not just the watershed's visitors, residents, and regional populace, but national and international individuals as well.

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4 ISSUES AND ASSOCIATED INDICATORS

4.1 Introduction

This chapter identifies key natural resource-related issues to be addressed in the Redwood Creek watershed and relevant “indicators” of attainment of the natural resource-related DFCs associated with implementation of management measures. Issues were identified as natural resources and/or processes that are threatened or degraded by past, present, or likely future conditions, based on the assessment of existing conditions (Chapter 2, *Watershed Characterization*) and communications with land owners and managers and other stakeholders. These issues were identified within a common vision framework for the watershed (Vick 2003). All thirty-three issues described in this chapter were identified by the multiple stakeholder group as priorities for the watershed. Under “Prioritization of Issues” towards the end of this chapter, a process is described by which the thirty-three priority issues were ranked to identify seven issues whose solutions are not yet well articulated and yet near-term action is highly desirable. The discussion makes recommendations on studies to address critical information gaps, and identifies priority actions and enhancement measures that are most likely to improve watershed conditions or “health.”

4.1.1 Development of a Common Vision for Watershed Management

In 2002, public agencies in the Redwood Creek watershed joined with concerned individuals to define the DFCs for the watershed. The purpose of this process was to create a document based on consensus, that outlined common views on how to manage the watershed for “its ecosystem function, local residents and visitors, educational opportunities, cultural and agricultural resources, recreation, and rural character” (Vick 2003). The final product of this year-long process was a vision for the future for Redwood Creek watershed, stating:

> *The Redwood Creek watershed exists as an intact natural ecosystem that offers opportunities for people to learn about, experience, and protect a rich blend of nature, rural character, and cultural history in an urbanized area” (Vick 2003).*

Based on this guiding vision, specific DFCs were defined, with a focus on the watershed’s natural and cultural resources, resident communities, visitor experience, local infrastructure, facilities, and emergency services. NPS staff and agency partners participated in two facilitated work sessions in 2002, to define watershed issues that should be considered in the Redwood Creek watershed vision process. In the February 2002 workshop and thereafter, issues identified by the public at the workshop and through letters and response forms were sorted, based on the issue topics developed by the agency partners or into additional categories that were added, as needed. Key management goals for the watershed were summarized in a series of DFCs for each of the five resource areas: natural resources, cultural resources, resident communities, visitor experience, and local infrastructure, facilities, and emergency services (Vick 2003).

4.1.2 Identification of Issues Using the Vision Framework

The vision statement for Redwood Creek watershed was designed to provide a framework for future management planning, decision making, and cooperative action in the watershed. Because this assessment document provides technical background for future watershed management, these DFCs are used as a framework for identifying and discussing important natural resource issues. The assessment describes all important issues that interface with natural resources; thus, issues related to natural resource DFCs are the focus of this assessment. In addition, several natural resource concerns interface with cultural resources and infrastructure DFCs. Therefore, as appropriate, issues related to non-natural resource DFCs are included (Table 4-1). The natural resource DFCs help identify the processes and characteristics of the watershed that are ecologically important and personally valued. The importance of supporting a functioning watershed comes into focus when the watershed is viewed through a lens that addresses both human needs and ecological values (ESA 1997, Daily 1997). The DFC framework is similar to that of ecosystem services, in which the human values of healthy, functioning ecosystems are clearly enumerated (ESA 1997, Daily 1997).

Table 4-1. Vision Statement and Desired Future Conditions for Natural Resources

The Vision

The Redwood Creek watershed exists as an intact natural ecosystem that offers opportunities for people to learn about, experience, and protect a rich blend of nature, rural character, and cultural history in an urbanized area.

Natural Resource Desired Future Conditions

1. The watershed is managed as an intact, continuous, and linked system from the ridge tops to the ocean, with all parts contributing to the health of the whole.
2. Ecosystem management in the watershed is founded on the restoration and protection of natural processes and disturbance regimes, such as fire and flooding.
3. Native plant communities are healthy and comprise a mosaic of diverse cover types, including native grasslands, chaparral, riparian woodland, hardwood and redwood forests, and wetlands.
4. Restoration and protection of a full range of natural geomorphic and hydraulic functions in Redwood Creek from its headwaters to the Pacific Ocean support complex instream and floodplain structure that, in turn, supports a diverse community of native aquatic and riparian-dependent species.
5. Aquatic ecosystem health is not impaired by water diversion or water quality degradation.
6. Invasion by and the adverse effects of non-native plant and animal species on the ecosystem are reduced or reversed, and imperiled habitats are restored.
7. Special-status and locally rare plant and animal species are protected and, where appropriate, their populations are expanded.
8. Human-caused erosion on watershed lands does not impact fish and aquatic habitat.
9. Native wildlife populations are viable and diverse, and key habitats and habitat linkages are protected and restored.
10. Potential negative impacts of surrounding land uses are minimized.

Source: Vick 2003

Although ten DFCs are described for natural resources, not all ten of these were used to frame the existing issues in the Redwood Creek watershed. Two of the natural resource DFCs transcend the remaining eight by describing the principles and approaches on which the natural resources of the watershed should be managed. The first DFC describes the scope of thinking and planning that should go into each management decision, stating that the watershed is “managed as an intact, continuous, and linked system from the ridge tops to the ocean, with all parts contributing to the health of the whole.” The second natural resource DFC places a priority on preserving and restoring critical natural processes that maintain the integrity of all parts of the watershed. Based on these directives, each issue identified for the watershed is developed in the context of the whole watershed and as an expression of natural processes.

A third DFC for natural resources states that “potential negative impacts of surrounding land uses are minimized.” Because most if not all existing issues are caused by processes that occur across property boundaries, other DFCs that address particular issues capture this goal. For example, impacts associated with increased sediment input, alterations to the hydrograph, and introduction of non-native invasive animal or plant species occur across boundaries, and addressing those processes requires minimizing impacts from surrounding lands. Thus, these three natural resource DFCs are not explicitly used to frame existing issues and associated indicators in the watershed.

As a result of the integrated view of the DFCs, individual issues in the watershed are frequently related to multiple DFCs. As such, the issues are organized under the DFC that most directly, but not exclusively, addresses the impact of that issue. For example, one issue concerns potential lack of flood capacity in existing culverts (see Section 4.2.3). Although resolution of this issue is encompassed under the first DFC as stated above, the current conditions and likely solution most directly involve infrastructure (e.g., culverts), so this issue is placed under the third DFC on infrastructure. Issues that concern multiple DFCs are cross-referenced at the end of each issue description below.

Furthermore, climate change will increasingly affect many of the natural processes and populations in the Redwood Creek watershed. Because the effects of a changing climate are so thoroughly integrated into nearly every issue, these effects are not identified and discussed as a separate issue. Instead, climate change effects are highlighted in the sections describing issues most likely to be directly and profoundly impacted, such as isolation of Frank Valley, flood conveyance, invasive non-native plant species, and vulnerability of local fish and frog populations.

4.1.3 Selecting Indicators of Change in Condition

“Indicators” are measurable physical, ecological, or social variables used to track trends in conditions caused by activities or processes in the watershed so that progress toward goals and desired conditions can be assessed. Comparison to management objectives or indicator standards reveals the acceptability of any resource changes. Indicators provide a means for restricting information collection and analysis to the most essential elements needed to answer management questions.

Selected indicators need to be attributes that allow efficient, reliable, and accurate measurements, understandable to the public. Criteria used for the selection of indicators are summarized in Table 4-2, based on work of Cole (1989), Marion (1991), and Merigliano (1990). Indicator measures primarily need to reflect changes caused by human activities that are responsive to management actions. A small number of general indicators were selected to address the identified issues, to keep the monitoring program manageable.

On this basis, a description of where and under what circumstances each issue is most apparent, along with an explanation of why each issue is important and relevant to attaining the DFCs, are provided. In addition, a set of indicators are provided that can be used to discern whether or not the general goals set forth for each issue have been met. The selected indicators of change in condition thus reflect empirical measurements of an underlying environmental process or condition and/or tangible evidence that information gaps have been filled.

Table 4-2. Criteria for Selecting Resource Condition Indicators

Criteria	Rationale
Quantitative	Can the indicator be measured?
Relevant	Does the indicator change as a result of the process or activity of interest?
Efficient	Can the measurements be taken by available personnel within existing time and funding constraints?
Reliable	How precise are the measurements? Will different individuals obtain similar data of the same indicator?
Responsive	Will management actions affect the indicator?
Sensitive	Does the indicator act as an early warning, alerting you to deteriorating conditions before unacceptable change occurs?
Integrative	Does the indicator reflect only its condition or is its condition related to that of other, perhaps less feasibly measured, elements?
Significant	Does the indicator reveal relevant environmental or social conditions?
Accurate	Will the measurements be close to the indicator's true condition?
Understandable	Is the indicator understandable to non-professionals?
Low impact	Can the indicator be measured with minimal impact to the resource or the visitor's experience?

Sources: Adapted from Cole 1989, Marion 1991, and Merigliano 1990

4.1.4 Watershed Issues and the San Francisco Area Network Vital Signs Monitoring Plan

GGNRA staff participated in the development of the *Vital Signs Monitoring Plan* (NPS 2005c) for the six NPS sites within the San Francisco Bay Area Network (SFAN) of parks, including Fort Point, Eugene O'Neill and John Muir National Historic sites, the GGNRA, the Muir Woods and Pinnacles National Monuments, and the Point Reyes National Seashore. The plan describes three reasons why the SFAN resources are important to the National Park System, which: (1) shows support of many endemic species and communities despite being adjacent to the highly urbanized areas of the San Francisco Bay region; (2) ensures preservation of biologically and geologically diverse habitats and their associated species; and (3) makes provision of opportunities for recreation, education and aesthetic enjoyment to a large urban population. Internationally, the SFAN falls within the eighth most significant "hot spot" in the world for biodiversity and is at great risk because of rapid human population growth. The major threats to the SFAN resources, labeled as "stressors," were identified as follows: global climate change; air quality degradation; water quality degradation; water quantity alteration; human population increase; land use changes/development; resource extraction; soil alteration; nutrient enrichment; park development and operations; recreational use; fire management; non-native invasive species/disease; and native species decline and extirpation. As part of the process of identifying natural resource-related issues for the Redwood Creek watershed, these SFAN resource areas and major stressors were closely considered. In developing indicators that reflect the on-the-ground status of each issue, first monitoring protocols developed through SFAN (NPS 2005c) were examined to maximize consistency among data sets within the GGNRA. Where these protocols do not describe measures that would directly indicate conditions of a specified issue, new metrics are described.

4.2 Redwood Creek Watershed Issues and Associated Indicators

The DFCs that interface with natural resource issues[1] have been organized under the natural resource they most centrally concern. Because geomorphic and hydrologic processes and conditions often have important impacts on other resource areas (such as aquatic habitat, water quality, and wildlife), they have been placed at the front of the sequence. These are followed by DFCs and associated issues related to water flow and quality, which also typically are associated with impacts on biological resources. Finally, DFCs and associated issues concerning plants and wildlife are presented. Table 4-3 presents these DFCs and their associated issues and indicators. Following Table 4-3, a more complete summary of each issue and the associated recommended indicators of ecosystem health are presented, based on metrics developed by the SFAN *Vital Signs Monitoring Plan*, the NPS Inventory and Management program, scientific literature, and professional judgment. Although a great deal of information on the natural resources of Redwood Creek exists, still more is needed to inform management decisions; thus, many of these issues include critical information gaps, and several of these issues are only information gaps. Some information gaps, such as those associated with the effects of SOD, reflect a new need caused by changing conditions in the watershed. Other gaps, such as those related to the isolation of Frank Valley from the floodplain and those on potential excess sediment inputs, reflect an evolution in scientific understanding and valuation of natural resources. Responding to natural resource problems and managing natural resource issues require the support of adaptive management, informed by adequate information.

Table 4-3. Redwood Creek Watershed Priority Natural Resource Issues

DFC for hydraulic and geomorphic function: *Restoration and protection of a full range of natural geomorphic and hydraulic functions in Redwood Creek from its headwaters to the Pacific Ocean support complex instream and floodplain structure that, in turn, supports a diverse community of native aquatic and riparian-dependent species*	
Issue 1	Gather sufficient information on stream flow for lower Redwood to assess water use/availability, habitat conditions/effects, and flood control needs
Issue 2	Reconnect Frank Valley floodplain to Redwood Creek mainstem
Issue 3	Establish baseline and perform ongoing monitoring of channel geomorphic structure for Redwood Creek watershed
DFC for erosion effects on fish habitat: *Human-caused erosion on watershed lands does not impact fish and aquatic habitat.*	
Issue 4	Quantify and reduce high potential sediment yields resulting from human actions in tributaries, including Camino del Canon
Issue 5	Quantify and reduce excessive sediment yields due to mainstem and tributary incision in Frank Valley impact water quality, fish habitat, and flood conveyance
DFC for infrastructure: *Infrastructure and its maintenance are appropriate to the anticipated use and public safety, while minimizing impacts on natural resource and cultural resources.*	
Issue 6	Reduce flood hazard during high flow events along Pacific Way
Issue 7	Increase flood capacity in existing culverts
Issue 8	Remove constraints on natural processes by existing structures and parking lots
DFC for water flow and quality in relation to aquatic ecosystem health: *Aquatic ecosystem health is not impaired by water diversion or water quality degradation.*	

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[1] During the development of this Watershed Assessment the Natural Resource "Issues" were rephrased as actions in order to be more tangible for decision making.

Table 4-3. Redwood Creek Watershed Priority Natural Resource Issues

Issue 9	Minimize effects of water withdrawal on fish populations
Issue 10	Reduce vulnerability of lower Redwood Creek to additional water diversions
Issue 11	Characterize and minimize negative water quality effects from stormwater runoff from parking lots and roads
Issue 12	Quantify dissolved metal levels throughout the watershed
Issue 13	Identify sources and reduce bacterial contamination of lower Redwood Creek and Muir Beach
Issue 14	Identify sources and reduce nutrient enrichment of lower Redwood Creek
DFC for native plant community health: *Native plant communities are healthy and comprise a mosaic of diverse cover types, including native grasslands, chaparral, riparian woodland, hardwood and redwood forests, and wetlands.*	
Issue 15	Allow for regeneration and natural disturbance regimes in Muir Woods and other redwood forests in watershed
Issue 16	Determine baseline structure and composition of Muir Woods
Issue 17	Characterize and minimize Sudden Oak Death effects on plant community composition and structure
Issue 18	Slow or reverse conversion of native grasslands to shrub-dominated plant communities
Issue 19	Characterize extent of and threats to native serpentine and dune communities and species
DFC for non-native species effects and native habitat: *Invasion by and the adverse effects of non-native plant and animal species on the ecosystem are reduced or reversed, and imperiled habitats are restored.*	
Issue 20	Limit introduction and spread of invasive plant species through systematic monitoring and public outreach
Issue 21	Improve invasive non-native plant species control and eradication
Issue 22	Minimize impacts of non-native animals and native “pest” species on native species
DFC regarding the protection of special-status animals and plants *Special-status and locally rare plant and animal species are protected and, where appropriate, their populations are expanded.*	
Issue 23	Increase amount of winter refugia for rearing coho salmon and steelhead
Issue 24	Survey and increase if necessary suitable habitat for listed terrestrial invertebrate species
Issue 25	Increased California red-legged frog breeding areas and consider reintroduction of Foothill yellow-legged frog in watershed
Issue 26	Characterize and address potential long-term negative threats to local northern spotted owl population
Issue 27	Assess and enhance conditions for native bat populations in the watershed
Issue 28	Assess potential for marbled murrelet habitat in watershed and if supported, manage lands for marbled murrelet habitat
DFC regarding native wildlife populations and habitat *Native wildlife populations are visible and diverse, and key habitats and habitat linkages (i.e., corridors) are protected and restored.*	
Issue 29	Reduce wildlife habitat fragmentation associated with roads and development
Issue 30	Halt declines in wetland bird species due to the loss of suitable habitat
Issue 31	Halt decline of local native song bird populations due to nest predation and brood parasitism by non-native predator birds
Issue 32	Minimize effects of human-caused sound, light, and activity disturbances on wildlife
Issue 33	Perform comprehensive study on coho salmon and steelhead populations

4.2.1 Desired Future Condition for Hydraulic and Geomorphic Function

Vision Statement: Restoration and protection of a full range of natural geomorphic and hydraulic functions (such as sediment transport, channel migration, and recruitment of large wood) in Redwood Creek from its headwaters to the Pacific Ocean support complex instream and floodplain structure that, in turn, supports a diverse community of native aquatic and riparian-dependent species.

This DFC is based on the understanding that when geomorphic and hydraulic processes are unconstrained along the entire length of a watershed, aquatic and riparian communities will be restored by the fundamental processes that support them. Mobilization, transportation, and deposition of water and sediment are processes that shape habitat for vegetation, fish, and wildlife that inhabit the river, riparian zone, and uplands of a watershed. For example, erosion, scouring, and deposition of sediment create new habitat and surfaces for seed germination. Similarly, seed release, germination, leaf drop, and other aspects of native riparian plant species life cycles are adapted to pre Euro-American era flood intensity, timing, and duration, such that changes in the flood time can fail to deliver seeds to newly created downstream surfaces; and changes in summer draw down can reduce seedling survival rates. Changes in the hydrograph directly and indirectly (through effects on riparian vegetation) affect aquatic and wetland bird species. For example, reductions in late summer flows can increase fish mortality through effects on water quality, and reduced floodplain connectivity can result in reduced extent of riparian vegetation, which in turn, can reduce the availability of wetland bird species habitat. Thus, creating conditions that allow for geomorphic and hydraulic regimes closer to those of the pre Euro-American era are expected to increase native fish and wildlife habitat quality, extent, and diversity.

Under current conditions, processes such as flooding, erosion, and sediment delivery are subject to legacy management effects and are constrained by channel incision, constructed levees, realigned and straightened channels, bank protection, grade control, and road infrastructure. In many cases, a better understanding of how these processes are currently constrained as well as information on how the system might respond to specific changes in the physical conditions is needed.

Issue 1 Gather sufficient information on stream flow for lower Redwood to assess water use/availability, habitat conditions/effects, and flood control needs

An accurate, reliable rating curve (i.e., stage-discharge curve) does not currently exist for the Highway 1 flow gauge, the primary source of information on stream flows in lower Redwood Creek. More accurate flow records from stage measurements at the Highway 1 Bridge gauge are required as the basis for (1) providing baseline hydrological data for numerous management purposes as well as for tracking the trajectory of climate change effects; (2) developing a sediment rating curve and estimating sediment transport potential under different flows to help in the management and monitoring of the lower Redwood Creek restoration at Muir Beach project and other areas in the lower watershed; and (3) estimating water quality parameters in the lower watershed. As described in Section 2.4, *Hydrology*, the stage recorder was installed with the objective of providing a reliable hydrologic record of Redwood Creek near its mouth (and for comparison to gauges at upstream sites). Analysis of the stage and flow data at this location has identified uncertainties in the flow rating curve that limit the reliability of the derived discharge estimates (Stillwater Sciences 2005b). At least two sources of uncertainty exist, including: (1) aggradation and other localized changes of the channel bed at or near the gauge that reduce the reliability of the records; and (2) the limited number of validating discharge measurements, especially at the extremes of high and low flows, which reduce confidence in the accuracy of stage-derived discharge estimates. These uncertainties represent restrictions to a potentially very valuable data source. Further analysis of the current gauging station might reveal the necessity to relocate the gauging station.

This issue has implications for other DFCs, including those described in Section 4.2.2, *Erosion Effects on Fish Habitat*, Section 4.2.3, *Infrastructure*, and Section 4.2.4, *Water Flow and Quality in Relation to Aquatic Ecosystem Health*.

Selected Indicators

The objective in addressing this issue would be to obviate uncertainties currently inherent to utilization of gauging records from the Highway 1 Bridge gauge. Indicators that this issue has been addressed would include establishment of a reliable streamflow gauging station in the lower watershed that could be operated and maintained for the foreseeable future; achievement of a long-term source of flow records in lower Redwood Creek that could be referenced to either (1) a single datum with a field-verified stage-discharge relationship, or, (2) one of several datum each with a field-verified stage-discharge record.

Issue 2 Reconnect Frank Valley floodplain to Redwood Creek mainstem

Channel incision, constructed levees, realigned and straightened channels, bank protection, grade control, and road infrastructure have acted to limit the hydrological connectivity of Redwood Creek with its former floodplain areas in Frank Valley. The frequency, duration, and depth of floodplain inundation are far below historical levels and likely have significant impact on rearing habitat for coho salmon as well as overall flood conveyance to downstream areas. As described in Chapter 2, climate change is expected to increase the frequency of extreme events, including floods. Natural floodplains provide flexibility in the system for absorbing the energy and sediment delivered during such extreme storm events.

Large woody debris placed in the Redwood Creek channel at the Banducci site.

Various opportunities for floodplain re-connection are being explored. Some levee removal has already occurred in conjunction with instream engineered log jam placement at the Banducci farm site. Reconnection of the "old ball field" at the junction of Highway 1 and Muir Woods Road would be contingent on locally raising the elevation of Muir Woods Road. However, past channel realignment and floodplain regrading have isolated Redwood Creek from its floodplain along Frank Valley. Apparent aggradation of the mainstem creek in the lower Banducci farm site should serve to elevate flood flows, but is unlikely (in the near term) to effectively increase floodplain connectivity. Thus, regrading is required along much of the Frank Valley to fully re-establish connectivity. Because reconnecting and regrading are expensive, it is logical to first understand the extent of floodplain disconnection and its implications on salmon and steelhead rearing habitat as the basis for prioritizing areas that can be reconnected at lowest cost and with greatest environmental benefit.

This issue has implications for other DFCs, including those described in Section 4.2.2, *Erosion Effects on Fish Habitat*, Section 4.2.3, *Infrastructure*, Section 4.2.4, *Water Flow and Quality in Relation to Aquatic Ecosystem Health*, and Section 4.2.7, *Protection of Special Status Plant and Animal Species*.

Selected Indicators

The objective in addressing this issue would be to select priority areas and develop and implement restoration projects along Frank Valley, where restoring floodplain connectivity to the channel would yield the greatest environmental benefit. This would require understanding the extent to which current areas of the former floodplain are disconnected from flooding when flows are in excess of the statistical bankfull level (approximately 800 cfs) and to use this information as the basis for pursuing management measures designed to reconnect the floodplain and channel to near-historical levels in terms of frequency, duration, and depth. Indicators that this data gap has been filled would include field-based estimates of floodplain inundation frequency, duration, and extent under current conditions during different return period flows. Indicators that the Frank Valley floodplain has been reconnected to the channel would include recorded flood regimes (inundation frequency, duration of flooding) along the Valley that reflect target reference conditions, such as a pre-Euro-American settlement flood regime.

Issue 3 Establish baseline and perform ongoing monitoring of channel geomorphic structure for Redwood Creek Watershed

Information on channel size, structure, gradient, and bed composition at permanent transects along the upper, mid, and lower reaches of Redwood Creek can provide an essential point of reference for understanding overall condition and trends in channel incision and aggradation, as well as for detecting changes in response to restoration and/or stressors (e.g., undersized culverts; changes in flow and storm size/frequency associated with climate change; upland erosion) in channel condition, sediment input and routing, and aquatic habitat quality and distribution. Identification and tracking of headcuts, nickpoints, and grade controls along the mainstem and major tributaries also will provide essential baseline information on channel existing conditions.

This issue has implications for other DFCs, including those described in Section 4.2.2, *Erosion Effects on Fish Habitat*, Section 4.2.3, *Infrastructure*, Section 4.2.4, *Water Flow and Quality in Relation to Aquatic Ecosystem Health*, and Section 4.2.7, *Protection of Special Status Plant and Animal Species*.

Selected Indicators

The objective of this issue would be to establish a spatially explicit baseline on the existing channel structure and distribution and status of features affecting channel geomorphology, such as incision, aggradation, and meander formation, particularly in relation to current and/or historical stressors. Establishing this baseline map, and updating this over time (particularly following large events), would provide important information for understanding processes affecting channel and riparian conditions. This could be used to inform restoration and management decisions. Indicators that this data gap has been filled would include establishment of permanent cross-sections and performance of: (1) a baseline survey of channel structure and composition at cross-sections; (2) a survey of the locations of headcuts, nickpoints, and grade controls throughout the watershed; and (3) survey updates following large storm events and every 5 to 10 years.

4.2.2 Desired Future Condition for Erosion Effects on Fish Habitat

Vision Statement: Human-caused erosion on watershed lands does not impact fish and aquatic habitat.

Increased sediment inputs to the channel caused by land use activities is an important source of habitat degradation for West Coast coho salmon and other fish (Bash et al. 2001, as cited in Lendvay and Benning 2006a). Excess fine sediment can cause redd entombment, increasing mortality rates from egg to fry stages (Reichmuth et al. 2006b). Measures of turbidity collected during non-event times in 2005 were high at Banducci and Muir Beach (19.0 NTU to 25.1 NTU; Lendvey and Benning 2006b). Turbidities at these reported levels can adversely affect coho salmon spawning by negatively affecting growth and feeding while increasing stress on individual fish (Lloyd 1987, as cited in Lendvay and Benning 2006a). Event-driven increases in turbidity and sediment delivery to the channel were not included in the Lendvey and Benning (2006a) monitoring, and they could further increase negative effects on salmon growth and spawning, and increase redd entombment. To reduce sediment inputs, data gaps on the likelihood, extent, and locations of these potential event-driven sediment inputs in Redwood Creek watershed need to be filled and measures to minimize those inputs need to be implemented.

Issue 4 Quantify and reduce high potential sediment yields resulting from human actions in tributaries, including Camino del Canon

The geology of the Redwood Creek watershed leaves hillslopes and tributaries naturally prone to erosion by landsliding and debris flows (respectively) in rainfall events that exceed certain threshold values of intensity and duration. Before extensive Euro-American watershed modification, sediments from small tributaries in Frank Valley are likely to have been deposited in tributary fans rather than being delivered to the mainstem Redwood Creek. Human activities are suspected of having altered these natural rates of sediment production and delivery: land use changes have changed rates of production, and drainage improvements allow a greater proportion of tributary sediment to reach the mainstem Redwood Creek. As an example, a 2001 survey of road- and trail-related sites requiring remedial action to reduce existing sediment contribution or prevent future catastrophic contributions (from stream-related erosion associated with large storm events) identified 259 road sites and 121 trail sites (PacWA 2002). Similarly, results from the Redwood Creek sediment budget (Stillwater Sciences 2004) suggest that the since 1980, tributary sediment sources (including sediment from roads and trails) have been the primary source of sediment in the watershed, since rates of mainstem channel incision in Frank Valley have waned. Annualized estimates of road and trail erosion account for nearly one-quarter of all sediment production and are directly related to human activity; the explicit impact of human actions in affecting rates of hillslope and tributary sediment production and delivery (not related to roads and trails) is less easy to quantify over long time periods. However, as rates of sediment yield into Big Lagoon are still many times higher than estimated rates before Euro-American settlement (Stillwater Sciences 2004), contributions from headwater areas probably have important implications for any ongoing and/or planned restoration projects in the watershed, whether they cause short-term pulses of sediment, or long-lasting periods of aggradation. Such pulses, especially from fine sediment sources, may have significant negative impacts on downstream fish and other aquatic habitats.

Although historical and recent sediment delivery to the lower watershed from Camino del Canon appears to be relatively minor (Stillwater Sciences 2004), its potential as a future sediment source may be significant (Section 4.1.4), with debris flows and landslides noted after the 1982 and 1997 storm events. Camino del Canon is the only tributary in the upper watershed with significant residential development, creating a management challenge different from other upper tributary watersheds. Significant sediment yields from Camino del Canon can exacerbate sediment-related impacts on fish and aquatic habitats in the lower watershed and Big Lagoon.

This issue has implications for other DFCs, including those described in Section 4.2.1, *Hydraulic and Geomorphic Function*, Section 4.2.3, *Infrastructure*, Section 4.2.4, *Water Flow and Quality in Relation to Aquatic Ecosystem Health*, and Section 4.2.7, *Protection of Special-Status Plant and Animal Species*.

Selected Indicators

This issue has two sequential objectives: (1) to understand the extent to which sediment yields from tributary watersheds would exceed natural rates, potentially causing negative impacts on downstream hydrology and aquatic habitat; and (2) if high tributary sediment yields were occurring and negatively impacting aquatic habitat, the second objective would be to describe and implement strategies for reducing tributary sediment yields. Establishing whether or not, and by how much, tributary sediment yields exceed natural rates would require a hypothesis-driven experimental technique initially, followed by several comparative tests to establish the extent to which sediment yields could practically be reduced. These data would be useful for identifying land and/or water uses that would be particularly susceptible to high sediment production during storm events and thus, if possible, should be avoided. Indicators that these knowledge gaps have been filled would be descriptions of rates of sediment production and yield (delivery) from tributaries that would include inter-annual and event driven variability, and a comparison of current measured rates to long-term historical rates (e.g., identified reference conditions or reference watershed). Indicators that management actions have reduced trail or road-related sediment input and delivery from small tributary watersheds would be provided by post-implementation field measures of sediment delivery from targeted areas that show lower sediment yields than expected, based on the pre-implementation sediment rating curves.

Issue 5 Quantify and reduce excessive sediment yields due to mainstem and tributary incision in Frank Valley

Land use disturbances and channel management actions in Frank Valley have resulted in massive incision of the Redwood Creek mainstem since Euro-American arrival in the watershed. Mainstem and tributary channel sediment yields derived largely from channel incision and associated bank erosion were estimated to be the largest single component of the sediment budget for Redwood Creek in the period 1840–1980 (Stillwater Sciences 2004). Field surveys indicated that rates of incision along the mainstem since 1980 have reduced somewhat from their historical high but still account for over one-quarter of the sediment yield to Big Lagoon. Field evidence suggests that lower Redwood Creek may now be recovering (i.e., now subject primarily to aggradation rather than incision), but that tributaries entering Redwood Creek in Frank Valley are likely to incise in the future as a legacy effect of incision in mainstem Redwood Creek.

The implications of human disturbance in the watershed had two effects on sediment dynamics in Frank Valley: first, mainstem Redwood Creek began to incise, reducing overbank sediment deposition and making the mainstem a source rather than sink for watershed sediments, and thus increasing total sediment yield to Big Lagoon. Second, because the Frank Valley floodplain accreted largely from overbank fine sediment deposition, incision bank erosion into these deposits released increased fine sediment. Both changes in the quantity and texture of sediment entering Redwood Creek and Big Lagoon are likely to have had significant negative impacts on downstream fish and other aquatic habitats.

This issue has implications for other DFCs, including those described in Section 4.2.1, *Hydraulic and Geomorphic Function*, Section 4.2.3, *Infrastructure*, Section 4.2.4, *Water Flow and Quality in Relation to Aquatic Ecosystem Health*, and Section 4.2.7, *Protection of Special-Status Plant and Animal Species*.

Selected Indicators

The objective in addressing this issue would be to fill data gaps regarding the extent to which Redwood Creek has shifted from a degrading to an aggrading system, and the likelihood and locations of associated bank erosion and tributary incision that have increased fine sediment loading. In this way, land and/or water uses that increase storm-related sediment loading from channel and tributary erosion could be identified and avoided. Indicators that these data gaps have been filled would include field mapped and monitored morphological changes in Redwood Creek through Frank Valley and location of areas of tributary incision. This could include a detailed map of the tributary vertical profiles, headouts, and natural grade controls. Indicators that these issues have been successfully addressed would include field surveys that demonstrated ongoing reductions in bank erosion, tributary incision, and knickpoint progression.

4.2.3 Desired Future Condition for Infrastructure

Vision Statement: Infrastructure and its maintenance are appropriate to the anticipated use and public safety, while minimizing impacts on natural and cultural resources.

The natural resources of Redwood Creek watershed offer many attractions for visitors and residents, but human use of the watershed requires infrastructure that allows for access such as roads, bridges, modern amenities (such as water and electricity for residents), parking lots and public bathrooms for visitors, and some commercial development (e.g., Pelican Inn). Infrastructure includes bridges, roads and transportation routes, culverts, buildings, and parking lots. Numerous such structures exist in Muir Woods itself, including the parking lot, the visitor center, park service office and supply buildings, and public bathrooms. Buildings and parking lots introduce high visitor densities to the immediate surroundings and can thereby disturb sensitive wildlife species. Parking lots and high human foot-traffic can compact soil and act as conduits of invasive exotic plant species. Bridges cross over Redwood Creek in Muir Woods (along the walk ways) as well as in Frank Valley on Redwood Creek Road and on Highway 1. Culverts associated with large and small tributaries affect the passage of water and sediment during high flow events. This DFC sets a goal of allowing for these human uses while minimizing the impacts of the required infrastructures on key natural resources and processes.

Issue 6 Reduce flood hazard during high flow events along Pacific Way

Flooding of Pacific Way affects access to the Muir Beach community for residents and, perhaps more critically, for emergency vehicles. In this location, Redwood Creek has been channelized to a perched position on the north side of the valley floor and is of low gradient. Flood discharges overtop its south bank and flow through the lower central portion of the floodplain to lower Redwood Creek, crossing Pacific Way. The low gradient also promotes sediment deposition on the channel bed, causing bed elevations to rise over time and the channel to lose flood capacity. The result is extended periods of flooding on Pacific Way during relatively wet water years. Sufficient flood conveyance will become increasingly important if climate change models have accurately predicted increases in extreme events for the watershed. Periodic dredging of the channel bed sediments, to increase channel capacity and reduce the frequency of flooding, has been demonstrated to be largely ineffective, and this activity also can adversely affect rare species. The ongoing, multi-phased restoration project of lower Redwood Creek at Muir Beach will address some of these concerns through construction of a new Pacific Way bridge with greater conveyance capacity, repositioning of the channel downstream of the bridge and increasing downstream flood water storage capacity. The long-term effectiveness of these restoration measures to provide sustained conveyance for flood flows and sediment transport is unknown.

This issue has implications for other DFCs, including those described in Section 4.2.1, *Hydraulic and Geomorphic Function.*

Selected Indicators

The objective in addressing this issue would be to reduce the frequency of flooding of Pacific Way to a prescribed recurrence interval. The sustainability of the solution likely would depend on morphological changes to Redwood Creek in the vicinity of the bridge, and on changes in the hydrology of Redwood Creek in response to management measures. Selected indicators that this issue has addressed would include cessation of flooding and associated traffic disruption below a prescribed acceptable flood recurrence interval. This prescribed recurrence interval (50-year flood event) was developed as an integral part of bridge design for the restoration of lower Redwood Creek at Muir Beach (Moffatt & Nichol and Jeff Anderson & Associates 2009). Sustainability of actions would be indicated by field surveys of channel morphology directly following restoration and regularly thereafter for at least 10 years, along with surveys after large flood events. Surveys of as-built channel bed and floodplain morphology, and channel bed texture would be used as baseline conditions. Periodic post-implementation surveys of channel bed elevation would check whether flood capacity was being lost beyond acceptable levels, and whether trends occurred in sediment deposition that were indicative of persistent aggradation. Channel surveys should occur frequently at the outset, with subsequent frequencies adjusted according to the apparent rate of depositional change (if any). Floodplain areas should be re-surveyed after events that exceeded bankfull discharge.

Issue 7 Increase flood capacity in existing culverts

Numerous culverts through the watershed have insufficient capacity to pass flood flows, resulting in local upstream flooding, downstream hydraulic erosion, and potential culvert failure and site erosion. As mentioned above for Issue 5, sufficient flood conveyance will become increasingly important if climate change models have accurately predicted increases in extreme events for the watershed. Replacement of culverts requires funding and multi-agency commitment.

This issue has implications for other DFCs, including those described in Section 4.2.1, *Hydraulic and Geomorphic Function*.

Selected Indicators

The objective in addressing this issue would be to reduce the frequency of upstream flooding from undersized culverts (e.g., at the intersection of Muir Woods Road and Highway 1), and potential erosion and culvert failure problems. Indicators that this issue has been successfully managed would be a decreased incidence of flooding and/or erosion at and around culvert locations during flood events.

Issue 8 Remove constraints on natural processes by existing structures and parking lots

Several instances occur in the Redwood Creek watershed where existing structures, including buildings and parking lots, constrain or impinge on natural processes. For example, the existing parking lot for Muir Woods is located on the floodplain for Redwood Creek in the ancient redwood forest. In its current location, the parking lot affects ecological processes associated with flooding, including scour, creation of new surfaces for germination and aquatic habitat, as well as channel migration. Soil compaction and stormwater runoff associated with the parking lot likely affect adjacent trees as well as soil and surface water quality. Similarly, the parking lot at Muir Beach, before the 2009 restoration, was located in the wetland associated with lower Redwood Creek and affected channel migration, plant community composition, and wildlife behavior. The implementation of restoration activities at lower Redwood Creek began in August 2009, and will ultimately include reorientation of the Muir Beach parking lot so that it is parallel to the valley side slopes, occupies less area of the existing wetland, and impinges less on channel migration (Moffatt & Nichol and Jeff Anderson & Associates 2009). Follow-up surveys will be needed to ensure that this parking lot re-orientation results in the desired effects on natural channel processes. Other structures constraining natural processes in the watershed include channel rockwork in Muir Woods and between the Highway 1 and Pacific Way bridges, the concession stand located on the floodplain in Muir Woods, and Muir Woods Road just downstream of Muir Woods, where natural channel migration overlaps with and continuously erodes the roadway. Options on how to reduce the effects of these structures need to be explored, and priorities identified and implemented.

This issue has implications for other DFCs, including those described in Sections 4.2.1, *Hydraulic and Geomorphic Function*, Section 4.2.3, *Infrastructure*, Section 4.2.4, *Water Flow and Quality in Relation to Aquatic Ecosystem Health*, Section 4.2.5, *Native Plant Community Health*, and Section 4.2.7, *Protection of Special-Status Plant and Animal Species*.

Selected Indicators

Solutions for this issue would involve actions to identify critical infrastructure constraints in the watershed and reduce those constraints on natural processes. Best actions would need to be prioritized and implemented to achieve this objective. Indicators that this issue is being addressed would include structure- and process-specific pre- and post-implementation monitoring at identified critical areas. Such monitoring would evaluate whether the actions taken to reduce constraints on targeted natural processes had effectively reduced adverse effects on those natural resources and processes. Structure-specific indicators for the effectiveness of any management actions would be developed, along with implementation plans. Examples of known important infrastructure constraints on natural processes include the current location and structure of the Pacific Way Bridge and multiple infrastructure issues along Muir Woods Road downstream of Muir Woods National Monument. Indicators of reduced hydraulic impacts associated with the current form of Pacific Way Bridge would include improved continuity in sediment transport in the vicinity of the road crossing (e.g., less deposition and scour upstream and downstream of the bridge) and decreased frequency of flooding of Pacific Way. Actions to reduce infrastructure constraints associated with Muir Woods Road downstream of Muir Woods National Monument could include realignment of Muir Woods Road so that channel confinement caused by the road was reduced and connectivity between channel and floodplain was increased. Indicators of effectiveness of these changes on channel processes in the vicinity of road realignment areas would include increased geomorphic complexity (e.g., gravel bars and pools), increased frequency and extent of floodplain inundation, increased establishment of native riparian species on formerly eroded banks, and enhanced summer rearing habitat and winter refugia for salmonids.

4.2.4 Desired Future Condition for Water Flow and Quality in Relation to Aquatic Ecosystem Health

Vision Statement: Aquatic ecosystem health is not impaired by water diversion or water quality degradation.

Under current conditions, tensions exist between human uses and aquatic ecosystem health. Redwood Creek and its tributaries provide water for the Muir Beach community and Green Gulch Farm; diversions and ground water pumping are believed to reduce summer low flow, an important limiting factor on native fish and amphibian species. Development and visitor use in the watershed also impacts water quality. Septic system use by much of the Muir Beach community likely affects water quality along lower Redwood Creek. Similarly, stormwater runoff and fertilizer and manure leachates from agricultural lands and livestock facilities may be negatively affecting water quality and aquatic ecosystem health. Climate change models indicate that the frequency and duration of extreme events, including droughts, can increase over the next 50 to 80 years (Cayan et al. 2006a); prolonged or more frequent drought will exacerbate tensions over the limited supply of water. This DFC sets a goal of resolving these tensions in such a way that aquatic ecosystem health will be protected.

Issue 9 Minimize effects of water withdrawal on fish populations

A recent study on the effects of water pumping on fish habitat and survival indicates that pumping during dry water years reduces surface water levels, sometimes below the stream bed surface, and increases the number of disconnected pools. These isolated pools tend to have lower dissolved oxygen concentrations than those upstream of the MBCSD pumping facility (Fong et al. 2007). The report concludes that dry year low flow conditions can result in a 10 percent reduction in watershed fish production (Fong et al. 2007).

Water is diverted directly from Redwood Creek and its tributaries by the MMWD, including from seven locations in the upper watershed, on Fern, Laguna, Spike Buck, and West Fork Rattlesnake creeks, although only the latter has been used in recent years (Johns 1993, PWA 1995, Martin 2000). Lower in the watershed, Green Gulch Farm has developed an elaborate system of reservoirs to store and divert flow from Green Gulch Creek and its tributaries. The Farm holds two appropriative water rights: one to an unused diversion on Redwood Creek in Big Lagoon, with an annual allocation of 47 acre-feet between April 15 and September 30; and the second for currently used diversions from Green Gulch and the unnamed tributary to its south for 17 acre-feet per year, with withdrawals limited to the period of November 1 to April 30 (Johns 1993). Thus, the Farm has appropriative water rights from the Redwood Creek watershed that total 64 acre-feet per year. Because the appropriative water rights that have not been used for over 5 years (unless by a municipality) are, in most cases, forfeited (Johns 1993), the unused 47 acre-feet per year withdrawal from lower Redwood Creek is likely defunct. However, this status needs to be confirmed by the SWRCB.

The greatest withdrawals from the main stem supply the Muir Beach community. The MBCSD supplies water to the Muir Beach community, serving approximately 350 people through 147 connections (Martin 2000). The MBCSD operates two wells on the Redwood Creek floodplain near the Banducci property, for which it has a permit from the SWRCB to withdraw up to 50.6 acre-feet per year (SWRCB 2001). Stream flows in Redwood Creek during the summer and fall are typically in the range of 0 to 1 cfs at the Highway 1 Bridge downstream of the MBCSD pumping facility. The permit includes terms and conditions for avoiding impacts to the creek, particularly during low flow. These terms and conditions include requirements to develop a water conservation plan, evaluate the feasibility of obtaining water from alternative sources, and evaluate the feasibility of increasing storage capacity in the system. In response to these terms and conditions, MBCSD increased storage capacity to 450,000 gallons through construction of a new water storage tank during summer 2010, and has explored alternatives for developing additional water storage capacity to protect instream flows during the low-flow period. Installation of an additional reservoir in lower Frank Valley, merging with the MMWD, and desalination are among a set of potential solutions that have been explored for ensuring domestic supplies without impacting fish habitat during low flow season. Implementation of any one or combination of these options will require access to additional external funding.

This issue has implications for other DFCs, including those described in Section 4.2.1, *Hydraulic and Geomorphic Function*, and Section 4.2.7, *Protection of Special-Status Plant and Animal Species*.

Selected Indicators

The objective would be to minimize the effects of water withdrawals on fish populations through one or a combination of: (1) reduced diversions (e.g., through conservation); (2) increased storage; and (3) alternative sources of supply (e.g., desalination). Several stages of funding would need to be secured to further investigate, develop, and implement one or several of these options. Actions to address this issue would include development and implementation of alternatives that would reduce or eliminate the need for late summer water withdrawals. Indicators that negative effects of withdrawals on fish reproduction and survival have been reduced would include increased flows during late summer, increased fish counts during low flow years along lower Redwood Creek, and increases in the connectivity and water quality (e.g., DO) of pools during the low flow period of dry water years.

Issue 10 Reduce vulnerability of lower Redwood Creek to additional water diversions

Water resources in the watershed have not been declared “fully appropriated” by the SWRCB, leaving the watershed vulnerable to future additional claims for water diversions. The residential community at Green Gulch Farm and Zen Center, which relies on diverted and stored water from the Green Gulch subwatershed, typically faces severe conservation measures during the late summer and fall months, adding to pressure to develop additional water resources. A study of all existing used and unused water rights in the watershed is needed to identify the degree of vulnerability of lower Redwood Creek to additional water diversions and/or ground water pumping.

This issue has implications for other DFCs, including those described in Section 4.2.1, *Hydraulic and Geomorphic Function*, and Section 4.2.7, *Protection of Special-Status Plant and Animal Species*.

Selected Indicators

A report detailing all existing used and unused water rights in the watershed and describing possible mechanisms for purchasing or securing unused water rights (e.g., official recognition by the SWRCB that specific water rights within the watershed left unused for over 5 years are in fact, forfeited) would indicate that the data gap has been filled. Removal of existing, unused water rights from the possibility of future out-of-channel use would indicate that lower Redwood Creek was no longer vulnerable to this threat.

Issue 11 Characterize and minimize negative water quality effects from stormwater runoff from parking lots and roads

Stormwater runoff from parking lots and roads can release ecologically harmful levels of contaminants (copper, polycyclic aromatic hydrocarbons [PAHs], petroleum) to downstream aquatic ecosystems. Past exceedances of U.S. Environmental Protection Agency-defined water quality parameters for dissolved copper levels in lower Redwood Creek may have had adverse effects on sensitive aquatic species. Although dissolved metal sources are unknown, copper is released from brake pads and can be a component of runoff from roads, driveways, and parking lots (Rosselot 2006). Contamination from stormwater runoff inputs can potentially escalate if visitor vehicle use increases in the future. Existing roads and parking lots have large impermeable surfaces that increase and concentrate water runoff to potentially erosive levels, increasing sediment loads and vectors of water contamination (e.g., copper, PAHs, petroleum) and trash. Such infrastructure frequently lacks catch basins and drains directly to intermittent or perennial streams. Buildings can magnify water runoff rates, particularly when located in areas with serious erosion problems, such as the Cameron House in Muir Woods. Lendvay and Benning report low copper and zinc levels collected at five locations in the watershed on nine dates during February through March in 2004 to 2006 (undetected below 0.17 µg/L copper and undetected below 1.22 mg/L zinc) (Lendvay and Benning 2006a and b). The Lendvay and Benning surveys did not focus specifically on stormwater runoff from parking lots and roads, and were not linked to storm events. No reports regarding contamination from runoff stormwater were identified in the review of historical data (Section 2.6, *Water Quality*); however, the anticipated increase in visitor use suggests the need for data regarding pollutant loads from parking lot and road runoff as well as the implementation of best management practices to control potential discharges.

This issue has implications for other DFCs, including those described in Section 4.2.1, *Hydraulic and Geomorphic Function*, and Section 4.2.7, *Protection of Special-Status Plant and Animal Species*.

Selected Indicators

The objective would be to fill a data gap of how stormwater runoff associated with developed areas affects water quality, and then to address deleterious sources by reducing/treating stormwater inputs. Indicators that the data gap has been filled would include the source of pollutants for which contaminant levels and frequencies exceeded regulations based on chemistry measurements from regularly collected stormwater runoff samples. Comparison of exceedance frequency (and actual levels) before and after implementing management responses would provide an objective means of assessing the success of those actions in reducing stormwater runoff pollution.

Issue 12 Quantify dissolved metal levels throughout the watershed

As discussed in Section 2.6, *Water Quality*, periodic exceedances of hardness-based water quality criteria (USEPA 2000b) for dissolved copper in lower Redwood Creek may have adverse effects on sensitive aquatic species (Stillwater Sciences 2005a). Potential sources of metals include: (1) catchment scale concentration of air-deposited metals (e.g., mercury, zinc) and many soil-borne metals in runoff; (2) leaching of copper used in stable operations at Golden Gate Dairy, (3) septic leachate from Muir Beach community, Green Gulch Farm and Zen Center, and individual dwellings in the upper watershed; (4) unknown metals contributions from the former Mill Valley Air Force Station and State Parks Gun Range; and (5) stormwater runoff associated copper released from brake pads. Whether these sources are contributing any significant quantities of metals to local watercourses or whether these sources are controllable is unknown. Heavy metals occur in aquatic systems in several phases, including dissolved in the water column or associated with sediment or organic colloids with differing availabilities to aquatic organisms. Heavy metals can move between these phases, based on changes in channel water pH, salinity, or redox potential (Bartenhagen et al. 2006).

This issue has implications for other DFCs, including those described in Section 4.2.1, *Hydraulic and Geomorphic Function*, and Section 4.2.7, *Protection of Special-Status Plant and Animal Species*.

Selected Indicators

The objective would be to fill a data gap associated with dissolved metals through systematic event-based sampling. Indicators that this data gap has been filled would include estimates on dissolved metal concentrations and the frequency with which each sampled location exceeded applicable water quality objectives. Particular locations and associated exceedance frequencies could be tracked and used as a means of targeting future actions found necessary to reduce metal concentrations. The effectiveness of any actions taken to reduce dissolved metals would be reflected by sub-threshold levels collected throughout the year, including during storm events.

Issue 13 Identify sources and reduce bacterial contamination of lower Redwood Creek and Muir Beach

Bacterial contamination periodically occurs along lower Redwood Creek and Muir Beach because of unidentified contamination sources; however, several studies have suggested that septic systems may be contributing. Periodic beach closures at Muir Beach by Marin County Department of Health and Human Services as well as analysis of historical data indicate reduced but continued bacterial contamination of lower Redwood Creek. In response to elevated coliform levels in water below Muir Woods during the period 1986–1988, the NPS began pumping effluent out of the watershed to Mill Valley for treatment (Auwaerter and Sears 2006). However, all other communities and facilities in the watershed rely on septic systems, which have the potential to affect water quality. Equestrian use along Redwood Creek trail, which includes two direct channel crossings, is an additional potentially important source of bacterial contamination.

Bacterial contamination has direct impacts on water contact-based recreation as well as potential impacts on domestic and municipal water supplies. Potential sources of bacteria include: (1) resident and migratory bird populations; (2) equestrian uses at Heather Horse Camp, Golden Gate Dairy, Green Gulch Farm and Zen Center, and along Redwood Creek trail; and (3) human septic sources from the Muir Beach community, Green Gulch Farm and Zen Center, and individual dwellings in the upper watershed. Although bacterial levels have been reduced in the lower Redwood Creek in recent years, contributions from these potential sources have not been thoroughly investigated for the development of potential control measures.

Selected Indicators

The objective would be to better understand bacterial contamination levels and frequencies along lower Redwood Creek, to identify sources, and then to reduce inputs from those identified sources. An indicator that these information gaps have been filled would include a map showing collection sites where exceedances were recorded, associated contributing areas, and likely or known contaminant sources. The effectiveness of any actions taken to reduce bacterial contamination would be reflected by sub-threshold levels measurements of total and fecal coliform collected according to the SFAN Fresh Water Quality Monitoring Protocol, described in SOP 6: Field methods for sampling fecal indicator bacteria (NPS 2005c).

Issue 14 Identify sources and reduce nutrient enrichment of lower Redwood Creek

Seasonal violations of ambient water quality criteria for dissolved oxygen have been regularly identified in lower Redwood Creek (Stillwater Sciences 2005a, Fong et al. 2007, Lendvay and Benning 2006a), with potential impacts on benthic macro-invertebrates and the fish community structure. Analysis of historical data (Section 2.6, *Water Quality*) indicates a gradient of increasing nutrient concentrations above regional reference levels from headwater reaches to Big Lagoon (see also Lendvay and Benning 2006a). Potential sources of nutrients include: (1) catchment scale concentration of air- and soil-borne nutrients in runoff; (2) local fertilizer and septic leachate from Muir Beach community, Green Gulch Farm and Zen Center, and individual dwellings in the upper watershed; and (3) farm animals maintained at Heather Horse Camp, Golden Gate Dairy, and Green Gulch Farm. Although nutrient levels have been reduced in the lower Redwood Creek in recent years, they remain high. Although high phosphorous and total suspended solids (TSS) have been observed in Redwood Creek (Lendvay and Benning 2006a), the upper reaches of the creek are believed to be nitrogen limited whereas lower reaches are phosphorous limited (see Section 2.6.3, *Comparisons of Water Quality Data with Applicable Criteria*). Therefore, the focus of water quality sampling needs to be on nitrogen in the upper reaches and phosphorous in the lower reaches (Cooprider 2004). As with sources of bacterial contamination, contributions from these potential sources have not been thoroughly investigated, but such studies are needed to support development of control measures.

Selected Indicators

The objective would be to fill a data gap on nutrient enrichment and nutrient sources of lower Redwood Creek, and then to reduce inputs from those identified sources. An indicator that these information gaps have been filled would include water quality monitoring reports that reveal the season, associated event characteristics, and location of water quality exceedances. These data would be useful in pinpointing likely nutrient sources. Indicators that lower Redwood Creek was no longer experiencing nutrient enrichment would include measures of total nitrogen, nitrate, orthophosphorous, and dissolved oxygen that were consistently below (or above, in the case of dissolved oxygen) threshold levels. Findings from the benthic invertebrate surveys would be expected to corroborate nutrient quality measures, but could also reveal points along stream reaches where the BMI food quality abruptly changed, thus indicating downstream alterations in water quality.

4.2.5 Desired Future Condition for Native Plant Community Health

Vision Statement: Native plant communities are healthy and comprise a mosaic of diverse cover types, including native grasslands, chaparral, riparian woodland, hardwood and redwood forests, and wetlands.

The Redwood Creek watershed hosts ancient redwood forests, native perennial and annual grasslands, coastal wetlands, native riparian communities, oak woodland, serpentine chaparral and other serpentine communities, and Douglas-fir forests. Muir Woods is highly valued around the world for its ancient redwoods. This DFC emphasizes the importance of protecting and maintaining the health of Muir Woods as well as the surrounding native plant communities. This DFC also addresses the importance of maintaining healthy native plant communities throughout the landscape because the health of each plant community can affect adjacent and/or downstream plant communities by acting as vectors or reservoirs of invasive non-native, pathogens, or increasing high intensity wildfire hazard in adjacent areas. Birds and wildlife also move among plant community types, so that a landscape of healthy native plant communities provides superior habitat than one that is fragmented and occupied by non-native plants.

Existing challenges to achieving this DFC include balancing the positive ecological effects of restoring natural disturbance regimes with the potential negative effects on transportation and adjacent lands fire hazard. SOD and other unknown future diseases pose the challenge of protecting native plant communities from diseases that are not known or well understood. Similarly, long-standing as well as recently introduced non-native invasive plant species can affect plant community composition, dynamics, and ecosystem processes (such as nutrient cycling and availability). Managing for an ever-changing set of invasive non-native plant species requires vigilance, resources, and labor. Climate change model projections for California indicate a warmer and more variable climate for the rest of this century and beyond (Cayan et al. 2006a). These changes in climate are likely to create stressful habitat conditions for some native species currently existing near the edge of their preferred habitat and call for increasing biodiversity, redundancy in plant communities, and for building rare populations so that they can withstand periodic stresses.

Issue 15 Allow for regeneration and natural disturbance regimes in Muir Woods and other redwood forests in watershed

Redwood forests occur in Muir Woods, the upper reaches of Redwood Creek (along Fern, Rattlesnake, and Spikebuck Creeks), and along Kent Creek (see Figures ES-1 and 2-30). Fire is a key natural disturbance in the coastal alluvial redwood forest. Frequent, low intensity fires were maintained by Native Americans (20–30 year intervals). Since Euro-American settlement, historic fire regimes have changed in Muir Woods and the other redwood forests in the watershed, with the most recent major wildfire in the watershed over 150 years ago (Hall 2008; GGNRA 2005). Although noticeable effects on plant community composition and structure have not been measured in the redwoods, likely resulting from the longevity of the dominant species, suspension of frequent, low intensity fires can lead to increased vulnerability to pests and disease (such as fungal pathogens), and a reduction in mineral soil for redwood germination. The Park Service has experimented with introducing some controlled burns to Muir Woods. This might be particularly important with the increase in lower and mid-canopy fuels caused by SOD.

Some of the largest known redwood forests occur on alluvial flats where flooding is frequent. Like fire, flooding creates bare mineral soil surfaces where redwoods and other light-seeded species can germinate.

Flooding of the alluvial flat also increases the exchange of plant propagules and nutrients between the channel and forest, which in turn increases riparian plant community diversity and structure. The flood frequency of Redwood Creek through Muir Woods is believed to be lower than the pre-Euro-American contact flood regime.

This issue has implications for other DFCs, including those described in Section 4.2.1, *Hydraulic and Geomorphic Function*, Section 4.2.6, *Non-Native Plant and Animal Species*, and Section 4.2.7, *Protection of Special-Status Plant and Animal Species*.

Selected Indicators

Direct indicators that natural disturbance regimes have been restored to Muir Woods and to other redwood forests in the watershed would be an increase in fire frequency to pre-Euro-American settlement (20- to 30-year recurrence interval) (McBride and Jacobs 1978), or to the pre-native American period (135- to 350-year recurrence interval) (Greenlee and Langenheim 1990). Similarly, an indicator that the alluvial flats in Muir Woods and elsewhere in the watershed have been reconnected to the channel would be increased floodplain inundation extent and frequency.

Issue 16 Determine baseline structure and composition of Muir Woods

Muir Woods is an iconic stand of old growth coastal redwoods, enjoyed by millions of visitors each year; earlier studies of the structure and composition of Muir Woods need to be updated and expanded to cover more of the forest, so that a baseline on the composition and structure of this forest can be established from which to identify responses to stressors such as climate change, SOD, human disturbance, and non-native species invasions. This baseline is essential for early detection of changes in the rate and distribution of redwood regeneration, recruitment, encroachment of the redwood forest by adjacent Douglas fir stands, effects of SOD on understory composition and structure, effects of new diseases on plant species, and the changes in the distribution and character of snags and log.

This issue has implications for other DFCs, including those described in Section 4.2.7, *Protection of Special-Status Plant and Animal Species*, and Section 4.2.8, *Native Wildlife Populations and Habitat*.

Selected Indicators

Indication that this issue has been addressed would include completion of a survey of the stand structure and composition, including understory, logs and snags, of Muir Woods ancient redwoods as well as adjacent Douglas fir stands.

Issue 17 Characterize and minimize Sudden Oak Death effects on plant community composition and structure

Changes in the forest canopy structure because of the die-off of tan oak (*Lithocarpus densiflorus*) and other affected tree and shrub species from SOD is creating openings in the forest canopy that may increase the risk of Douglas-fir encroachment and non-native plant invasion into Muir Woods. SOD was first observed in Muir Woods in 1995, primarily affecting tan oak. However, SOD also is hosted by understory and shrub species native to redwood forests, such as huckleberry, madrone, bigleaf maple, toyon, California coffeeberry, and California buckeye (Rizzo and Garbelotto 2003). California bay is subject to foliar infection by SOD, and thereby becomes a local source of infection and can spread by releasing SOD spores from infected leaves (Rizzo and Garbelotto 2003).

Demise of tan oak in the sub-canopy and replacement by other species, such as redwood and/or California bay, will affect litter quality and decomposition rates, possibly resulting in cascading effects on nutrient cycling and availability (Cobb et al. 2008). The progression of SOD in Muir Woods also has implications for changes to wildlife habitat. For example, the die-off of tree and shrub species because of SOD is occurring throughout Northern spotted owl habitat in Marin County, which may have long-term impacts on nesting habitat and prey populations in the region (Adams et al. 2004). Similarly, the increase in dead foliage, branches, and trees associated with the large scale loss of tan oaks and other affected species is increasing fuel levels. In the case of tan oak, dead standing trees create ladder fuels that can connect ground fires to the mid and upper canopy, increasing fire severity (Sugihara et al. 2006). Such changes in fuel levels and distribution can affect fire behavior, favoring high intensity over low intensity burns (Sugihara et al. 2006). The effects of SOD on plant community composition and structure, as well as its effects on wildlife, represent existing data gaps.

SOD can spread easily from infected to uninfected areas, causing more damage to plant and animal communities. The current rate and methods of spread of SOD from the valley floor in Muir Woods to other parts of the watershed are unknown. Under moist conditions, SOD spores can be spread on the soles of shoes, tires, and other implements, making trails, roads and other work locations areas likely avenues of spread to uninfected stands. Muir Woods has worked with the California Oak Mortality Task Force to identify the extent of SOD throughout Muir Woods and to install infrastructure (e.g., boot washing stations) and public outreach, necessary to minimize the spread of SOD from Muir Woods to uninfected areas (Hall 2008).

This issue has implications for other DFCs, including those described in Section 4.2.3, *Infrastructure*, Section 4.2.7, *Protection of Special-Status Animals and Plants*, and Section 4.2.8, *Native Wildlife Populations and Habitat.*

Selected Indicators

The objective would be to fill data gaps on the effects of SOD on plant community structure and composition and ecosystem processes, and to take actions that effectively minimize the effects of SOD on the existing native plant communities. A report that presents information on SOD-induced changes in stand structure and composition in infected areas in the Redwood Creek watershed, and that presents findings on the effects of SOD on potential fire behavior, would be needed to fill these data gaps. Following these studies, actions to reduce or minimize the effects would be needed. Ultimately, reduced or minimized effects of SOD on plant community composition, structure, and fuel loading, as measured during through field monitoring (e.g., every 5 years) would be the best indicator of the efficacy of the research and subsequent management actions.

Issue 18 Slow or reverse conversion of native grasslands to shrub-dominated plant communities

Qualitative and quantitative observations of vegetation composition in the Redwood Creek watershed have indicated a sharp reduction in area occupied by grassland and an increase in shrub-dominated plant communities relative to historical conditions (MMWD 1995; Bicknell et al. 1993). Relative to pre-Euro-American conditions, less than 1 percent of California’s native grassland are estimated to remain intact (Barry 1972; Jones & Stokes 1987, as cited in Schoenherr 1992; Barbour et al. 1998). The increased human development in the watershed and resulting change to the fire regime in favor of suppression (which alters successional processes), the decrease in grazing (grazing maintains/promotes open areas for forage), and the increase in invasion of native grasslands by non-native invasive species are all factors likely contributing to the loss of historical grassland area and changes in species composition. Lack of information on the current extent, location, and condition of native grasslands in the watershed limits the ability of resource managers to adequately assess current conditions, prioritize areas for management, develop appropriate management actions, and implement strategic monitoring.

Known methods to protect native grasslands from conversion to annual grasslands and shrub-dominated communities involve prescribed burns. Fall burning can favor native purple needlegrass (*Nasella pulchra*; Bartolome and Gemmill 1981) and has been shown to slow invasion of coyote brush (*Baccharis pilularis*) (McBride and Heady 1968 and McBride 1974). Burning within the first 3 weeks following the first fall rains can destroy germinating annual grasses and forbs, thereby reducing competition for native perennials (Bartolome 1979, Bartolome 1984). A controlled burn program that favors native grasslands is part of the GGNRA *Fire Management Plan* (GGNRA 2008). Marin County and the MMWD also have fire management plans that incorporate prescribed burns; however, these institutions focus application of prescribed burns on invasive species control (French and Scotch broom) along roadways (Marin County Fire Department 2005, Leonard Charles & Associates and Wildland Resource Management 2008).

This issue has implications for other DFCs, including those described in Section 4.2.7, *Protection of Special-Status Animals and Plants*, and Section 4.2.8, *Native Wildlife Populations and Habitat*.

Selected Indicators

The objective would be to fill data gaps on the extent of existing native grasslands in the watershed and to use adaptive management with monitoring to identify the specific and most appropriate methods for protecting native grasslands. Indicators that these data gaps have been filled would include basin-wide maps based on field surveys of native versus non-native grasslands, and of woody species encroachment on pre-existing and existing grasslands. Similarly, documentation of plant community response to various types of control methods, including various types and timing for prescribed burns, would indicate that adaptive management and monitoring strategies were being used to develop optimal methodologies. Finally, indicators of the effectiveness of actions taken to protect native grasslands would include maps based on field surveys linked with photo-interpretation, showing that the extent and health of native grasslands was constant or increasing over time (2 to 10 or more years).

Issue 19 Characterize extent of and threats to native serpentine and dune communities and species

Coastal dune communities at Muir Beach support a few common native dune species but are sparse because of trampling and domination by non-native dune species such as European sea rocket (*Cakile maritime*), ice plant (e.g., *Carpobrotus edulis*), kikuyu grass (*Pennisetum clandestinum*), and ripgut brome (*Bromus diandrus*). These invasive non-native species and the extensive trampling from beach visitors need to be addressed through the ongoing restoration project for lower Redwood Creek at Muir Beach. Recommendations for rehabilitating native beach and dune plant communities at Muir Beach and for controlling both non-native invasive plants and human trampling there have been proposed (Baye 2008). Some of these recommendations have been adopted by GGNRA and are planned for implementation in 2011 (Friedel 2009). Current GGNRA revegetation plans include more robust protection of incipient foredunes, located on the beach side of the existing willow thickets west of the lagoon, removal of Kikuyu grass, and active planting of native beach species, including yellow sand-verbana (*Abronia latifolia*), beach-bur (*Ambrosia chamissonis*), and Pacific dune grass (*Leymus mollis*) (Friedel 2009). GGNRA plans also call for reintroduction of a locally extirpated beach species, pink sand verbena (*Abronia umbellata*).

Serpentine soils are characterized by high levels of exchangeable magnesium and low levels of calcium; they are usually deficient in primary nutrients and often have high amounts of iron and nickel (Kruckeberg 1984). Because of the limited available nutrients and high amounts of heavy metals, plant species native to serpentine soils often are uniquely adapted and have high rates of endemism. On the upper slopes of the Redwood Creek watershed and in other areas of Mount Tamalpais, serpentine grasslands are some of the few grasslands still dominated by native perennial grass species.

Several areas of serpentine chaparral have been mapped by the MMWD in the upper reaches of the watershed (Figure 2-30). These communities often are dominated by dwarfed leather oak (*Quercus durata*), Jepson's ceanothus (*Ceanothus jepsonii*), and Mount Tamalpais manzanita (*Arctostaphylos hookeri* ssp. *montana*). Other CNPS-listed species include the Mount Tamalpais thistle (*Cirsium hydrophilum* var. *vaseyi*), found in serpentine seeps along the west side of the upper watershed; Carlotta Hall's lace fern (*Aspidotis carlotta-halliae*); Oakland mariposa lily (*Calochortus umbellatus*); Tiburon buckwheat (*Eriogonum luteolum* var. *caninum*); Marin County navarretia (*Sidalcea hickmanii* ssp. *viridis*); Marin checkerbloom (*Streptanthus glandulosus* ssp. *pulchellus*); and Mount Tamalpais bristly jewel-flower (*Streptanthus batrachopus*). Special-status plant surveys along roads and trails have been performed in the serpentine areas by the MMWD and less formally by interested citizens that report their sitings through the California Native Plant Society Inventory of Rare and Endangered Plants (CNPS 2009).

Threats to these species include competition with non-native invasive species such as French broom and European annual grasses, control of non-native species through prescribed burns, and human trampling. In addition, responses of native serpentine species to the projected changes in climatic conditions for Redwood Creek are unknown. The MMWD and Mount Tamalpais State Park, in partnership with the Marin Chapter of the CNPS, monitor several patches of serpentine chaparral and grassland in the upper reaches of the Redwood Creek watershed. However, many of these areas are in close proximity to hiking trails, introducing invasive non-native plant species as well as trampling impacts to the native serpentine communities.

Selected Indicators

Rehabilitation of native dune communities is underway at Muir Beach (Friedel 2009). Monitoring and adaptive management will be critical in the coming 5 to 10 years, to ensure that these efforts are successful. Indicators of success would include: (1) healthy native foredune vegetation that is protected from trampling; (2) multiple self-sustaining populations of pink sand verbena; and (3) relative percent cover of invasive non-native vegetation that is kept below a prescribed threshold.

Indicators of successful management of serpentine plant communities would be spatially explicit records of the extent, location, and health of all existing native serpentine grassland and chaparral communities and target species in the watershed that were updated every 2–3 years through a regular monitoring program. Based on these monitoring efforts, the ultimate indication of successful management of this issue would be steady and/or increasing populations of serpentine plant species in the upper reaches of the Redwood Creek watershed and other areas of Mt. Tamalpais. A second critical indicator would be that areas known to be degraded would exhibit increases in native species cover and diversity over the 2- to 3-year monitoring periods.

4.2.6 Desired Future Condition for Non-Native Species Effects and Native Habitat

Vision Statement: Invasion by and the adverse effects of non-native plant and animal species on the ecosystem are reduced or reversed, and imperiled habitats are restored.

The introduction, dispersal, and spread of non-native species are of central importance to the management of Redwood Creek watershed because of impacts on native species and ecological processes. Most invasive, non-native plant species are found only in disturbed areas near roads, fuel breaks, buildings, utility lines, and along trails. However, some of these species are able to out-compete native vegetation in essentially undisturbed habitats. These species require greater attention to prevent their establishment and dispersal, which can often be directly associated with visitors and residents. For example, the seeds from non-native plants can be introduced from visitors through attachment to footwear, horses, vehicles, or equipment. Non-native invasive species planted at residences also can disperse to adjacent protected lands. Once introduced, the seeds of these species can spread along road and trail corridors by humans or natural forces, including wind, water, and wildlife.

Invasive non-native plant species out-compete native plant species, simplify plant community composition and structure, affect soil nutrient dynamics, and reduce habitat diversity (D’Antonio and Hobbie 2005, Brooks et al. 2004, and Corbin and D’Antonio 2004). In particular, invasive exotic plant species can affect large alterations on the riparian plant community. For example, cape ivy has contributed to an estimated 33 percent loss in shrub and herb species in the riparian corridor along the Redwood Creek watershed (Scoggin et al. 2000). These understory riparian plants are important for nesting riparian birds in the watershed. Introduction of non-native animals is perhaps of lesser concern in the watershed but can be associated with the release of unwanted pets, live fishing bait, or insects carried on vehicles, within building materials, or on landscaping plants. The following issues related to the increase in non-native species were identified.

Issue 20 Limit introduction and spread of invasive plant species through systematic monitoring and public outreach

Invasive plant species are introduced to the watershed from many avenues and, once established, can spread rapidly along transportation or riparian corridors. Continuing land development and vegetation management practices, primarily in the three private settlement communities, are likely removing or converting native vegetation to non-native lawns, gardens, and woody plants. Non-native invasive species (such as forget-me-not) can escape from these developed areas into adjacent lands that support native communities. In addition, invasive species often are found along transportation corridors, including trails and alongside stream channels. Seeds and propagules of invasive non-native species are carried into uninfected areas via hikers and pets (dogs, horses) along trail corridors and enter the riparian corridors with hikers, via water borne propagules, and by adjacent land disturbance. Public outreach and education could reduce invasive species introductions along trails, roads, and from lawns and gardens by encouraging visitors and land owners to minimize the spread of these species through such actions as planting native gardens and cleaning seeds from footwear and clothes before entering new areas.

Within the upper reaches of the watershed, French broom, and to a lesser extent Scotch and Spanish broom (*Cytisus scoparius* and *Spartinum junceum*), have invaded scrub and grasslands and areas of frequent soil disturbance, such as trails and road sides. French broom has not yet become established in Muir Woods, but it is approaching the National Monument by way of Muir Woods Road (Baxter, pers. comm., 2008, as cited in Hall 2008). Yellow starthistle occurs in Camino del Canon (Hall 2008 draft), but has yet to spread farther. In the future, other invasive exotic species are likely to appear in the watershed.

Panic veldt grass (*Erhata erecta*) is a shade tolerant, fast growing species that has recently become established in the watershed and is spreading along the riparian corridors. With new invasive species being continually introduced and established species spreading, a monitoring program is critical for detecting new and for tracking established invasive species so that a control program is based on the best available information. Several monitoring efforts have occurred in the watershed under the auspices of the MMWD and the NPS. In 1999, the NPS and the MMWD inventoried and mapped the distribution of non-native invasive plant species in the watershed. Through the Golden Gate Weed Watchers program (coordinated by the NPS), many invasive species on NPS lands in the watershed are now mapped and managed, using the methods from *Early Detection of Invasive Plant Species in the San Francisco Bay Area Network A Volunteer-Based Approach* (Williams and Speith 2008). A regular, ongoing monitoring program is needed (in coordination with the Weed Watchers) for non-NPS lands in the watershed.

This issue has implications for other DFCs, including those described in Section 4.2.5, *Native Plant Community Health*, Section 4.2.7, *Protection of Special-Status Animals and Plants*, and Section 4.2.8, *Native Wildlife Populations and Habitat.*

Selected Indicators

Indicators that invasive non-native plant species introductions and spread in the watershed are known and priority control actions identified based on sufficient information would include field survey-based maps, produced on a regular basis (e.g., updated annually), with priority plant and target areas also updated at least annually. In addition, reduced frequency of invasive exotic escapes and introductions along trails and roads and from the three developed areas into adjacent lands would indicate the success of public outreach and education actions.

Issue 21 Improve invasive non-native plant species control and eradication

Controlling invasive species can involve unexpected complications. Ironically, vegetation removal and management around buildings, roads, parking lots, recreation facilities, and trails can sometimes contribute to the disturbance of native vegetation or the displacement of native communities. In addition, the most effective control methods often require herbicide application, which can negatively affect fish and wildlife. Prescribed burns and herbicide applications have been used to manage French and Scotch broom in the upper reaches of the watershed, where such efforts can threaten special-status serpentine plant species. Coordination among resource managers is needed to ensure that all weed control activities have minimal effects on other resources.

Control and eradication efforts are often labor-intensive, expensive, and require long-term efforts. Because of the large number of invasive species in the watershed, priority must be given to those invasive species that pose the greatest threat. For example, concerted efforts to mechanically control and remove cape ivy from areas at the Banducci property and in Camino del Canon in the late 1990s were successful but expensive, and they require ongoing efforts to maintain. Efforts to control other invasive exotics in Muir Woods, including forget-me-not (*Myosotis latifolia*) also have been successful, but they are very labor-intensive. Coordination among land managers in the watershed will help to increase efficient use of resources for weed control.

Panic veldtgrass is a relatively new invasive species in the watershed that can spread very rapidly through wind-borne seeds (Frey 2005), creating dense monocultures. Staff members at Muir Woods are currently experimenting with physical, chemical, and fire-control treatments for panic veldtgrass (Baxter, pers. comm., 2008, as cited by Hall 2008). New invasive non-native species will continue to appear in the watershed, particularly as the climate changes and plant species ranges extend into new areas. Because control techniques need to be tailored to the natural history and other ecological constraints associated with each species, free exchange of “lessons learned” and other information on weed control can expedite new control efforts. Coordination among land managers within the watershed will allow for greater information exchange regarding new treatment techniques.

Selected Indicators

Indicators that increased coordination and communication is occurring among land managers in the watershed regarding invasive plant species control could include a common set of control and eradication methods, reduced conflicts and concerns regarding negative effects of control actions on other resources, and an increased number and extent of inter-agency coordinated weed control projects.

Issue 22 Minimize impacts of non-native animals and native “pest” species on native species

Non-native animals and pest species have the potential to threaten visitor safety or negatively affect other native species because of their unnaturally large population sizes. Non-native animals such as turkeys and Chukar partridges (*Alectoris chukar*) have been introduced as game birds, and an interest exists in reducing or removing these species. Because of human-induced changes in wildlife habitats and human food sources, some native animals, such as raccoons and birds (e.g., ravens, crows, and jays) can become more prevalent.

This issue has implications for other DFCs, including those described in Section 4.2.7, *Protection of Special-Status Animals and Plants*, and Section 4.2.8, *Native Wildlife Populations and Habitat*, and DFCs that address visitor experience.

Selected Indicators

Indicators of successful management of this issue would be declining numbers of non-native pest animal species, based on regularly performed (e.g., every 2–5 years) bird and wildlife surveys, and a reduction of reported conflicts between non-native pest species and humans.

4.2.7 Desired Future Condition for Protection of Special-Status Animals and Plants

Vision Statement: Special-status and locally rare plant and animal species are protected and, where appropriate, their populations are expanded.

The ancient redwoods, surrounding Douglas-fir forests, and Redwood Creek itself support special-status birds, amphibians, and fish. This DFC emphasizes the importance of protecting and possibly expanding these populations in the watershed. The greatest defense against the negative effects of climate change is to build and support native populations so that they are large and diverse enough to rebound from temporary losses associated with extreme events. Management actions must reflect an integrated view of geomorphic, hydraulic, and plant community processes that support the habitat needs of each species.

Issue 23 Increase amount of winter refugia for rearing coho salmon and steelhead

Reduced LWD frequency, aquatic habitat complexity, and floodplain connectivity in the watershed have likely diminished the amount of winter refuge habitat for rearing coho salmon and steelhead. Smith (2000) stated that a lack of overwintering habitat may be one of the most important factors limiting salmonid production in wet years with high winter flows. Historical land uses have caused sediment deposition in Redwood Creek, reducing the amount of pool habitat and complexity used for rearing by juvenile coho salmon and steelhead. Reduced complexity/pool spacing downstream of Muir Woods also is thought to have resulted from historical NPS practices of regularly removing wood from the creek (PWA 2000), which has now been discontinued. Lack of available habitat is especially acute in dry years, when consumptive water withdrawals potentially further reduce the naturally low stream levels (Smith 2000, Reichmuth et al. 2006a; Fong et al. 2007). As a way to restore complexity and reestablish connectivity to the floodplain, wood has been added to the creek in two phases of engineered log jams on the Banducci property in Frank Valley (Kamman Hydrology & Engineering 2006). Initial indications are that this activity has produced the desired results. However, this assessment is largely qualitative and, therefore, subjective. One of the goals of the ongoing restoration of lower Redwood Creek, implementation of which began in August 2009, is to increase winter refuge for Coho and steelhead.

This issue has implications for other DFCs, including those described in Sections 4.2.1, *Geomorphic and Hydraulic Processes*, and Section 4.2.4, *Water Flow and Quality in Relation to Aquatic Ecosystem Health.*

Selected Indicators

The objective would be to increase high quality winter refugia for coho and steelhead. Therefore, an indicator of successful management of this issue would be an increase of such habitat, supported by field survey and mapping efforts on fish habitat, fish use, instream LWD, and LWD sources based on field surveys. Specific metrics on fish habitat quality and distribution in the watershed would include: (1) reach-wide estimates of suitable fish rearing area; (2) trend monitoring of fish use by habitat type (e.g., run, riffle, pool); (3) instream LWD frequency and LWD source assessment per stream reach; and (4) analysis of pool frequency per channel length. The effectiveness of these surveys and management responses could be measured by the change in the quantity and quality of rearing habitat and refugia for juvenile coho salmon and steelhead. Because the restoration of lower Redwood Creek includes addition of a substantial amount of winter refugia, these areas would need monitoring to ensure that the project was having positive and significant effects.

Issue 24 Survey and increase if necessary suitable habitat for listed butterfly species

A preliminary survey for the federally endangered Myrtle’s silverspot butterfly was conducted in 1992, but no individuals were observed; similarly, surveys for the federally endangered Mission blue butterfly were conducted in 1984 and 1985, but no individuals were observed. Myrtle’s silverspot butterfly occurs in coastal dune, scrub, and grassland areas, and this butterfly lays eggs on species of violet (*Viola adunca*), for which only four known populations occur, all in Marin and Sonoma counties. None are known to exist in the Redwood Creek watershed; however, potential habitat may occur there. GGNRA mapped and modeled potential Mission blue butterfly habitat in 2004, corresponding with the occurrence of lupine host plants in the Redwood Creek watershed, but why the species does not occur in these areas is unknown. An NPS (2003) report indicates that blue butterflies located in Oakwood Valley (outside and to the southeast of the Redwood Creek watershed) contained a large percentage of the Mission blue subspecies, the northernmost population known. Further surveys on these and other listed terrestrial invertebrate species may help provide potential habitat associations and lead to appropriate conservation measures.

Conversion of native grasslands to non-native grasses, as well as to scrub and chaparral, may have reduced availability of suitable habitat for these listed butterflies. These changes in the vegetative landscape may reduce abundance of larval host plants and native nectar sources. Illegal collecting of butterflies in the watershed poses another potential threat to these species.

This issue has implications for other DFCs, including those described in Section 4.2.5, *Native Plant Community Health*.

Selected Indicators

Presence of Mission blue butterfly and Myrtle's silverspot butterfly in the watershed would be an indicator of successful management practices aimed at restoring habitat for the species. However, because factors other than habitat availability could prevent repopulation of an area, indicators that habitat has been restored, based on habitat extent and quality for each of the butterfly species, should be used. Such indicators would be based on field surveys and mapping of the extent and native plant species composition of appropriate habitat for each species, including lupine for the Mission blue, and coastal dune, scrub, and grasslands supporting violet species for the Myrtle's silverspot.

Issue 25 Increase California red-legged frog breeding areas and consider reintroduction of foothill yellow-legged frog in watershed

California red-legged frogs have been recorded in the wetland complex near the mouth of Redwood Creek, which is currently comprised of both perennial and seasonal wetlands (Ely 1993, Fong 2000, Fellers and Guscio 2004). California red-legged frogs have not been documented in the mainstem of Redwood Creek, though frogs may use it for summer refuge and as a movement corridor. One frog was documented in the lower reach of Green Gulch Creek (Fellers and Guscio 2004).

Past flood management, land use, and water use practices have lowered the water table in the lower portion of Redwood Creek, preventing tadpoles from metamorphosing because of breeding areas drying up either too quickly in the spring, or altogether. A freshwater wetland is part of the current restoration project for lower Redwood Creek at Muir Beach (Moffatt & Nichol and Jeff Anderson & Associates 2009), and successful implementation of this plan may save red-legged frogs from local extirpation (Fellers and Guscio 2004). Balancing flood control with habitat protection and restoration objectives remains a substantial management challenge for the Redwood Creek watershed. Other issues pertaining to California red-legged frog in the watershed may include nearby pond management practices that preclude breeding, invasion of non-native predators, and water quality degradation. Maintained water quality and prevention of water quality degradation from nearby human activities will go hand in hand with habitat protection.

Foothill yellow-legged frog is a California Species of Special Concern that was historically present in the upper mainstem and tributaries of Redwood Creek (Ely 1993, Fong 1997). Although suitable habitat, such as slow-moving sections of streams with cobble and gravel substrates, exists for this species along Redwood Creek, no individuals have been found during survey efforts over the past 15 years (Ely 1993). Reintroduction of any species must be carefully considered, particularly in regards to potential spread of diseases, genetic diversity, and meta-populations (Germano and Bishop 2009). Any plans for reintroducing Foothill yellow-legged frog to the Redwood Creek watershed will need to be based on well-informed consideration of these broader ecological issues.

This issue has implications for other DFCs, including those described in Section 4.2.1, *Geomorphic and Hydraulic Processes*, Section 4.2.2, *Erosion Effects on Fish Habitat*, and Section 4.2.4, *Water Flow and Quality in Relation to Aquatic Ecosystem Health.*

Selected Indicators

The main indicator of successful management for California red-legged frog in the watershed would be to observe an increase in the red-legged frog population in the wetland complex near the mouth of Redwood Creek at Muir Beach to stable numbers, including a sufficient representation of all age classes. Another indicator might be an increase in availability of suitable breeding habitat, non-breeding habitat, and movement corridors, along with protection of ample buffers to help protect these areas. Protected dispersal corridors would help provide a pathway to allow gene flow with nearby populations.

Indicators for progress regarding Foothill yellow-legged frog would be a series of studies that would provide a sound basis for assessing the possible risks and benefits associated with a reintroduction program in Redwood Creek. An indicator of success for both frog species would be the continued absence of bullfrogs, and exclusion of other non-native predators, such as non-native warm water fishes and crayfish from lower Redwood Creek.

Issue 26 Characterize and address potential long-term negative threats to local northern spotted owl population

The southern limit of the northern spotted owl range occurs in coastal California, just north of San Francisco Bay in Marin County. The Marin County population is isolated, both geographically and genetically, from populations farther north (Adams et al. 2004; Barrowclough et al. 2005, Henke et al. 2003; both as cited in Jensen et al. 2006). Given the low rates of dispersal from more northerly populations, potential threats to the productivity and survivorship of the local population include threats to habitat through urban development along open space boundaries, disturbance caused by recreational activities, hazardous wildland fuel management practices and potential for catastrophic wildfires along the urban/wildland interface, and habitat alterations caused by SOD. The population is further threatened by displacement resulting from continued range expansion of the barred owl and susceptibility to West Nile Virus (WNV).

In its updated *Revised Recovery Plan for the Northern Spotted Owl*, the USFWS considers competition from barred owls as posing a significant threat to the northern spotted owl (USFWS 2011). Barred owls are slightly larger than northern spotted owls and occupy similar habitat, although barred owls exhibit more flexible habitat-selection patterns (Dark et al. 1998), which give barred owls a slight competitive edge. Barred owls first appeared in California after 1970, and quickly expanded their range (Dark et al. 1998). Barred owls have been detected at Muir Woods each year since 2003 (Adams et al. 2004), including the first documented barred owl pair in Marin County in August 2005 (Jensen et al. 2006). Barred owls were confirmed to have nested in Muir Woods in 2007 through observation of adults with recently fledged young (Merkle, pers. comm. 2011). In addition to concerns about displacement, barred owls have been known to hybridize with northern spotted owls, albeit infrequently. The potential for hybridization with barred owls has direct implications for spotted owl reproductive success and population dynamics (Dark et al. 1998). Indirectly, hybridization can affect the northern spotted owl conservation status because hybrids are not covered under the federal Endangered Species Act.

As described previously, SOD affects several oak, tan oak and shrub species throughout northern spotted owl habitat in Marin County (Jensen et al. 2006). Continued loss of oaks because of SOD could directly affect nesting habitat for northern spotted owls as well as indirectly impacting the habitat of their primary prey species in Marin County, the dusky-footed woodrat (Jensen et al. 2006).

WNV has been confirmed in fourteen birds in Marin County (Jensen et al. 2006). Although no record exists for northern spotted owl mortality resulting from WNV in Marin County, the virus is known to be lethal to northern spotted owls (Jensen et al. 2006).

This issue has implications for other DFCs, including those described in Section 4.2.5, *Native Plant Community Health*, and possibly DFCs related to visitor experience (e.g., visitor disturbance of spotted owls).

Selected Indicators

Increased productivity and survivorship of northern spotted owls in the watershed, based on regular field monitoring, would be the key indicators of successful management for northern spotted owls. Annual monitoring of Redwood Creek northern spotted owl populations would help identify trends in species abundance, distribution, and reproductive success. Ideally, annual monitoring would also help determine trends in survivorship by color banding individual owls. Information regarding causes of mortality may be gleaned from opportunistically submitting carcasses for testing. An ambitious monitoring plan would include assessing northern spotted owl populations in surrounding Marin parklands to determine statistical trends in the watershed. Annual monitoring of barred owls should be coupled with observations of northern spotted owl and barred owl interactions, to evaluate the potential threat posed by barred owls. Additionally, mapping roosting, breeding, and foraging habitat quality and extent, and modeling future conditions would indicate whether sufficient habitat existed that could support the local northern spotted owl population, including the presence of a sufficient prey base.

Issue 27 Assess and enhance conditions for native bat populations in the watershed

At least twelve species of bats occur or are expected to occur in the Redwood Creek watershed (Heady and Frick 2004). Of these, three are California Species of Special concern: western red bat, Townsend’s big-eared bat, and pallid bat. Additionally, five species are listed as “High Priority” for conservation in this region by the Western Bat Working Group (http://wbwg.org/species_matrix/spp_matrix.pdf): fringed myotis (*Myotis thysanodes*), long-legged myotis (*Myotis volans*), western red bat, Townsend’s big-eared bat, and pallid bat. Each species is associated with different roosting and foraging habitats, ranging from tree and rock crevices to caves, mines, bridges, and buildings. Roosting and foraging habitat for bats is particularly abundant in Muir Woods because old growth redwoods provide roosting habitat in the form of hollows and bark crevices (Heady and Frick 2004). Foraging habitat and drinking water is found in the riparian corridor of Redwood Creek as well as in the open wetland habitat of Big Lagoon. Still or slow-moving open water typically supports a high density of insects, providing important foraging habitat for bats.

Bats may be impacted by habitat removal or through human disturbance, particularly at hibernacula and maternity roost sites. Prescribed burns may destroy old trees or large snags with cavities that provide roost sites for forest bats; although alternatively, prescribed burns also may create new hollows and subsequently new habitat (Heady and Frick 2004). Human activities that affect roosting and foraging areas, such as bridge replacement, disturbance in riparian areas, off-trail use, or new trail construction, may negatively impact bat populations. Townsend’s big-eared bats are especially sensitive to disturbance, and may completely evacuate hibernacula. Human disturbance causing failure of maternity colonies can be particularly detrimental and contribute to population decline because most females typically have one litter of one to two young per year. Also, insecticide use for mosquito abatement or agriculture may result in secondary poisoning to bats.

This issue has implications for other DFCs, including those described in Section 4.2.5, *Native Plant Community Health*, and possibly DFCs related to visitor experience (e.g., visitor disturbance of bats).

Selected Indicators

The objectives would be to (1) map existing bat colonies and potential disturbances (location and timing); (2) identify critical areas and disturbances; and (3) minimize sources of disturbance to local bat populations so that stable and/or growing bat populations were supported. Indications of progress on this issue would include documentation of the distribution of all existing bat colonies, a map and description of all human activities that could potentially disturb bat populations, and protocols to avoid and/or minimize disturbance that were agreed on and implemented by all land managers in the watershed. Indicators of successful management for bats would be maintaining or increasing abundance and diversity of bats in the watershed, as reported based on regular field surveys (every 5 to 10 years). An associated indicator would be an increase in available day roosts, night (foraging) roosts, winter hibernacula, and maternity roosts, while still maintaining opportunities for human recreation and use.

Issue 28 Assess potential marbled murrelet habitat in watershed and if supported, manage lands for marbled murrelet habitat

Intensive survey work provides some evidence that the federally threatened and state endangered marbled murrelet may not breed in the old-growth forests of Muir Woods (Gardali and Geupel 2000). Surveys for the marbled murrelet were conducted from 1995 through 1998, but no confirmed sightings were reported (Chow 1996, Gardali and Geupel 2000). These surveys included intensive census stations, eggshell surveys, and shore-based surveys. At least two studies assessing offshore distribution and abundance reported no marbled murrelets in waters adjacent to Muir Woods during the breeding season (Briggs et al. 1987, Ralph and Miller 1995), and no surveys have detected murrelets in the near-shore waters off Muir Beach (Gardali and Geupel 2000).

One explanation for the absence of nesting marbled murrelets in Redwood Creek watershed may be the insufficient number of trees that possess suitable nest site characteristics for marbled murrelets (Gardali and Geupel 2000, Hamer and Nelson 1995). These characteristics may include the limited presence of platforms (USFWS 1996), high occurrence of edges and habitat fragmentation, and low canopy cover density (Ralph and Miller 1995). Common ravens (*Corvus corax*) and Steller’s jays (*Cyanocitta stelleri*) may prey on murrelet nests; in turn, murrelets may respond with aggressive behavior or nest abandonment (Long and Ralph 1998). Human disturbance can have a direct impact on nesting success by causing nest abandonment or by causing the birds to choose alternative, more remote areas to nest (Long and Ralph 1998). Muir Woods is designated as critical habitat for marbled murrelet, and management already includes implementation of breeding season restrictions on maintenance activities. Decisions may need to be made include whether or not try to manage the watershed to provide suitable nesting habitat for marbled murrelets in its old growth forests.

This issue has implications for other DFCs, including those described in Section 4.2.5, *Native Plant Community Health*, and possibly DFCs related to visitor experience (e.g., visitor disturbance of marbled murrelets).

Selected Indicators

If a decision was made to improve marbled murrelet habitat in the watershed, then indications that such improvements have succeeded would be based on field surveys for habitat characteristics, such as upper canopy platforms, forest fragmentation, and low forest cover. Of course, direct observations of nesting marbled murrelets in the watershed would be another indicator of successful management practices to provide breeding habitat for these birds.

4.2.8 Desired Future Condition for Native Wildlife Populations and Habitat

Vision Statement: Native wildlife populations are viable and diverse, and key habitats and habitat linkages (i.e., corridors) are protected and restored.

This DFC addresses the need to protect all listed and non-listed wildlife populations and habitat. Without a particular species focus, natural habitat types are considered. Therefore, this DFC overlaps with the other natural resource-related DFCs, particularly the DFCs for healthy native plant communities (Section 4.2.5), and for water flow and quality that supports aquatic health (Section 4.2.4). It also calls for a landscape scale view of the watershed, in which the conditions and interdependence and connectivity of all habitat types must be protected.

Issue 29 Reduce wildlife habitat fragmentation associated with roads and development

Existing land uses, trails, fire roads, lack of wilderness areas, invasive species, and fire suppression all contribute to habitat fragmentation. Existing parking lots and roads fragment habitats by increasing edge-to-area ratios and reducing connectivity (NPS 2005c). Migratory wildlife species need intact migration and foraging routes. Riparian corridors are particularly important movement corridors. Changes in land use within and adjacent to parks also can create barriers preventing the normal distribution or dispersal of species, isolating them on islands of parklands and altering gene flow within the population. Barriers to the integration of continuous easements, green belts, and trails across public and private lands affect the feasibility of controlling increased habitat fragmentation.

This issue has implications for other DFCs, including those described in Section 4.2.3, *Infrastructure*, Section 4.2.5, *Native Plant Community Health*, Section 4.2.6, *Non-Native Species Effects and Native Habitats*, and Section 4.2.7, *Protection of Special-Status Plant and Animal Species*.

Selected Indicators

The objectives would be to describe existing conditions for wildlife habitat continuity and fragmentation and to identify and implement change, such as re-establishment of dispersal corridors or minimizing extent of edge habitat that could importantly support wildlife populations. Successful management of this issue would be reflected by a reduction in habitat fragmentation, as indicated by inventory data showing increased movement and dispersal of sensitive species, and spatial analysis of habitat including GIS-based edge: area ratio analysis, barrier frequency, and nearest neighbor distance for key habitats.

Issue 30 Halt declines in wetland bird species due to the loss of suitable habitat

The loss of historical wetland habitat may have decreased suitable habitat for wetland bird species, affecting abundance, productivity and distribution in the Redwood Creek watershed. As discussed for California red-legged frog habitat above, past flood management, land use, and water use practices have lowered the water table in the lower portion of Redwood Creek, affecting the availability of suitable wetland habitats for bird species as well. Conversion of emergent wetland to riparian woodland habitat through the restoration of lower Redwood Creek at Muir Beach will mark an important shift in abundance of these habitats in the watersheds (Moffatt & Nichol and Jeff Anderson Associates 2009).

This issue has implications for other DFCs, including those described in Section 4.2.1, *Hydraulic and Geomorphic Function*, Section 4.2.3, *Infrastructure*, Section 4.2.5, *Native Plant Community Health*, Section 4.2.6, *Non-Native Species Effects and Native Habitat*, and Section 4.2.7, *Protection of Special-Status Plant and Animal Species*.

Selected Indicators

Regular field surveys of bird species abundance, density, diversity, richness, and reproductive success associated with emergent wetlands and riparian woodlands could be used to assess the status of wetland birds because of habitat improvements or conversion from cattail-dominated to more diverse emergent wetland community types. These metrics could be used to monitor population trends and identify those locations that should be protected or might benefit from restoration. Birds could be further grouped, based on wetland/water dependency to focus attention on the needs of those species that were obligate wetland species or sensitive to alterations in wetland habitat specifically. Additionally, habitat utilization information would provide insight into whether existing wetland habitat was being fully utilized by wetland birds.

Issue 31 Halt decline of local native song bird populations due to nest predation and brood parasitism by non-native predator birds

Noticeable declines in songbird populations, particularly neotropical migrants, have elicited growing concern. Many bird species utilize emergent wetland habitat (e.g., marsh wren, red-winged blackbird, common yellowthroat, and Virginia rail [*Rallus limicola*]), and riparian woodland habitat (e.g., Swainson's thrush, Wilson's warbler, yellow warbler, and black-headed grosbeak). Riparian corridors have been identified as key habitat for protection neotropical migrants and resident birds (Miller 1951, Gaines 1974, Manley and Davidson 1993; all as cited in Geupel 1997). The degradation and overall loss of wetland and riparian habitat, alteration of forest understory habitat, and habitat fragmentation have direct and indirect impacts on song bird populations. Several studies also have attributed declines in local native songbirds to brood parasitism and nest predation. Ninety warbler nests were monitored from 1997–2000, and only 16 of these produced young. A reported 73 percent (54/74) of the failures were caused by nest predation. Brown-headed cowbirds were responsible for parasitism of 33 percent (30/90) of the nests. Results of this study complement evidence from other studies, implicating high levels of nest predation and brood parasitism in the decline of many songbird populations. One potential reason for increases in brood parasitism is the feed used for pack animals/horse stables, which may attract cowbird flocks. Another potential reason is related to habitat fragmentation resulting from roads, trails, and other development, which serves to decrease the width of individual forest stands relative to their perimeter (i.e., edge effect) and provides more opportunity for brood parasitism by cowbirds (Donovan et al. 1997) and nest predation. Section 4.2.6 includes a discussion on non-native pest species and describes management concerns about pest animal species, which includes controlling populations of corvids (crows, jays, and ravens), the primary nest predators in the Redwood Creek watershed.

This issue has implications for other DFCs, including those described in Sections 4.2.3, *Infrastructure*, Section 4.2.5, Native Plant Community *Health*, and Section 4.2.6, *Non-Native Species Effects and Native Habitat*, and also could potentially interface with DFCs related to visitor experience.

Selected Indicators

Species abundance, density, diversity, richness, and reproductive success based on regular field surveys could be used to assess the status of local songbird populations caused by protection measures, such as cowbird trapping and removal or habitat alteration that minimize nest predation and brood parasitism. Other metrics could measure songbird habitat improvement and expansion. These metrics could be used to monitor population trends and identify those locations that should be protected or might benefit from restoration. Tracking numbers and general distribution of corvids and cowbirds would help in developing a watershed-wide (or ideally, region-wide) plan for their management.

Issue 32 Minimize effects of human-caused sound, light, and activity disturbances on wildlife

Human activities, such as large vehicular use or frequent visitation by hikers, can affect behavior of native species and potentially reduce breeding and foraging success. Noise and vibration may affect nesting birds by resulting in nest failure, abandonment, or premature fledging. Night lighting affects wildlife species, particularly those that are nocturnally active (e.g., bats and amphibians), by altering patterns in behavior, metabolism, and/or growth. The extent, duration, timing, and character of human actions in relation to the particular wildlife species determine the level of disturbance and impact. Periods when many wildlife species are known to be particularly sensitive include breeding and nesting seasons. This issue needs greater exploration regarding the type, location, and timing of human disturbances in the watershed and regarding potential impacts to native species specific to the Redwood Creek watershed.

Selected Indicators

The first indicator of progress on this issue would be a preliminary survey to evaluate the distribution and timing of potentially disturbing human activities relative to the geographic distribution of native species and timing (seasonal and diurnal) of sensitive behaviors; particularly those that produce noise, vibration, and/or night light. Timing and location of activities with effects that were clearly affecting wildlife behavior and survival would be identified in this report, along with critical knowledge gaps. Activities that produce noise and night light would be identified and ways to reduce noise and night light would be developed. Indicators of successful management would be that activities identified as resulting in negative effects on native species are known (timing, location, activity type), and no longer occurring or occurring to an extent that had negligible effects.

Issue 33 Perform comprehensive study on coho salmon and steelhead populations

Although surveys have been performed on fish in the watershed, a comprehensive study on fish populations and habitats is needed to identify and fill important knowledge gaps. Examples of likely important knowledge gaps include assessment of winter refugia in upper portions of the watershed, performance of spawning gravels, and effects of exotic aquatic species (such as crayfish) on food availability (food web). Such a study will benefit the fish populations themselves as well as other aquatic species, and will improve the understanding and management for improving water quality and geomorphic processes.

Selected Indicators

An indicator that progress on this issue has been made would be an initial synthesis of existing knowledge on aquatic habitats in watershed that also would articulate specific knowledge gaps. As a second step, field studies would be performed to fill some of these gaps, and ongoing monitoring programs would be developed and implemented to fill other information gaps.

4.3 Prioritization of Issues

In the preceding sections, 33 issues and associated indicators that interface with natural resources in the Redwood Creek watershed have been described. They have been organized by the DFCs they most directly address. Because addressing all 33 issues at once would be challenging, priority issues that are otherwise not being addressed for near-term action have been identified in a way that incorporates stakeholder views and values. This prioritization process is inherently a relative comparison among issues to identify the highest priorities for the watershed. Stillwater Sciences worked with the GGNRA natural resources staff and other stakeholders in the watershed to develop a watershed-specific, stakeholder supported methodology for identifying priority issues. The prioritization process was placed within the DFC framework for the Redwood Creek watershed. Several of the criteria reference established DFCs as part of assigning scores. As such, an understanding of the DFCs is necessary for critically assessing the draft scoring (see Section 4.1.2, *Identification of Issues Using the Vision Framework*, and Vick 2003).

On December 19, 2006, Stillwater Sciences presented a draft prioritization approach to GGNRA and representatives of fellow public agencies in the watershed. Suggestions on how to improve the approach were incorporated into a second draft prioritization framework. This framework was again presented to GGNRA natural resources staff as well as representatives from other public agencies involved in the watershed. Workshops to develop and refine prioritization criteria were conducted on September 2 and September 15, 2009. The group realized that it made most sense to divide the issues into two sets—Action Issues, issues that call for a specific single or set of well defined action(s) in the watershed, and Study Issues, issues that call for collection and/or synthesis of data to inform development of specific actions in the watershed. Issues were divided into these two groups based on the question: “Is there information readily available on which to develop specific action plans or designs?” These two sets of issues were scored separately, using very similar sets of criteria that were presented and refined at multiple stakeholder meetings.

The Action Issues were scored according to a two-tiered approach. The first tier criteria are meant to highlight issues that are considered critical to watershed health, such as Ecological Significance and Threat Severity (see below for definitions). For example, Issue 9. Minimize effects of water withdrawal on fish populations, received a score of 3 for Ecological Significance because low, late summer flows associated with water withdrawal have been linked to reduced salmonid success. The second tier criteria are meant to be used as a means of distinguishing among issues with similar first tier scores, based on the likelihood of effective and important outcomes, and potential synergies with multiple natural resource or non-natural resource goals; these second tier criteria include Natural Resource Enhancement Value (EV), synergy with multiple natural resource DFCs (BNR), and synergy with other non-natural resource DFCs (B-Oth).

The Study Issues were scored with just one tier of criteria, including Ecological Significance and Threat Severity from tier one of the Action Issues, as well as an assessment of the Information Value based on the degree to which filling the information gap would provide critical and actionable information for natural resource management in Redwood Creek.

Assigning scores involved considering each issue in relation to each particular criterion, scoring that issue on a scale of 1 to 3 (low, medium, or high) to indicate how well that issue addresses each criterion, and describing the rationale for that score (see Appendices G through I). Scores were initially assigned by Stillwater staff, and then reviewed and adjusted through several meetings with GGNRA natural resources staff and other public jurisdiction representatives (meetings held January 13, 2010; February 2, 2010; and February 10, 2010). Once scores were assigned for each criterion and each issue, the Action Issues were first sorted by first tier scores and secondarily by the second tier scores. Study issues were ranked by the sum of scores for the three criteria per issue. Because very small differences in scoring might not reflect important differences in the ecological value of addressing issues, the action and study issues were clustered into high, medium, and low categories. Draft scores and explanations regarding each score are provided in Appendices G through I (first and second tier criteria scores for the Action Issues, followed by scores for Study Issues).

All 33 issues described in this chapter were identified by stakeholders and agency personnel because they were considered important and to be high priority for resolution. Based on the first and second tier criteria described below, seven of these 33 priority issues were highlighted. These seven issues were chosen because they are in need of near-term action/study and would benefit from additional effort to frame the issue and associated studies/actions. On this basis, frameworks for implementing the top four ranked actions and top three ranked studies are presented in Section 5 of this Watershed Assessment.

All 33 priority issues were scored again, according to a third tier of criteria based on pragmatic concerns such as funding sources, costs, technical feasibility, and community support. Draft scores for this third set of criteria are provided in Appendix J.

4.3.1 Tier One Criteria

The scores ranged from 0 (no significance or threat) to 3 (highest significance or threat). The tier one criteria were based on the first two “guiding principle” DFCs: (1) the watershed is managed as an intact, continuous and linked system from the ridge tops to the ocean; and (2) management of the watershed is founded on the restoration and protection of natural processes and disturbance regimes, such as fire and flooding. As mentioned above, criteria scores for each issue were assigned a high (3), medium (2), or low (1) score, based on the relative degree to which each issue satisfies the criterion compared to the other 32 issues considered.

Ecological Significance

The ecological significance of an issue can be assessed based on (1) whether or not it directly affects sensitive species and/or habitat; (2) if it increases resilience/sustainability of watershed system; (3) if it supports natural processes and disturbance regimes; (4) if it increases connectivity of natural processes; and (5) if it fosters diverse, native wildlife and plant communities. More specifically, if the issue directly addresses any or several of these aspects of ecological significance, it is given a score of 3. If the issue indirectly addresses one or several of these aspects of ecological significance, it is given a score of 2; or if the issue does not address any these aspects of ecological significance, it is given a score of 1 for this criteria. For example, issues that affect local spotted owl populations are given a high score for this category.

Threat Severity

Threat severity reflects the time-sensitivity of addressing the issue (how quickly may it get worse and how much worse?) as well as the geographic extent of the potential impact, and the reversibility of impacts associated with the issue if it is not addressed. For example, if the issue relates to a problem that is going to worsen significantly in the face of no action, such as Issue 20, Limit introduction and spread of invasive plant species, it is given a score of 3. If the issue will persist but not worsen or spread geographically and/or is practically reversible, it is given a score of 2. If the impacts associated with the issue are easily reversed or improve with time, such as Issue 2, Reconnect Frank Valley, it is given a score of 1.

Information Value

This criterion was applied for Study Issues only. If addressing this issue will provide information that is critical to management of natural resources in the Redwood Creek watershed, it is assigned a score of 3. If little to no information is to be gained by addressing this issue, it is assigned a score of 1. For example, Study Issue 1, Gather sufficient information on stream flow, was assigned a score of 3 under the Information Value criterion because addressing this issue will provide critical and broadly useful information needed for managing the watershed.

4.3.2 Tier Two Criteria

These criteria are aimed at assessing how much addressing one issue will enhance the natural resources of the Redwood Creek watershed compared to what may be achieved by addressing other issues.

Natural Resource Enhancement Value

The natural resource enhancement value reflects (mainly) the certainty of benefits to natural resources and processes that will be gained by addressing a particular issue (i.e., bang for your buck); the expected sustainability of those benefits (i.e., durability); the biological response time to changes brought about by addressing the issue (i.e., will the system respond to these changes soon enough to support critical species?); and the geographic extent of positive action effects. Issues with highly ranked Natural Resource Enhancement Values are assigned a 3, and those with low ranked Natural Resource Enhancement Value are assigned a 1. For example, Issue 23, Increase amount of winter refugia, will score highly and, because of the large uncertainty of impact, Issue 24, Survey and increase if necessary butterfly habitat, will get a low score in this category.

Synergy with Other Natural Resource DFCs

If addressing an issue also will benefit multiple sensitive species, natural processes, and/or increase connectivity in the watershed, it will be given a score of 3 for this criterion. Alternatively, an issue could be assigned a low score of 1 for this criterion if acting on this issue raises conflicting natural resource protection objectives. For example, Issue 2, Reconnect Frank Valley will score highly because several natural resource DFCs will be enhanced by addressing this issue.

Synergy with Non-Natural Resource DFCs

If addressing an issue also will benefit non-natural resource DFCs, such as improve infrastructure functions, or increase visitor enjoyment at the same time that natural resource objectives are being met, the issue will receive a high (3) score for this criterion. For example, Issue 13, Identify and reduce bacterial contamination, will score highly because addressing this issue will enhance visitor experience and reduce the likelihood of Muir Beach closings.

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5 PRIORITY ACTIONS AND STUDIES

Based on the prioritization process described in Chapter 4, *Issues and Associated Indicators*, contributing agency personnel and other stakeholders identified seven issues in the watershed for which near-term solutions are needed, but not yet well articulated. These priorities were identified through a series of meetings in 2010. Four of the issues require near-term actions; however, many of these actions require an initial study phase to evaluate the range and feasibility of potential alternative actions. Three other issues were identified that require near-term initiation of studies. These seven priority actions and studies are outlined in this chapter.

5.1 Priority Actions

5.1.1 Minimize Effects of Water Withdrawal on Fish Populations

As described in Section 2.4.8, *Flow Diversions*, the greatest withdrawals from mainstem Redwood Creek supply the Muir Beach Community, which includes approximately 350 people through 147 connections (Martin 2000). The MBCSD operates a well on the Redwood Creek floodplain near the Banducci property, for which it has a permit from the SWRCB to withdraw up to 50.6 acre-feet per year (SWRCB 2001). Streamflows in Redwood Creek during the summer and fall typically are in the range of 0 to 1 cfs at the Highway 1 Bridge downstream of the MBCSD pumping facility. According to the AMP submitted to the SWCRCB in 2005 as required by the permit (MBCSD 2005), when reduced flows begin to affect the continuity of pools (creating adverse conditions for salmonids), the MBCSD must reduce its pumping rate from an average of about 45,000 gpd to no more than 35,000 gpd, and water conservation measures must go into effect (MBCSD 2005). The 2001 permit defines the “low flow” period as follows:

> *During May through November or when streamflow as measured at the Highway 1 Bridge is less than 0.5 cfs, but greater than 0.3 cfs, the District shall limit diversions to a maximum of 45,000 gallons per day….. When the when streamflow as measured at the Highway 1 Bridge is less than 0.3 cfs, the District shall (1) limit diversions to a maximum of 40,000 gpd … (SWRCB 2001).*

The AMP further restricts pumping during “Noticed Water Conservation Periods:”

> *During a “Noticed Water Conservation Period”, the District will limit its gross water production to no more than 35,000 gpd... Water Conservation Periods are defined as times when ‘any separation of pools occurs’ in the mainstem below the MBCSD well in Franks Valley, as observed by daily walks up the stream by District personnel when the Highway 1 gage reads less than 13.10 ft (interpreted to reflect less than 0.3 cfs; MBCSD 2005).*

The AMP also requires that the MBCSD increase its storage capacity from 250,000 gallons to 300,000 gallons and explore funding possibilities for additional increases storage capacity so that pumping during low flow periods can be reduced. In 2010, the District obtained permits and constructed a new tank, adjacent to the original water storage tank on Seacape Drive above Muir Beach, with a 200,000 gallon capacity during summer 2010 (Shoulders, pers. comm., 2011). The existing first tank capacity is 150,000 gallons, the new tank capacity is 200,000 gallons, and a third Lower Tank capacity is 100,000 gallons, for a total current storage capacity of 450,000 gallons. The existing 150,000-gallon tank needs to be repaired, so that it is seismically sound, or replaced (Marin Community Development Agency Coastal Permit Application March 2010). A self-imposed parcel tax of $300/year for each resident since 1991 garnered $475,000 as of 2010, and this fund was used to pay nearly the entire cost of the new 2010 storage tank (Marin Community Development Agency Coastal Permit Application March 2010).

Several studies regarding flow needs for resident coho and steelhead during the late summer and fall indicate a need for higher flow for longer periods than are outlined in the AMP (MBCSD 2005; Snider 1984; Fong 2007). Fong (2007) questions the 15 inch “dry year” criterion that triggers conservation periods in the AMP because observations between 1997 and 2004 show that minimum annual rainfall associated with maintaining a continuous stream flow (no isolated pools) was 31 inches, or two-times the existing threshold (MBCSD 2005). It also must be recognized that the discontinuity of creek flow during many late season years likely is caused by a combination of factors, including alterations in channel form (lack of structural diversity), reduced groundwater recharge because of channel incision, and altered weather patterns, as well as MBCSD withdrawals. However, when flows are below 1 cfs, which occurs frequently during the late summer and fall, maximum allowed withdrawals rates of 0.07 cfs (monthly average) could substantially reduce baseflow (SWRCB 2001; MBCSD 2005).

Based on the recorded increase in storage capacity and withdrawal rates of 35,000 gallons per day (per AMP; MBCSD 2005), the Muir Beach Community would be able to go for roughly 12 days with no pumping or 24 days with a 50 percent reduction in pumping during noticed conservation periods. However, the Water Conservation Period (discontinuous flow) can last 45 days or more, depending on the water year (Marin Community Development Agency Coastal Permit Application March 2010; Fong 2007).

Alternative Actions

Several alternatives to address the current situation have been proposed and explored, to various degrees in the past, as follows:

1. Merge Muir Beach Community with MMWD through Muir Woods water supply lines

This option was explored through development of the Twenty Year Plan for MBCSD (Hyde & Associates and ABCC 1996) and later in the AMP (MBCSD 2005). In 2005, MMWD offered a $3 million fee to provide service to the Muir Beach Community, plus the cost of constructing the water line connecting Muir Woods to the MBCSD system, and an agreement that in dry water years, Muir Beach Community needs would be subordinate to needs of other MMWD customers. A cost estimate of connecting to the MMWD through the Muir Woods supply main in 1994 was $300,000, which translates to $433,000 in 2011 dollars[2] (Hyde & Associates and ABCC 1996). No mention of upgrading the Lower Zone facilities to MMWD standards was made in the AMP report (MBCSD 2005)[3]. Thus, excluding potential costs of upgrading the Lower Zone facilities, the total potential cost of merging with MMWD could be in the range of $3.5 to $4.5 million.

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[2] Based on 2008 CPI of 2.15303 and OMB and CBO Spring 2009 inflation estimates for 2009-1019; 1.5% for 2011; *oregonstate.edu/cla/polisci/faculty-research/sahr/cv2009.xls.*

[3] As an example for potential costs up upgrading the Lower Zone facilities, the cost for permitting and constructing the new 2010 tank was roughly $500,000 (Marin Community Development Agency Coastal Permit Application March 2010).

2. Merge with Stinson Beach Water District

This alternative also was briefly explored in the Twenty Year Plan for MBCSD (Hyde & Associates and ABCC 1996) because Stinson Beach Water District (SBWD) is close by and has a large reserve water supply that could meet the needs of the Muir Beach Community. However, MBCSD concluded that this was not viable because: (1) although five to six times larger, SBWD also is small and limited in capacity; (2) the 6 miles of pipeline between SBWD and MBCSD facilities would be too expensive to construct and maintain; and (3) the SBWD does not have transferrable water rights. These reasons appear to make this a less attractive option than others presented here, particularly the lack of transferrable water rights; however, further exploration of the assumptions stated above (cost to hook up, potential for water rights transfer or other options, overall capacity) is warranted.

3. Move the district wells farther downstream

This option was addressed in the 2001 SWRCB permit for MBCSD and later in the AMP. Because low flows have been observed to result in discontinuous water flow starting just up from the Highway 1 Bridge, studies were performed to ensure that shifting the pumping to downstream of this bridge would not result in discontinuous stream flow. However, water quality issues in these locations were of great concern to Muir Beach residents because of past experiences with the old well water from this area (near the Pelican Inn), and the large number of residential septic systems, stables, and other sources in this area. Moreover, no landowners willing to sell or swap land were identified (MBCSD 2005). An alternative scenario to establishing drinking water wells in other locations would be to establish a ground water well in the upper Frank Valley or tributary that would draw from an aquifer separate from the channel underflow, to be used only for replenishing channel water flows during the low season.

4. Additional storage facilities

Shifting late summer and fall withdrawals to high flow periods in the winter and spring could alleviate potential effects on fisheries habitat associated with current late season pumping. This change in pumping regime would require additional storage for MBCSD. Several simple estimates of increases in storage needs were developed, based on pumping regimes that ranged from a dry season definition offered by NPS of 184 days (May 1 to October 31, MBCSD 2005) to a minimal “Water Conservation Period” of 45 days (September 15 to October 31), with a range of withdrawal rates. These storage need estimates are presented in Table 5-1. The calculations indicate that one or a series of tanks or reservoirs with 700,000 to 6.24 million gallons of storage capacity above the current 450,000 gallons would be required, assuming 250,000 gallons also must be stored at the end of the dry season, in case of fire. Values presented in this table highlight the potential of reducing withdrawal rates on storage capacity needs.

In 2005, a Technical Advisory Committee for the MBCSD permit estimated that a 6.25 million-gallon storage facility would cost roughly $7.5 million. Shifting withdrawals from late season to the winter-spring would fulfill requirements for addressing the aquatic ecology impacts associated with pumping that were put forth in the 2001 permit and additionally referred to in the AMP. The possibility and potential extent of permitting or management plan amendment needs that could be required by the Water Resources Board associated with this seasonal shift in withdrawals should be investigated if further action on this option is undertaken.

Table 5-1. Simple Estimates on Potential Storage Needs to Transfer Late Season Withdrawals to the High Flow Winter/Spring Season

Withdrawal Rate (gallons/day)	Days	Storage Needs (gallons)	Storage Needs less existing 200,000 gallons[1]
35,000	45	1,575,000	**1,375,000**
35,000	90	3,150,000	2,950,000
35,000	120	4,200,000	4,000,000
35,000	184	6,440,000	6,240,000
25,000	45	1,125,000	**925,000**
25,000	90	2,250,000	2,050,000
25,000	120	3,000,000	2,800,000
25,000	184	4,600,000	4,400,000
20,000	45	900,000	**700,000**
20,000	90	1,800,000	1,600,000
20,000	120	2,400,000	2,200,000
20,000	184	3,680,000	3,480,000

Note:

1. 200,000 gallons were subtracted from the total storage need to reflect 450,000 gallons existing storage capacity less the 250,000 gallons that must be retained at the end of the dry period in case of fire.

Source: MBCSD 2005

5. Off-channel storage for instream replenishment during critical periods

Creation of ponds or other holding structures for retaining water during high flows to be used to replenish stream flow during the low season while continuing pumping could alleviate impacts on fish, assuming water quality characteristics of stored water were acceptable. Execution of this option would require, at the least, establishment of standards for water quality and input rates and timing for water pumped into the channel. Existing restrictions on the duration that water can be stored under the current permitting agreement also would need to be assessed, to ensure that off-channel storage is allowed and feasible.

6. Reduce late summer water withdrawals

Possible methods for reducing withdrawals from the channel underflow include increased conservation, gray water recycling, and importation of bottled water, to mention a few. GGNRA natural resources staff are working with the MBCSD to assess pumping schedules that may minimize the multiple effects of consumptive withdrawal and transpiration that occur during mid to late summer (Fong, pers. comm., 2011).

7. Desalination

A study by the TAC for the AMP reported that the water needs of the Muir Beach community are similar to those of a very small cruise ship. Access to salt water and potential cool sea water pumped from depth could allow for lower cost “low temperature thermal desalination” that essentially uses a vacuum and cool deep sea water, to boil and recondense water at lower pressures and temperatures (lowering energy requirements) and create a purified condensate. More research on potential options and associated capital, maintenance, and operating costs for a desalination facility for the Muir Beach Community need to be explored.

Summary and Recommendations for Minimizing Effects of Water Withdrawal on Fish Populations

Potential costs for all viable options for substantial reduction in stream underflow withdrawals during late summer run into millions of dollars. More research is needed to refine cost estimates and perform feasibility assessments for the options that appear most promising. Also needed is a better understanding of the effects of withdrawals by the MBCSD wells on downstream baseflow in Redwood Creek during the summer, especially the late summer period. Consideration of any of the alternatives that include withdrawal and storage of high flow season water should be accompanied by an assessment of potential impacts to downstream sediment transport dynamics, aquatic habitat, and water quality. Based on existing information, the most promising options include:

- creating off-channel storage capacity for instream replenishment;
- expanding existing potable water storage facilities while reducing late season water consumption rates;
- conservation and reduced summer withdrawal rates; and
- desalination.

An assessment and cross-comparison of the costs and feasibility of these options, as well as research into funding opportunities, are needed to articulate next steps towards reducing impacts of water withdrawals on fish populations in lower Redwood Creek.

5.1.2 Remove Infrastructure Constraints on Fluvial Processes

Transportation infrastructure (e.g., roads, bridges, and parking areas), utility infrastructure, and engineered channel infrastructure (e.g., bank protection and levees) alter natural processes along the Redwood Creek corridor, including channel hydraulics, channel sedimentation and erosion, channel geometry and morphology, floodplain functions, riparian and aquatic habitat, and terrestrial habitat connectivity. Existing structures in lower Redwood Creek that potentially affect fluvial geomorphology and related ecosystem functions include:

- Pacific Way Bridge
- Buildings and parking lots in the vicinity of Muir Beach
- Muir Woods Road along Upper Frank Valley
- Muir Woods Road Bridge immediately downstream of Camino del Canon
- Buildings and parking lots in the vicinity of Muir Woods National Monument
- Bank stabilization and channelization of Redwood Creek in the vicinity of Muir Woods National Monument

Several of these constraints have been identified and actions developed to address them, including actions related to reducing channel confinement imposed at the bridge crossing of Redwood Creek at Pacific Way Road and by the parking lot at Muir Beach. Changes that have been implemented or are planned include:

- A new, longer bridge on Pacific Way over Redwood Creek
- Removal of the levee road between Pacific Way Bridge and Muir Beach
- A reconfigured Redwood Creek channel from Pacific Way Bridge to Muir Beach
- A newly configured Muir Beach parking lot that is realigned at the edge of the floodplain

Channel restoration has been implemented on a portion of the Banducci site in Frank Valley, and a second phase of restoration is proposed over the remaining length of channel within the site. Additional recommendations for assessing restoration feasibility in the reach of Redwood Creek between the upstream boundary of the Banducci site and the Muir Woods Road Bridge immediately downstream of Camino del Canon are discussed in Section 5.1.4; recommendations for a road assessment and management plan to address a range of problems and potential constraints on ecosystem processes in lower Redwood Creek imposed by Muir Woods Road downstream of Muir Woods Monument are discussed in Section 5.1.3, and recommendations for a channel monitoring program are discussed in Section 5.2.1.

Relatively little analysis is publically available that describes the extent and potential impacts of buildings and parking lots, bank stabilization and channelization, and other related infrastructure in Muir Woods National Monument in the vicinity of the visitor's center. Recommended elements of an assessment and plan include:

- An evaluation of the impact of existing structures within Muir Woods National Monument (including the main parking lot at the Muir Woods National Monument) on ecosystem processes
- A summary of opportunities and constraints to improving ecosystem processes through modification and/or removal of infrastructure
- Identification of options for improving ecosystem processes through modification and/or removal of infrastructure
- An evaluation of the feasibility of the options
- An implementation plan

Further upstream, existing, future, and potential erosion and sediment delivery sites associated with road-related infrastructure in the upper Redwood Creek watershed have been inventoried and treatment priorities identified (PacWA 2002). These treatment priorities are intended to guide long-range transportation planning, erosion prevention, and erosion control activities in the watershed. The treatment recommendations resulting from the work in 2002 are the most cost-effective prescriptions for reducing sediment delivery to the stream network. Additional activities could be considered to achieve broader ecosystem restoration goals, including more extensive outsloping and elimination of as much inboard ditch as possible, rerouting or abandoning problematic sections of roads or trails, and complete topographic obliteration on decommissioned roads. The Mount Tamalpais Road and Trail Management Plan (2003) developed by the Marin Municipal Water District incorporates some of these treatment recommendations for roads and trails in the upper Redwood Creek watershed.

5.1.3 Address Road Conditions along the Lower Muir Woods Road Corridor and Associated Effects on Ecosystem Functions

Muir Woods Road is one of several county roads linking the greater San Francisco Bay area to coastal destinations in the western Marin County portion of the Golden Gate Recreation Area. The road receives a large volume of traffic from recreational users of Mount Tamalpais State Park and Muir Woods National Monument, as well as a small number of local residents. Lower Muir Woods Road parallels Redwood Creek between the visitor's center at Muir Woods National Monument and Highway 1. Through this extent, the valley bottom is narrowly to moderately confined and the road is situated directly adjacent to the banks of the Redwood Creek in some locations. At several of these locations, the road is damaged or potentially threatened by a combination of problems related to road surface drainage, tributary drainage, and channel bank erosion associated with processes of lateral migration.

Failure of Muir Woods Road due to streambank erosion

A sediment source assessment and erosion prevention plan was developed for roads and trails within the Redwood Creek watershed, including lower Muir Woods Road (PacWA 2002). Surveys conducted during the assessment identified about 20 erosion sites (including road surfaces, ditch relief culverts, stream crossings, and bank erosion sites) with varying treatment priority along lower Muir Woods Road. Additional erosion sites have developed along the road since the time the surveys were conduc ted. One of the more severe examples occurs where erosion of the fill slope has restricted vehicular traffic to one lane near the intersection of Deer Park Fire Road and Muir Woods Road. The site is apparently failing because of a combination of outfall from a tributary culvert and bank erosion in the confined reach of Redwood Creek.

The Muir Woods Road crossing at Kent Creek was identified as both a jump and velocity barrier to fish passage (Ross Taylor and Associates 2003). In 2007, an open-bottom arch culvert was installed to replace the undersized pipe, providing anadromous fish access to an additional mile of high quality habitat. The crossing replacement was funded by the State Coastal Conservancy, NOAA Open Rivers Initiative and County of Marin (Kull, pers. comm., 2010).

A county-wide study by EDAW (2003) identified the following options for addressing erosion and seasonal traffic congestion problems in portions of the Golden Gate National Recreation Area and nearby Marin communities, including Muir Woods Road:

- Relocate and/or realign portions of lower Muir Woods Road away from Redwood Creek
- Reduce or prohibit roadside parking on Muir Woods Road
- Reduce and redesign existing parking areas to minimize impacts to Redwood Creek

- Provide parking on the upper Banducci property
- Increase road shoulder width for bicycles and pedestrians
- Limit vehicular access along lower Muir Woods Road

An updated road assessment and specific management plan is needed for lower Muir Woods Road to address the range of existing problems related to vehicular and pedestrian traffic needs, road surface and tributary drainage, erosion, and associated ecosystem effects. An integrated rather than a piecemeal approach is recommended because many of these problems and associated potential solutions are interdependent.

The plan for the lower Muir Woods Road corridor between Muir Woods National Monument and Highway 1 should include the following elements:

- A detailed inventory of existing road erosion, road surface and tributary drainage conditions, and the potential effects of the road on ecosystem processes within the corridor
- A traffic and needs analysis
- A study of opportunities and constraints to improving drainage; stabilizing erosion sites; relocating and/or realigning the road; and improving vehicular, pedestrian, and bicycle circulation
- A feasibility assessment of potential actions
- A plan and implementation strategy developed for treatments that address road issues and improve ecosystem functions

The assessment and management plan for lower Muir Woods Road should be developed in accordance with ongoing and planned programs and projects, coordinated by the County of Marin, GGNRA, Marin Municipal Water District, Mt. Tamalpais State Park, and Muir Beach Community Services District.

5.1.4 Restore Floodplain Connectivity in Frank Valley

Lower Redwood Creek has become disconnected from its former floodplains by channel relocation and realignment, floodplain modifications (e.g., land leveling and construction of levees), and disequilibrium in fluvial processes (e.g., incision) (Stillwater Sciences 2004). Various obstructions to natural floodplain connection, the feasibility of restoring floodplain and riparian processes, and restoration actions that would improve hydrologic and geomorphic function have been identified in the reach from Mt. Tamalpais State Park to the Highway 1 Bridge (referred to as Lower Frank Valley; Figure 2-1) and in the reach from Highway 1 to Muir Beach, as described below.

The Banducci site is divided into Upper (“Upper Alley”), Middle (“Bowling Alley”), and Lower (extending to the Highway 1 Bridge) reaches (PWA 2000, 2002), with potential restoration actions focused in each. A first phase of restoration work was completed in the Middle reach in 2003, by NPS and the Parks Conservancy. The restoration work has created more geomorphic complexity (e.g., through creation of gravel bars and pools associated with large wood emplacement), allowed more frequent and extensive floodplain inundation, promoted establishment of native riparian species on formerly eroded banks, and is expected to enhance summer rearing habitat and winter refugia for salmonids. A second phase of restoration that includes over 2,500 linear feet of channel in the Upper and Lower reaches is under consideration by NPS and the Parks Conservancy (Kamman Hydrology & Engineering 2006, NPS 2007b).

Less emphasis has been placed on evaluating the feasibility of restoring channel and floodplain functions in the reaches of Redwood Creek from the upstream boundary of the Banducci site to the Muir Woods Road Bridge just below Camino del Canon. This length includes the upstream extent of Frank Valley and more confined channel reaches upstream of Frank Valley. The valley floor is relatively confined and has a dense riparian canopy over most of the reach between Frank Valley and the Muir Woods Road Bridge, except in the vicinity of the Kent Creek confluence, where the valley is wider and less confined.

Channel restoration at the upstream end of Frank Valley, in the reach between the upstream boundary of the Banducci site and the intersection of Deer Park Fire Road and Muir Woods Road, likely is a priority. The characteristics of this reach are similar to that described for the Upper reach of the Banducci site (PWA 2000): low quality in-channel and riparian habitat, incised in response to large-scale disturbances within the watershed, and an artificially raised floodplain. This reach is unlikely to recover natural functions over the next 50 years without active intervention, and it is unlikely that the quality of in-channel habitat or the degree of morphologic complexity will improve because of the degree of disconnect between the channel and floodplain without active intervention. An assessment of restoration feasibility is needed for this reach and should follow an approach similar to that used for the Upper reach of the Banducci site (PWA 2000), including the following:

- A reach-scale characterization of existing hydrology, fluvial geomorphology, and interactions between the channel and floodplain
- An evaluation of disturbances that have occurred to the channel and floodplain and their impact on ecosystem processes
- An appraisal of the likelihood of ecosystem recovery without intervention
- A summary of opportunities and constraints to ecosystem recovery with intervention
- Identification of restoration options for ecosystem recovery
- An evaluation of the feasibility of restoration options

Restoration options in the reach at the head of lower Frank Valley immediately upstream of the Banducci site likely include: (1) creating a bench in the abandoned floodplain, to increase floodplain inundation, enhance summer rearing habitat and winter refugia for salmonids, and promote establishment of native riparian species; and (2) placement of large in-channel structures (e.g., boulders and large woody debris) to increase channel complexity. The potential effects of the Muir Woods Road Bridge crossing of Redwood Creek on fluvial processes within the reach also should be assessed.

A framework for monitoring and adaptive management should be established for the purpose of evaluating the effectiveness of channel restoration actions and other management activities on ecosystem recover in lower Redwood Creek. Channel monitoring (for geomorphology, aquatic habitat quality, and fish populations) and adaptive management should be coordinated with assessment and monitoring of channel condition (refer to recommendations included in Section 5.2.1).

5.2 Recommended Studies

5.2.1 Assessment and Monitoring of Channel Condition

The *Sediment Budget for the Redwood Creek Watershed* (Stillwater Sciences 2004) and Chapter 2, *Existing Conditions* of this document define the historical and existing context for channel changes in Redwood Creek and identify key gaps in the current understanding of fluvial processes and geomorphology. Cycles of channel instability (e.g., incision, bank erosion, and aggradation) and changes in channel morphology (e.g., pool spacing, bankfull width and depth, floodplain connectivity) have occurred in lower Redwood Creek in response to land use development, channelization, structural modifications to the channel from roads and other infrastructure, and other resource management activities. Ongoing channel instability has important implications for managing existing infrastructure and ecological resources associated with the channel and estuary. Repeated observations of channel geometry, bed and bank morphology, sediment storage, and bed material composition in responsive reaches of Redwood Creek and the valley bottom reaches of larger tributaries would: (1) provide a measure of channel response to changes in water, sediment, and wood inputs; (2) provide a means of evaluating the effectiveness of restoration activities on fluvial processes, geomorphology, and aquatic habitat conditions; and (3) inform future resource management and restoration in the watershed.

A conceptual framework for a channel monitoring program should include the following:

- Key questions that guide monitoring
- Criteria for locating a network of long-term channel monitoring reaches
- Appropriate metrics for focusing data collection in monitoring reaches (e.g., see Stillwater Sciences 2009b for potential template)
- Guidelines for the frequency and timing of monitoring activities
- Guidelines for data sharing and reporting

Key questions guiding long-term channel monitoring in the Redwood Creek should include, but would not be limited to the following:

- What influence does channelization throughout Muir Woods National Monument have on fluvial processes, channel morphology, and floodplain connectivity in downstream reaches?
- How do in-channel structures (e.g., large wood) affect fluvial processes and channel complexity in different mainstem reaches of Redwood Creek?
- Are the mainstem channel and the lower reaches of the major tributaries in Franks Valley incising, aggrading, or stable?
- How are sediment storage and bed material size changing in reaches of Redwood Creek downstream of Muir Woods National Monument?
- How does channel modification downstream of the Muir Woods Road Bridge at Camino del Canon affect channel hydraulics, sediment transport, and floodplain function? How effective have

recent changes been in improving flood routing and continuity in sediment transport in lower Redwood Creek?

A survey of the longitudinal channel profile and general geomorphic mapping (e.g., reach morphology, sediment storage, grade changes, bed and bank instability, large wood occurrence, and structural channel modifications) from Muir Beach through Muir Woods National Monument would be a critical first step in selecting appropriate response reaches for long-term monitoring. Similar surveys have been conducted in reaches within the Banducci site during restoration feasibility studies (PWA 2000). Important monitoring parameters in responsive reaches would include survey of channel cross-sections that extend above and beyond the flood-prone area, sampling of bed particle size (e.g., bulk sampling and pebble counts), and description of bank conditions. An effort should be made to reoccupy existing cross-sections (e.g., cross-sections surveyed in the reach within the Banducci site [PWA 2000, Kamman Hydrology & Engineering 2006]). Bed surface texture (i.e., facies) and sediment storage by geomorphic feature type and activity class should be mapped over specified reaches in the vicinity of cross-sections. A network of control points should be established to tie the longitudinal profile and cross-section surveys in monitoring reaches to a common horizontal coordinate system and vertical datum. Repeated survey of the longitudinal profile and cross-sections could be used to quantify changes in channel geometry, slope, and local base level. These data also could be used in combination with information on cross-section geometry, bed particle size, and flow to assess channel response to incision, aggradation, and changes in water and sediment supply. Ongoing monitoring of suspended sediment load at key locations in the vicinity of monitoring reaches would be useful to assess channel response to changes in sediment load and the influence of restoration activities on sediment load. Channel geometry and channel instability (lateral and vertical) should be assessed in the major tributaries within Franks Valley. Measurements in monitoring reaches should integrate with the NPS Inventory and Monitoring Program.

Monitoring of different parameters may occur over different schedules and time frames, depending on the time-scale over which controlling variables influence change. Resurvey of cross-sections, description of bed and bank conditions, sampling of bed material, and mapping of sediment storage could occur following bankfull flow events, while resurvey of the longitudinal profile could occur following large flood events (e.g., flows with a 5 to 10-year return interval). Monitoring methods, data, analyses, results, and conclusions should be reported in NPS Natural Resource Data Series standard format, in years following resurvey of cross-sections. All spatial data should be provided with metadata in a format suitable for GIS.

5.2.2 Assessment of Stream Gauging Needs

The sporadic record of stream gauging in Redwood Creek leads to numerous uncertainties in the flow record that hinder hydrologic and fluvial geomorphic analyses useful for resource management and restoration in the watershed. Short records of continuous gauging measurements exist for Redwood Creek at Pacific Way (March 1992–December 1993), the Muir Woods Road Bridge (January 2003–March 2004), and the Highway 1 Bridge (1998–present). Semi-continuous gauging measurements also have occurred at two locations in Green Gulch (2003–2005). Additional discontinuous gauging measurements describe seasonal stream flow and peak flows at these and other locations in Redwood Creek, since about 1962. At the Highway 1 Bridge, the site with the longest continuous gauging record, the stage–discharge relationship has shifted over time because of changes in channel slope, cross-sectional area, and flow hydraulics caused by channel changes (e.g., scour and deposition) at the site and by downstream modifications to the channel and floodplain. As a result, little or no correlation exists between stage for the overlapping period of record at the Highway 1 Bridge and the Muir Woods Road Bridge at Camino del Canon.

Long-term, continuous gauging at a network of stations in the watershed is needed to better understand the hydrologic (e.g., storm hydrograph characteristics, peak flood discharge, baseflow, and flow exceedance) and fluvial geomorphic (e.g., hydraulic geometry and sediment transport rates) responses to changes in watershed inputs, ongoing baselevel change (i.e., incision or aggradation), and to inform restoration and resource management in the watershed. The flow record for Redwood Creek could be improved by: (1) establishing a reliable stage–discharge relationship at the existing Highway 1 gauge site, and (2) expanding the network to include additional gauge sites that account for accretion from large tributaries.

Improving the relationship between stage and discharge at existing gauge sites would involve several potential steps. The likelihood of future channel changes and the suitability of existing hydraulics related to any recent structural modifications to the channel or floodplain in the vicinity of the Highway 1 Bridge site should be evaluated to determine the potential influences on the stage-discharge relationship. If the existing gauge site is considered adequately stable or could be modified with artificial control to ensure stability, the pressure transducer should be relocated to a lower elevation that is closer to a stable channel thalweg, to better describe low flow. Sample discharge measurements should occur more frequently at both high and low flows, to better define the stage–discharge relationship at the site. If the existing gauge site is considered hydraulically unsuitable and/or is unstable because of ongoing or anticipated channel adjustments, an alternative gauge site should be identified in a nearby channel reach that is stable, has more suitable hydraulics, and a relatively uniform channel geometry suitable for cross-section survey and good discharge measurement over a range of flows.

Expanding the network of continuous gauges to include sites that describe flow accretion from major subwatershed areas would be useful in differentiating the effects of management activities in different parts of the watershed. Gauge sites ideally should be located in mainstem Redwood Creek at Muir Woods Road and in the lower reach of Green Gulch upstream of any backwater influence of Redwood Creek. Additional gauge sites would be useful in the lower reach of Kent Creek upstream of Muir Woods Road and in Fern Creek near the confluence with Redwood Creek but upstream of any backwater influence. These two tributary locations are lower priority than long-term gauging at Muir Woods Road and Green Gulch.

5.2.3 Status of Ancient Redwood Grove in Muir Woods National Monument as well as Adjacent Douglas-Fir Forests

Measurements of the structure and composition of the redwood forest and its adjacent Douglas-fir forests in Muir Woods National Monument have not been made for over 30 years (McBride and Jacobs 1978). During this time, many new stressors have been introduced and the effects of ongoing stressors on the forest likely have changed. Given the ecological and social importance of Muir Woods as one of the last stands of old growth coastal redwood, renewed efforts to track and understand the health and response of this ecosystem to its conditions is warranted. Establishing baseline forest structure and composition data would be essential for early detection of changes in the rate and distribution of redwood regeneration and recruitment, encroachment of the redwood forest by adjacent Douglas fir stands, effects of Sudden Oak Death on understory composition and structure, effects of new diseases on plant species, and effects of changes in the distribution and character of snags and logs on wildlife species. Early detection would allow for early and often more effective management responses.

Potential target questions and associated methodological approaches for such a baseline survey and ongoing monitoring program for the forests at Muir Woods National Monument should include the following:

- What are the current and future changes in the structure and health of each individual old growth redwood tree within the Monument and how changes in climate may be affecting physiology of these trees?

- Identify best indicators of individual tree health, including where possible, indicators of changes in water balance, effects of disease, and soil compaction. Establish clear and repeatable methods for measuring indicators.

- Identify critical structural data to collect to characterize individual trees for volume, canopy structure, and wildlife habitat potential (e.g., height, diameter at breast height [dbh], canopy height and width, trunk burn scars [cat scars], cavities, burl growth, broken tree branches; epiphytic community composition).

- Identify critical data to collect to characterize snags and downed logs (e.g., species, length, dbh, level of decay, wildlife habitat characteristics).

- Establish baseline to track, at the individual tree, snag, and downed log level, the location, structure and health indicators of each old growth tree, snag, and downed log within the alluvial old growth stand.

- Collect, store, and report data in spatially explicit format with critical attributes associated with each tree, snag, and downed log.

- Update every 5 years and possibly following major events (storm, flood, or fire).

- Is the extent and distribution of redwoods within and adjacent to the National Monument changing with time? If so, how and what are the potential causes?

- Establish a baseline map of current extent of redwood trees within the Monument and adjacent stands and track future changes in the extent and distribution of redwood trees (redwood – Douglas-fir boundaries).

- On either side of the Douglas-fir – redwood forest boundaries, establish plots to track species composition, age structure, and recruitment rates to support early detection in boundary shifts.

- How is Sudden Oak Death affecting plant species composition in and adjacent to the National Monument and what effects are these changes having on composition, succession, fuel loading, and fuel distribution as well as on wildlife species that were dependent on tan oak as a food source?

- Establish permanent plots of appropriate size (suggested size of 200 square meters) along gradient of SOD impact (high to low) within Muir Woods redwood stand.

- Within these plots, regularly measure (e.g., every 2 to 5 years) canopy gaps, species composition and structure of herbaceous, shrub, upper, mid and lower canopy forest, fuel load and distribution.

- What is the overall fuel load and distribution in the redwood and surrounding Douglas-fir forests at Muir Woods, and how might this affect potential behavior, intensity, frequency and extent of fire under different ignition and climate scenarios?

- Supplement data collected in the above efforts to ensure representation of variability in fuel load distribution and apply fire behavior models to assess potential fire characteristics in forest, based on the range of existing and potential fuel loads and distributions. Findings can be used to inform controlled burn prescriptions and other fuel management activities.

- What is the current ground cover and shrub composition, and how is this changing over time and with different management actions?

- Create a spatial map of old trails and roads within the Monument, where soil is compacted and has, in some cases, been repeatedly treated with oil to reduce dust.

- Create study plots (e.g., 50 to 100 square meters) to include areas with and without compacted soils (where possible with those established under the SOD study above).

- Monitor plots for changes in insolation, physical soils characteristics, soil carbon to nitrogen ratio and organic content, as well as herbaceous and shrub species cover and composition in response to different management actions (e.g., planting and soil decompaction).

- Can historical compaction and trail maintenance (e.g., oiling the trails for dust management) be counteracted to improve survival and vigor of planted or volunteer native ground cover and shrub species?

- Track planting effort locations, site characteristics, and success/failure for native species hypothesized to grow in Muir Woods historically that is currently absent or under represented (e.g., Pacific rhododendrum [*Rhododendrum macrophyllum*] and, less likely, salal [*Gaultheria shallon]).*

- What are the current and potential invasive non-native plant species in Muir Woods, and how are they impacting native species' composition and extent?

- Track distribution and potential future establishment sites through frequent (e.g., annual) monitoring and record findings in a geospatial database.

- Coordinate surveys and exchange information with the existing Exotic Plants Management Plan for the Muir Woods National Monument and with the Weed Watchers program run by GGNRA (http://www.parksconservancy.org/help/volunteer/habitat-restoration-monitoring/weed-watchers.html).

Monitoring methods, data, analyses, results, and conclusions should be reported in NPS Natural Resource Data Series standard format in years following resurveys or, at most, 5-year intervals. All spatial data should be provided with metadata in a format suitable for GIS.

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APPENDICES

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Appendix A

Watershed Disturbance Chronology

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Table A-1. Watershed disturbance chronology, Redwood Creek, Marin County, California. Source: Stillwater Sciences (2004).

Factor	Pre-1850	1851-1870	1871-1890	1891-1900	1901-1910	1910-1920	1921-1930	1931-1940	1941-1950	1951-1960	1961-1970	1971-1980	1981-1990	1991-2000	2000-
Climate															
Floods (see report for details)		1862 large flood – here?					**Feb 11 1925**: heaviest rainstorm “to date” (Hildreth), prompting Muir Wood rip-rap (Kimball)	Hildreth: Six floods since rip-rapping (as of 1966)	Feb 6 1942 – two feet of gravel deposited in trail (Hildreth) (Earliest gauge = 1946 @ Novato)	**Dec 19 1955** **Dec 22 1955** Jan 14, 1956 – 600 tons debris in parking lot following storm (Hildreth)	**Jan 21, 1967** **Jan 21, 1970**	**Jan 12 1973**	**Jan 4 1982** -= flood of record **Feb 17, 1986** - third largest recorded flood?	**Jan 9 1995** **Feb 3 1998 –** second largest recorded flood? **Feb 7 1999** – Small event 502 cfs at Hwy1	**Feb 14 2000** – Small event 501 cfs at Hwy1
Drought		1862-4 drought? (Jebens p22)													
Fire	1822 – possible last fire in Muir Woods area (Jebens): fires regular before European arrival	Mt. Tam (1859 – 3 months) “last major fire in upper RC” – (Kimball) protected thereafter	1881 – fire on ridge between Muir Woods and Kent canyon (Jebens)	1891, 1894 Mt. Tam fires (Jebens)		1913 fire in Fern Canyon – 2000 acres in 12 hours. (Jebens)	Great fire of ’29 on Mt Tam (Jebens)	Only minor fires following…					1985 NPS experiments with first prescribed burn (Jebens)		
Known Channel Changes							2/11/25 = two floor bridges and one road bridge washed out, severe bank erosion. Kimball: maybe veg changes increased flood effectiveness?	Kimball Figure 6 shows incised channel	1 debris landslide 1948-1952 (PacWA 2002)	2 debris landslides 1953-1965 (PacWA 2002)	Channel stabilizes at Banducci, very straight (PWA 2000).	8 debris landslides, 1 debris flow 1971-1982 (PacWA 2002)	3 debris landslides, 2 debris flows 1983-2000 (PacWA 2002)		20 years of LWD yielded up to 3ft aggradation in places (Monroe, in Kimball)
Channel Management															
Channelization	Naturally functioning channel-floodplain assumed – single thread or swampy-meadow in Franks Valley	Single thread channel depicted at Banducci site (1853 map) (PWA 2000)		RC alignment shifts in upper Banducci site – date disputed (1894 Geodetic vs 1892 Tamalpais Land & Water Co.) (PWA 2000)	RC realigned near Pacific Way (1900–1946) (PWA 1994)		Realignment for road improvements? Muir Woods: Feb 1928–1934 brush revetments on eroding banks. 1930 several gabions and placement of log dam (to raise water table) (Kimball)	RC Muir Woods straightened & 26 sections rip-rapped by CCC, grade control installed 1933-8 – only at threatened sites, some gabions now destroyed redwood log check dams (Fairley) – one still visible	‘Set-back’ levees constructed at Banducci beyond outermost braid; floodplain leveled at Banducci – sloped away from channel, 1948–9 (PWA 2000)			Additional levees at Banducci (PWA 2000)			Rip-rap now at 19(/29) bends in Muir Woods (Kimball) = 30% of Muir Woods streambank (60% of length)
Maintenance				RC gravel extracted for road construction at Banducci (?) (PWA 2000)				RC gravel extracted for road construction at Banducci and for personal use (1930s-1980) (PWA 2000)	Braided channel, wood removed from channel at Banducci (1947 photo – check?) (PWA 2000)			LWD removed from Muir Woods reach to 1986	Lower Banducci field flood (1982)		RC dredged u/s of Pacific Way 2002
Tributaries								2 sections of Fern creek also rip-rapped (Kimball)	RB tributaries diverted at Banducci site (PWA 2000)		Green Gulch tribs to drains and reservoirs constructed (assumed)				

Factor	Pre-1850	1851-1870	1871-1890	1891-1900	1901-1910	1910-1920	1921-1930	1931-1940	1941-1950	1951-1960	1961-1970	1971-1980	1981-1990	1991-2000	2000-
Big Lagoon	Wetland core deposits from 3500 BP min to mid 1800s. (Wells) Mix of wetland and lagoon assumed	1853 map indicates 12 acres open water, 13 acres of fringe wetland; water depths 1-4/5 ft.			Levees to protect house form flooding (PWA 1994)		Freshwater pond and fringing marsh converted to pasture by 1920 (PWA 1994)				RC dredged (to 1970); dammed and leveed; fill at Green Gulch assumed 1–2 ft (PWA 1994)	Car park constructed	Sediment delta begins post 1982 flood; levee repaired; Car park extended & raised 2-3 ft.		
	From cores, poss. 4ft deposition ca. 1840-1960 = (PWA 1994, p.17)											Dam destroyed (late 1970s). Post-dam deposition to 1992 = 450 yd^3 lower RC,1100 yd^3 d/s of beach footbridge			
Land Use Changes															
Land cover (change)	FP Oak & meadow Miwok mananged envt? (Bicknell) Woody riparian on Banducci floodplain? (PWA 2000) Redwoods in canyons and valleys? (Jebens). Uplands = Prairie/grass due to fire? * (Jebens)	Eucalyptus planted in Franks Valley. (PWA?) perennial native grasses being replaced by European annual grasses for grazing (Jebens)		Floodplain trees cleared at Banducci farm – dispute between 1894 Geodetic and 1892 maps; (PWA 2000)				1933-1942 firebreaks created by CCC (Kimball)		Heather replaces coastal scrub, planted on Banducci hillsides (PWA 2000)	Eucalyptus windrows planted on hillsides (PWA 1994)		Some riparian recovery at Banducci Farm; willows planted by NPS at Big Lagoon (PWA 2000)	Cape ivy extensive in riparian areas; wetland species & non-native grasses on floodplain (1995-)	
Agriculture	Coastal Miwok – periodic burning and grassland; (Bicknell) San Rafael mission (1817–1838); Cattle grazing by 1838 (Rancho Sausalito 1838–1856)	Sub-divided for Dairy ranches (Jebens)	Tamalpais Land & Water Co. owns most of watershed (1889–1898), promotes tourism: Grazing north to Dipsea Trail (Jebens)	Dairy ranches, flower farming (see Jebens Table 1).				Riparian flower and hay farming (PWA 2000)			Many dairy ranches condemned by State CA and purchased for State Park (?)			Farming ends 1995	
Forestry				Logging on ridges above Muir Woods late C19 (Jacobs *et al.* 1985) – similar age stumps to Bohemian Grove (cut 1890s)	Inaccessibility saves RC redwoods until early C20 (Jebens). Suggests often soil also stripped for brick clay.					Logging in Kent Canyon, 1953-1965: 1300 acres old growth redwood selectively removed by tractors yarding = 20-30% canopy. Ca. 4 miles road/trails constructed (PacWA 2002)					
Road construction		Sausalito – Bolinas Road (Hwy-1) 1870 (PWA 2000 & others)		Muir Woods Road - Four Corner to Redwood Grove (1893) – no connection to Franks Valley (Jebens)	Muir Woods Road extended to Hwy ca1905-10 Pacific Way extended to Muir Beach (1908) (Jebens / PacWA)		Panoramic Hwy opened 1928. Franks Valley & Muir Woods Roads upgraded (1925-6). Cars eventually banned from Muir forest floor 1923. Ridgecrest Blvd. to top of mt. Tam. (PacWA	First car park at Muir Woods – cut & fill, grading (Monroe). 16 footbridges over RC in Muir Woods, reduced to 4 by 1961 (Kimball) 1938 Federal adoption of Muir Woods Road		5 miles of roads and trails constructed to 1953–1965 (PacWA 2002)		Highway 1 bridge upgraded, raised to avoid flooding (PWA 2000) 4 miles of roads and trails constructed to 1971-1982 (PacWA 2002)			
	58 miles of roads and trails constructed to 1947 (PacWA 2002)							1933-1942 CCC constructed trails, bridges							

Factor	Pre-1850	1851-1870	1871-1890	1891-1900	1901-1910	1910-1920	1921-1930	1931-1940	1941-1950	1951-1960	1961-1970	1971-1980	1981-1990	1991-2000	2000-
Other infrastructure				Railroad constructed in upper watershed (1896); inns, & sporting club. Tam Land & Water develops Mill Valley. MMWD 1894: abstraction of flows from upper watershed to Mill Valley (Grant)	Muir Woods NM established (1908) to save last virgin trees; lots for vacation homes near confluence of Fern Ck / Sequoia Canyon. North Coast Water Company lands near NM given to St. park		Irrigation at Banducci site (PWA 2000); Inn and small cottages at Muir Beach, sub-division of Muir Beach Comm. (PWA 1994) St. Park N of Muir Woods operational by 1930 (Bicknell)		Reservoir built behind Banducci house fed by occasional spring (ca. 1950) (PWA 2000)	Well sunk for Muir Beach homes (1947) (well sometime prior to 1963, Martin)	Banducci well in bank used for irrigation; Muir Beach donated to State Park, Green Gulch sold to G. G. Farm (1967). Franks Valley purchased from State Park 1968. Abstractions to Mill Valley stop	GGNRA created 1972 (Bicknell)	Most watershed land protected as State or Federal park; irrigation (Muir Beach Comm supply) from 2 pumps 10ft from creek at Banducci (PWA 2000/ Martin); NPS obtains Banducci site 1980	Flows decreasing due to pumping (NPS 1994); pumping ends 1995 (PWA 2000 / Martin)	

State Park acquisitions 1928-1971

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Appendix B

Water Quality Data

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Table B-1. Monthly Stream Temperatures (oC) for all sites for entire period of record.

Location	Period of Record	Mean	n	SD	Mean	n	SD	Mean	n	SD	Mean	n	SD	Mean	n	SD	Mean	n	SD
		October			**November**			**December**			**January**			**February**			**March**		
Upper Redwood Creek																			
Bootjack Camp headwaters																	12.3	1	n/a
upstream of Buch Creek																			
Buch Creek																			
Fern Creek																			
Cathedral Grove																			
Lower Redwood Creek																			
Muir Woods Bridge	86-'98, '04, '05	13.3	4	0.8	12.9	2	0.2	11.9	3	0.4	11.3	4	0.5	11.9	3	0.5	11.1	3	0.2
Banducci (at MBCSD well)	1990-1993	13.4	3	0.5	10.7	2	2.3	9.0	1	n/a	6.0	1	n/a	9.5	2	0.7	9.3	3	0.6
Banducci tributary	1997-1998							9.5	2	0.7	11.5	2	0.7	13.0	2	1.4	11.0	1	n/a
Hwy 1 Bridge	1993-2005	13.2	24	1.3	12.8	1	n/a	11.9	2	1.1	10.9	3	0.8	12.0	3	0.6	11.8	4	0.6
Pacific Way Bridge	1986-2005	13.6	4	0.5	12.2	3	1.0	11.1	4	0.8	11.9	4	0.4	12.5	5	0.7	11.6	4	0.6
Backwater	1992-2003	16.0	1	n/a	14.0	1	n/a	12.5	1	n/a				12.9	1	n/a	13.6	1	n/a
Pedestrian Bridge	1992-2003	13.1	1	n/a				11.7	1	n/a	10.2	1	n/a	11.6	2	1.7	11.6	3	1.7
Green Gulch																			
Upper Green Gulch	1986-2002	15.5	1	n/a				11.9	2	1.0	9.3	4	2.5	11.0	7	1.5	13.2	3	1.2
Lower Green Gulch	1992-2003							11.7	3	1.2	7.8	2	0.1	11.5	7	2.8	14.0	3	1.0
Golden Gate Dairy																			
Golden Gate Dairy control	1997-2005				12.0	1	n/a	10.2	3	1.2	10.0	5	1.0	11.0	3	0.9	10.7	6	0.9
Golden Gate Dairy	1995-2005				12.3	2	0.4	10.6	3	1.3	11.8	3	0.6	11.6	4	1.0	11.1	6	1.0
Golden Gate Dairy below Hwy 1	1994-2002				12.0	1	n/a	11.8	5	1.9	10.6	4	1.9	11.2	9	1.7	10.2	4	4.1
		April			**May**			**June**			**July**			**August**			**September**		
Upper Redwood Creek																			
Bootjack Camp headwaters	1994	9	1	n/a															
upstream of Buch Creek	1994	10.1	1	n/a															
Buch Creek	1994	10.3	1	n/a															
Fern Creek	1994	10	1	n/a															
Cathedral Grove	1994	10.1	1	n/a															
Lower Redwood Creek																			
Muir Woods Bridge	1986-1998	10.2	1	n/a				13.0	2	0.7				16.0	1	n/a	18.0	1	n/a
Banducci (at MBCSD well)	1990-1993							14.3	2	0.3	13.4	2	0.1	14.1	2	0.1	13.6	3	0.24
Banducci tributary	1997-1998																		
Hwy 1 Bridge	1993-2003							14.0	2	0.1	13.3	1	n/a	14.0	1	n/a	13.7	1	n/a
Pacific Way Bridge	1986-2003							13.4	3	1.4							19.3	1	n/a
Backwater	1992-2003							13.8	1	n/a							24.5	1	n/a
Pedestrian Bridge	1992-2003	11.1	1	n/a				14.1	1	n/a									
Green Gulch																			
Upper Green Gulch	1986-2002							13.5	2	0.7									
Lower Green Gulch	1992-2003							13.7	1	n/a				14.5	1	n/a			
Golden Gate Dairy																			
Golden Gate Dairy control	1997-2002																		
Golden Gate Dairy	1995-2002																		
Golden Gate Dairy below Hwy 1	1994-2002																		

Notes:

* Period of record is not necessarily inclusive for all years, and is for all water quality parameters.

Sources:

Beutel 1998, Fong, D. 2003. Pers. comm., Leach et al 1997, Madej 1989, Marin County DHS 2003, NPS 2005, NPS 2003, NPS 2002, Podlech et al. 1994, PWA 1993, Shoulders, C. 2003. Pers. comm.

Table B-2. Conductivity (uS/cm) values for all sites for entire period of record (updated 9/16/05).

Location	Period of Record	Mean	n	SD	Mean	n	SD	Mean	n	SD	Mean	n	SD	Mean	n	SD	Mean	n	SD
		October			**November**			**December**			**January**			**February**			**March**		
Upper Redwood Creek																			
Bootjack Camp headwaters	1994																210	1	n/a
upstream of Buch Creek																			
Buch Creek																			
Fern Creek																			
Cathedral Grove																			
Lower Redwood Creek																			
Muir Woods Bridge	86-'98, '04,'05	210	4	10	125	2	85	147	2	3	136	4	21	141	3	2	162	3	1
Kent Canyon																			
Banducci (at MBCSD well)																			
Banducci tributary	1997-1998							255	2	35	140	2	14	120	2	14			
Hwy 1 Bridge	1993-2005	216	2	4	180	1	0	156	1	5	135	2	5	191	3	2	186	4	3
Pacific Way Bridge	1993-2005	247	4	11	183	3	15	180	4	12	132	4	15	151	5	9	187	4	9
Backwater	1992-2003	30,500	1	n/a	18,000	1	n/a	310	1	n/a				145	2	7	193	1	n/a
Pedestrian Bridge	1992-2005	268	1	n/a				158	1	n/a	203	1	n/a	177	2	7	220	3	8
Green Gulch																			
Upper Green Gulch	1986-2005	463	1	n/a				187	2	7	204	5	21	167	2	6	276	5	5
Lower Green Gulch	1992-2005				215	1	n/a	250	2	8	287	3	4	218	3	5	291	5	6
Golden Gate Dairy																			
Golden Gate Dairy control	1997-2005				505	2	177	340	3	34	188	5	46	169	4	25	353	3	25
Golden Gate Dairy	1995-2005				553	2	145	368	3	37	155	3	33	222	4	28	334	4	28
Golden Gate Dairy below Hwy 1	1994-2002				437	3	210	297	3	95	238	4	120	221	9	110	323	2	113
		April			**May**			**June**			**July**			**August**			**September**		
Upper Redwood Creek																			
Bootjack Camp headwaters	1994	160	1	n/a															
upstream of Buch Creek	1994	196	1	n/a															
Buch Creek	1994	160	1	n/a															
Fern Creek	1994	120	1	n/a															
Cathedral Grove	1994	160	1	n/a															
Lower Redwood Creek																			
Muir Woods Bridge	1986-1998	160	1	n/a				227	2	2							225	1	n/a
Kent Canyon																			
Banducci (at MBCSD well)																			
Banducci tributary	1997-1998				160	1	n/a												
Hwy 1 Bridge	1993-2003							177	1	n/a									
Pacific Way Bridge	1986-2003							187	2	15							260	1	n/a
Backwater	1992-2003							193	1	n/a							14500	1	n/a
Pedestrian Bridge	1992-2003	210	1	n/a				193	1	n/a									
Green Gulch																			
Upper Green Gulch	1986-2002							338	2	174									
Lower Green Gulch	1992-2003							276	1	n/a									
Golden Gate Dairy																			
Golden Gate Dairy control	1997-2002										208	2	12						
Golden Gate Dairy	1995-2002													210	2	14			
Golden Gate Dairy below Hwy 1	1994-2002																198	2	26

Notes:

Data are organized by season (October-March [Wet], April-Sept [Dry])

All "greater than" values are reported as that value.

For fields with multiple values, an average was taken. In cases where the average includes valuies < MRL, the MRL value was used..

Sources:

Beutel 1998, Fong, D. 2003. Pers. comm., Leach et al 1997, Madej 1989, Marin County DHS 2003, NPS 2005, NPS 2003, NPS 2002, Podlech et. al 1994, PWA 1993, Shoulders, C. 2003. Pers. comm.

Table B-3. Monthly DO Values (mg/l) for all sites for entire period of record.

Location	**Period of Record**	**Mean**	**n**	**SD**	**Mean**	**n**	**SD**	**Mean**	**n**	**SD**	**Mean**	**n**	**SD**	**Mean**	**n**	**SD**	**Mean**	**n**	**SD**
		October			**November**			**December**			**January**			**February**			**March**		
Upper Redwood Creek																			
Bootjack Camp headwaters	1994																10.1	1	n/a
upstream of Buch Creek																			
Buch Creek																			
Fern Creek																			
Cathedral Grove																			
Lower Redwood Creek																			
Muir Woods Bridge	86-'98, '04,'05	9.0	4	0.6	9.3	2	1.1	10.3	2	0.5	10.5	4	0.2	10.2	3	0.4	10.5	3	0.3
Banducci (at MBCSD well)		6.5	5	1.1	7.6	3	0.9												
Banducci tributary	1997-1998							8.7	2	0.4	10.5	2	0.1	10.4	1	n/a	10.4	1	n/a
Hwy 1 Bridge	1993-2005	5.7	25	7.2	8.3	2	1.6	9.6	1	n/a	10.0	2	0.6	10.6	4	1.0	10.7	4	1.1
Pacific Way Bridge	1993-2005	6.8	4	0.7	8.4	3	1.0	9.6	4	2.1	10.6	4	0.3	10.1	5	1.6	10.3	4	1.6
Backwater	1992-2003																9.6	1	n/a
Pedestrian Bridge	1992-2005	5.0	1	n/a				9.6	1	n/a	9.1	1	n/a	10.1	2	1.5	9.1	4	1.5
Green Gulch																			
Upper Green Gulch	1986-2005	7.4	1	n/a				10.1	2	0.9	11.0	5	0.4	11.3	2	0.6	10.1	5	0.6
Lower Green Gulch	1992-2005							10.2	2	1.6	12.2	3	0.4	11.0	2	1.0	10.7	5	1.1
Golden Gate Dairy																			
Golden Gate Dairy control	1997-2005				9.2	2	0.0	9.3	3	1.0	10.7	5	0.3	11.0	4	0.8	9.1	6	0.8
Golden Gate Dairy	1995-2005				6.7	2	3.0	7.1	3	1.5	10.3	3	0.2	10.5	4	1.1	7.0	6	0.9
Golden Gate Dairy below Hwy 1	1994-2002				8.0	3	0.6	8.3	3	4.6	8.3	4	2.7	8.2	7	5.1	8.6	4	5.2
		April			**May**			**June**			**July**			**August**			**September**		
Upper Redwood Creek																			
Bootjack Camp headwaters	1994	12.4	1	n/a															
upstream of Buch Creek	1994	11.8	1	n/a															
Buch Creek	1994	11.5	1	n/a															
Fern Creek	1994	11.6	1	n/a															
Cathedral Grove	1994	11.3	1	n/a															
Lower Redwood Creek																			
Muir Woods Bridge	1986-1998	10.7	1	n/a				8.9	2	0.4							7.5	1	n/a
Banducci (at MBCSD well)	1990-1993							8.3	2	0.3	8.1	2	0.2	7.2	2	0.7	6.4	3	0.6
Banducci tributary	1997-1998																		
Hwy 1 Bridge	1993-2003							8.3	2	1.0	7.2	1	n/a	5.8	1	n/a	5.5	1	n/a
Pacific Way Bridge	1986-2003							9.4	3	3.1							6.6	1	n/a
Backwater	1992-2003							8.5	1	n/a									
Pedestrian Bridge	1992-2003	9.5	1	n/a				7.7	1	n/a									
Green Gulch																			
Upper Green Gulch	1986-2002							7.5	2	1.7									
Lower Green Gulch	1992-2003							9.8	1	n/a									
Golden Gate Dairy																			
Golden Gate Dairy control	1997-2002																		
Golden Gate Dairy	1995-2002																		
Golden Gate Dairy below Hwy 1	1994-2002																		

Notes:

* Period of record is not necessarily inclusive for all years, and is for all water quality parameters.

Sources:

Beutel 1998, Fong, D. 2003. Pers. comm., Leach et al 1997, Madej 1989, Marin County DHS 2003, NPS 2005, NPS 2003, NPS 2002, Podlech et. al 1994, PWA 1993, Shoulders, C. 2003. Pers. comm.

Table B-4. Summary of nutrient data in Redwood Creek by season (pre 1997).

Location	Period of Record	Phos (mg/l)			NH$_3$ (mg N/l)			NO$_2$ & NO$_3$ (mg/l)		
		mean	n	SD	mean	n	SD	mean	n	SD
		October - March								
Upper Redwood Creek										
Bootjack Camp headwaters	1994	0.01	1	n/a	0.02	1	n/a	0.14	1	n/a
upstream of Buch Creek										
Buch Creek										
Fern Creek										
Cathedral Grove										
Lower Redwood Creek										
Muir Woods Bridge	1986-1996	0.01	4	0.01	0.02	2	0.01	0.22	4	0.19
Kent Canyon	1996									
Above Banducci	1990-1993							0.25	8	0.17
Banducci tributary	1997-1998									
Hwy 1 Bridge	1993-1996				0.02	2	0.01			
Pacific Way Bridge	1986-1996	0.01	3	0.01	0.02	2	0.01	0.32	3	0.24
Backwater	1992-1993									
Pedestrian Bridge	1992-1993									
Green Gulch										
Upper Green Gulch	1986-1988	0.03	5	0.03				0.46	5	0.42
Lower Green Gulch	1992-1995									
Golden Gate Dairy										
Golden Gate Dairy control site	1997-2002									
Golden Gate Dairy	1995									
Golden Gate Dairy below Hwy 1	1994-1996									
		April - September								
Upper Redwood Creek										
Bootjack Camp headwaters	1994	0.002	1	n/a				0.22	1	n/a
upstream of Buch Creek	1994	0.098	1	n/a				0.13	1	n/a
Buch Creek	1994	0.074	1	n/a				0.1	1	n/a
Fern Creek	1994	0.09	1	n/a				0.06	1	n/a
Cathedral Grove	1994	0.007	1	n/a				0.11	1	n/a
Lower Redwood Creek										
Muir Woods Bridge	1986-1996	0.06	2	0.04				0.10	2	0.05
Kent Canyon	1996									
Above Banducci	1990-1993	0.01	3	0.00	0.05	3	0.00	0.01	3	0.00
Banducci tributary	1997-1998									
Hwy 1 Bridge	1993-1996	0.04	3	0.04	0.05	3	0.03	0.01	3	0.01
Pacific Way Bridge	1986-1996	0.19	11	0.41	0.13	5	0.10	0.59	10	0.63
Backwater	1992-1993	0.12	5	0.04	0.20	3	0.11	1.40	3	1.08
Pedestrian Bridge	1992-1993	0.12	7	0.04	0.25	2	0.13	0.88	5	0.58
Green Gulch										
Upper Green Gulch	1986-1988	0.06	2	0.06				0.10	2	0.00
Lower Green Gulch	1992-1995	0.11	9	0.10	0.19	6	0.19	0.64	6	0.62
Golden Gate Dairy										
Golden Gate Dairy control site	1997-2002									
Golden Gate Dairy	1995									
Golden Gate Dairy below Hwy 1	1994-1996									

Notes:

Data are organized by season (October-March [Wet], April-Sept [Dry])

For fields with multiple values, an average was taken. In cases where the average includes valuies < MRL, the MRL value was used..

Note phosphorus form may be either as P or PO4 (unknown)

Sources:

Beutel 1998, Fong, D. 2003. Pers. comm., Leach et al 1997, Madej 1989, Marin County DHS 2003, NPS 2003, NPS 2002, Podlech et. al 1994, PWA 1993, Shoulders, C. 2003. Pers. comm.

Table B-5. Summary of nutrient data in Redwood Creek by season (Post 1997).

Location	Period of Record	Phos (mg/l)			NH_3 (mg N/l)			NO_2 & NO_3 (mg/l)		
		mean	n	SD	mean	n	SD	mean	n	SD
		October - March								
Upper Redwood Creek										
Bootjack Camp headwaters										
upstream of Buch Creek										
Buch Creek										
Fern Creek										
Cathedral Grove										
Lower Redwood Creek										
Muir Woods Bridge	1997, '98, '04, '05	0.1	5	0.01	0.19	8	0.02	0.3	5	0.08
Kent Canyon										
Above Banducci	1990-93, '04, '05	0.1	7	0.02	0.32	3	0.05	0.4	6	0.08
Banducci tributary										
Hwy 1 Bridge	1997-2005	0.1	7	0.03	0.25	5	0.04	0.4	6	0.10
Pacific Way Bridge	1997-2005	0.2	7	0.06	0.19	12	0.02	0.4	7	0.07
Backwater/Big Lagoon										
Pedestrian Bridge	2003-2005	0.2	7	0.04	0.34	3	0.04	0.6	7	0.06
Green Gulch										
Upper Green Gulch	1997-2005	0.17	17	0.03	0.14	17	0.02	0.6	5	0.10
Lower Green Gulch	1997-2005	0.18	17	0.06	0.13	18	0.01	1.9	7	0.11
Golden Gate Dairy										
Golden Gate Dairy control site	1997-2005	0.12	16	0.01	0.13	13	0.02	0.6	5	0.09
Golden Gate Dairy	1997-2005	0.21	13	0.02	0.18	10	0.02	0.6	5	0.11
Golden Gate Dairy below Hwy 1	1997-2002	0.24	10	0.10	0.05	14	0.04			
		April - September								
Upper Redwood Creek										
Bootjack Camp headwaters										
upstream of Buch Creek										
Buch Creek										
Fern Creek										
Cathedral Grove										
Lower Redwood Creek										
Muir Woods Bridge	1997-1998				0.10	1	n/a			
Kent Canyon										
Above Banducci										
Banducci tributary										
Hwy 1 Bridge	1997-2003	0.01	1	n/a						
Pacific Way Bridge @ Muir Beach	1997-2003	0.01	1	n/a	0.10	1	n/a			
Backwater/Big Lagoon	1997-2003	0.02	1	n/a	0.10	1	0.0			
Pedestrian Bridge	2003	0.02	1	n/a						
Green Gulch										
Upper Green Gulch	1997-2002									
Lower Green Gulch	1997-2003	0.12	1	n/a						
Golden Gate Dairy										
Golden Gate Dairy control site										
Golden Gate Dairy										
Golden Gate Dairy below Hwy 1										

Notes:

Data are organized by season (October-March [Wet], April-Sept [Dry])

All "less than" or "greater than" values reported as that value.

For fields with multiple values, an average was taken. In cases where the average includes valuies < MRL, the MRL value was used..

Note phosphorus form may be either as P or PO4 (unknown)

Sources:

Beutel 1998, Fong, D. 2003. Pers. comm., Leach et al 1997, Madej 1989, Marin County DHS 2003, NPS 2005, NPS 2003, NPS 2002, PWA 1993, Shoulders, C. 2003. Pers. comm.

Table B-6. Summary of bascteria data in Redwood Creek by season (pre 1997).

Location	Period of Record	Bacterial Concentration (MPN/100 ml)											
		Enterococcus			E. coli			Fecal			Total Coliform		
		mean	n	SD	mean	n	SD	mean	n	SD	mean	n	SD
		October - March											
Upper Redwood Creek													
Bootjack Camp headwaters	1994							2	2	n/a	2	2	n/a
upstream of Buch Creek													
Buch Creek													
Fern Creek													
Cathedral Grove													
Lower Redwood Creek													
Muir Woods Bridge	1986-1996							1022	11	2331	660	5	601
Kent Canyon													
Above Banducci	1990-1993							51	7	48			
Banducci tributary													
Hwy 1 Bridge	1993-1996							457	6	351	1533	6	480
Pacific Way Bridge	1986-1996							975	11	799	1983	6	1025
Backwater													
Pedestrian Bridge													
Green Gulch													
Upper Green Gulch	1986-1988							93	5	155			
Lower Green Gulch	1992-1995							7603	4	8542	5100	2	4458
Golden Gate Dairy													
Golden Gate Dairy control site													
Golden Gate Dairy	1995							130	2	0	130	2	0
Golden Gate Dairy below Hwy 1	1994-1996							3045	11	3752	2114	9	1869
		April - September											
Upper Redwood Creek													
Bootjack Camp headwaters													
upstream of Buch Creek													
Buch Creek													
Fern Creek													
Cathedral Grove													
Lower Redwood Creek													
Muir Woods Bridge	1986-1996							89	5	107	210	3	87
Kent Canyon	1996							27	2	0	27	2	0
Above Banducci	1990-1993							35	3	13			
Banducci tributary													
Hwy 1 Bridge	1993-1996							198	5	210	245	2	148
Pacific Way Bridge	1986-1996							859	7	1098	1310	2	552
Backwater													
Pedestrian Bridge	1994							7	1	n/a	27	1	n/a
Green Gulch													
Upper Green Gulch	1986-1988							4	2	1	50	1	n/a
Lower Green Gulch	1992-1995							121	4	96	34	1	n/a
Golden Gate Dairy													
Golden Gate Dairy control site													
Golden Gate Dairy													
Golden Gate Dairy below Hwy 1													

Notes:

Data are organized by season (October-March [Wet], April-Sept [Dry])

All "less than" or "greater than" values reported as that value.

For fields with multiple values, an average was taken. In cases where the average includes valuies < MRL, the MRL value was used..

Period of record is not necessarily inclusive for all years, and is for all water quality parameters.

Table B-7. Summary of bascteria data in Redwood Creek by season (Post 1997).

		Bacterial Concentration (MPN/100 ml)											
Location	**Period of Record**	**Enterococcus**			**E. coli**			**Fecal**			**Total Coliform**		
		mean	**n**	**SD**	**mean**	**n**	**SD**	**mean**	**n**	**SD**	**mean**	**n**	**SD**
		October - March											
Upper Redwood Creek													
Bootjack Camp headwaters													
upstream of Buch Creek													
Buch Creek													
Fern Creek													
Cathedral Grove													
Lower Redwood Creek													
Muir Woods Bridge	1997,'98, '04, '05							372	10	171	883	10	186
Kent Canyon													
Kent Canyon													
Above Banducci	1990, '93, '04, '05							446	5	150	446	5	126
Banducci tributary													
Hwy 1 Bridge	1997-2005							540	6	246	648	5	178
Pacific Way Bridge	1997-2005							1078	10	304	1871	10	416
Backwater/Big Lagoon													
Pedestrian Bridge	2003							3577	5	3081	4468	4	250
Muir Beach													
Muir Beach North	2000-2003	287	20	608	4	1	0						
Muir Beach Middle	2000-2003	93	20	195	2	1	0						
Muir Beach South	2000-2003	58	20	99	2	1	0						
Green Gulch													
Upper Green Gulch	1997-2005							234	18	95	873	7	90
Lower Green Gulch	1997-2005							219	19	56	871	8	145
Golden Gate Dairy													
Golden Gate Dairy control site	1997-2005							133	15	29	345	4	105
Golden Gate Dairy	1997-2005							299	11	109	580	4	273
Golden Gate Dairy below Hwy 1	1997-2002							443	14	636	5200	4	7200
		April - September											
Upper Redwood Creek													
Bootjack Camp headwaters													
upstream of Buch Creek													
Buch Creek													
Fern Creek													
Cathedral Grove													
Lower Redwood Creek													
Muir Woods Bridge	1997,'98, '04, '05							23	3	13	137	3	13
Kent Canyon													
Above Banducci	1990, '93, '04, '05							102	2	69	102	2	69
Banducci tributary													
Hwy 1 Bridge	1997-2003							320	3	290	465	2	435
Pacific Way Bridge @ Muir Beach	1997-2005							469	4	340	1147	3	453
Backwater/Big Lagoon	1997-2005												
Pedestrian Bridge	2003-2005							324	3	299	451	2	249
Muir Beach													
Muir Beach North	2003-2005	55	60	141	466	16	1515	451	2	449	1551	18	840
Muir Beach Middle	2000-2003	14	51	18	14	9	14						
Muir Beach South	2000-2003	21	50	47	9	10	0						
Green Gulch													
Upper Green Gulch	1997-2005							315	2	185	315	2	185
Lower Green Gulch	1997-2005							280	3	20	270	2	148

Table B-8. Summary of mineral data in Redwood Creek by season.

Location	Period of Record	Na (mg/l)	K (mg/l)	Ca (mg/l)	Mg (mg/l)	Alkalinity (mg/l)	Chloride (mg/l)	Sulfate (mg/l)
		October - March						
Upper Redwood Creek								
Bootjack Camp headwaters	1994	8.4	0.06	13.5	21.7	97	10.5	2.0
upstream of Buch Creek								
Buch Creek								
Fern Creek								
Cathedral Grove								
Lower Redwood Creek								
Muir Woods Bridge	1986-'88, '94	10.8	0.68	8.8	8.4	56	10.4	10.0
Kent Canyon								
Above Banducci								
Banducci tributary								
Hwy 1 Bridge								
Pacific Way Bridge	1986-1988		0.77	9.8	9.0	53	15.3	
Backwater/Big Lagoon								
Pedestrian Bridge	1994	13.5	0.58	9.1	13.0	76	17.4	13.0
Green Gulch tributary								
Upper Green Gulch	1986-1988		1.17	19.5	12.0	90	29.3	
Lower Green Gulch								
Golden Gate Dairy drainage								
Golden Gate Dairy control site								
Golden Gate Dairy								
Golden Gate Dairy below Hwy 1								
		April - September						
Upper Redwood Creek								
Bootjack Camp headwaters						110	10.0	2.0
upstream of Buch Creek						127	11.8	6.0
Buch Creek						57	10.3	2.0
Fern Creek						64	9.5	11.0
Cathedral Grove						99	11.6	8.0
Lower Redwood Creek								
Muir Woods Bridge	1986-1988		0.8	14.3	12.0	88	13.9	16.0
Kent Canyon								
Above Banducci								
Banducci tributary								
Hwy 1 Bridge								
Pacific Way Bridge @ Muir Beach	1986-1988		0.9	14.7	12.3	85	16.8	
Backwater/Big Lagoon								
Pedestrian Bridge								
Green Gulch								
Upper Green Gulch	1986-1988		1.2	33.0	20.3	145	38.1	12.0
Lower Green Gulch								
Golden Gate Dairy								
Golden Gate Dairy control site								
Golden Gate Dairy								
Golden Gate Dairy below Hwy 1								

Notes:

Data are organized by season (October-March [Wet], April-Sept [Dry])

All "less than" or "greater than" values reported as that value.

For fields with multiple values, an average was taken. In cases where the average includes valuies < MRL, the MRL value was used..

Period of record is not necessarily inclusive for all years, and is for all water quality parameters.

Table B-9. Summary of metals data in Redwood Creek by season.

Location	Period of Record	Ag (mg/l)	Al (mg/l)	As (mg/l)	B (mg/l)	Ba (mg/l)	Cd (mg/l)	Co (mg/l)	Cr (mg/l)	Cu (mg/l)	Fe (mg/l)	Hg (mg/l)	Mn (mg/l)	Mo (mg/l)
		October - March												
Upper Redwood Creek														
Bootjack Camp headwaters	1994	0.00	0.05	0.02	0.21	0.01	0.001	0.01	0.01	0.01	0.01	<0.001	0.00	0.02
upstream of Buch Creek														
Buch Creek														
Fern Creek														
Cathedral Grove														
Lower Redwood Creek														
Muir Woods Bridge	1986-'88, '94	0.00	0.05	<0.001	0.04	0.02	<0.001	<0.001	0.00	0.01	0.11	<0.0001	0.00	0.01
Kent Canyon														
Above Banducci														
Banducci tributary														
Hwy 1 Bridge														
Pacific Way Bridge	1986-1988				0.017		<0.01			0.037	0.11	<0.0001		
Backwater/Big Lagoon														
Pedestrian Bridge	1994	0.00	0.04	<0.001	0.079	0.03	<0.001	<0.001	0.002	0.001	0.02	<0.001	0.01	0.01
Green Gulch tributary														
Upper Green Gulch	1986-1988				0.02					0.04	0.07	<0.0001		
Lower Green Gulch														
Golden Gate Dairy drainage														
Golden Gate Dairy control site														
Golden Gate Dairy														
Golden Gate Dairy below Hwy 1														
		April - September												
Upper Redwood Creek														
Bootjack Camp headwaters														
upstream of Buch Creek														
Buch Creek														
Fern Creek														
Cathedral Grove														
Lower Redwood Creek														
Muir Woods Bridge	1986-1988				0.09		<0.01			<0.01	0.37	<0.0001		
Kent Canyon														
Above Banducci														
Banducci tributary														
Hwy 1 Bridge														
Pacific Way Bridge @ Muir Beach	1986-1988				0.03		<0.01			<0.01	0.03	<0.0001		
Backwater/Big Lagoon														
Pedestrian Bridge														
Green Gulch														
Upper Green Gulch	1986-1988				0.03		<0.01			<0.01	0.02	<0.0001		
Lower Green Gulch														
Golden Gate Dairy														
Golden Gate Dairy control site														
Golden Gate Dairy														
Golden Gate Dairy below Hwy 1														

Notes:

Data are organized by season (October-March [Wet], April-Sept [Dry])

For fields with multiple values, an average was taken. In cases where the average includes valuies < MRL, the MRL value was used.

Sources:

Madej 1989, Podlech et. al 1994

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Appendix C

Species Detections and Predictions: Amphibians and Reptiles

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Table C-1. Amphibian and reptile species detections and predictions in the Redwood Creek watershed

Class	Family	Common name	Scientific name	Status[1]	Habitat Association						Detection	Source[2]
					Forest (conifer or hardwood)	Grass-land	Coastal scrub	Riparian wood-land	Seasonal wetland	Creek		
Amphibians	Dicamptodontidae	California giant salamander	*Dicamptodon ensatus*		+			+		+	+	E
	Salamandridae	rough-skinned newt	*Taricha granulosa*		+			+		+	+	A,C,D
		California newt	*Taricha torosa*		+			+		+	+	A,C,D
	Plethodontidae	ensatina	*Ensatina eschscholtzii*		+	+	+	+	+		+	A,C,D
		arboreal salamander	*Aneides lugubris*		+	+	+	+	+		+	C,D
		California slender salamander	*Batrachaseps attenuatus*		+	+	+	+			+	C,D
	Bufonidae	California toad	*Bufo boreas halophilus*		+	+	+	+	+	+	+	C,D
	Hylidae	Pacific chorus frog	*Pseudacris regilla*		+	+	+	+	+	+	+	A,D
	Ranidae	California red-legged frog	*Rana draytonii*	FT, SSC	+	+	+	+	+	+	+	A,C, G
		foothill yellow-legged frog	*Rana boylii*	SSC	+			+		+	-	B,C,D
Reptiles	Emydidae	western pond turtle	*Clemmys marmorata*	SSC				+	+	+	+	B,C
		painted turtle	*Chrysemys picta*						+	+	+	E
	Phrynosomatidae	western fence lizard	*Sceloporus occidentalis*		+	+	+				+	A, B, C,D
	Scincidae	western skink	*Eumeces skiltonianus*		+	+	+	+			-	B,C
	Anguidae	southern alligator lizard	*Elgaria multicarinata*		+	+	+	+			-	B
		northern alligator lizard	*Elgaria coerulea*		+	+	+	+			+	B,C
	Boidae	rubber boa	*Charina bottae*		+			+	+		+	B,C

Class	Family	Common name	Scientific name	Status[1]	Habitat Association						Detection	Source[2]
					Forest (conifer or hardwood)	Grass-land	Coastal scrub	Riparian wood-land	Seasonal wetland	Creek		
Reptiles	Colubridae	ring-necked snake	*Diadophis punctatus*		+			+	+		+	B,C
		sharp-tailed snake	*Contia tenuis*		+			+	+		+	B,C
		western yellow-bellied racer	*Coluber constrictor mormon*			+	+				-	A,B,C
		gopher snake	*Pituophis melanoleucus*		+	+	+	+			-	B
		common kingsnake	*Lampropeltis getula*		+	+	+	+			-	B
		common garter snake	*Thamnophis sirtalis*		+	+	+	+	+	+	-	B
		western terrestrial garter snake	*Thamnophis elegans*		+	+	+	+	+	+	+	A,B,C,D
		aquatic garter snake	*Thamnophis atratus*		+	+	+	+	+	+	-	B
	Viperidae	western rattlesnake	*Crotalis viridis*			+	+				-	A

[1] **Status:** FT: Federally Threatened;
SSC: California Species of Special Concern.

[2] **Source:** (A) Fellers and Guscio 2004;
(B) California Wildlife Habitat Relationships System Version 8.2, 2008;
(C) PWA et al. 1994;
(D) Ely 1993;
(E) GANDA 2007.

[3] **Detection:** Species Detected (+); Species Not Detected (-): Detection = species that have been observed and documented in Redwood Creek watershed since 1992. If a species is categorized as Not Detected (-), there is either a historical record for the species in the watershed, suitable habitat for the species in the watershed, or both.

Appendix D

Fish Survey Results, 1992—2002

D1.1 Summary

This appendix summarizes available data collected from 1992–2002 to document fish distribution and abundance in Redwood Creek and its estuary. Fish surveys were conducted in 1992 and 1993 for the Preliminary Environmental Assessment (PWA et al. 1994). Subsequent investigations have included a report on the use of lower Redwood Creek and Big Lagoon by juvenile coho salmon (*Oncorhynchus kisutch*) and steelhead (*Oncorhynchus mykiss*) (Fong 1996), annual distribution and abundance surveys for juvenile coho salmon and steelhead (Smith 1994b, 1995, 1996, 1997, 1998, 2000, 2001), salmonid outmigrant trapping in 1996 (Fong 1997a), an anadromous salmonid spawner and carcass survey, conducted in the winter of 1996-1997 (Fong 1997b), and a study of the use of the Big Lagoon estuary (and other central California estuaries) by rearing coho salmon and steelhead (Laidig 2003). In addition to the species documented during the above surveys, NPS has observed Sacramento blackfish (*Orthodon microlepidotus*) and yellowfin gobies (*Acanthogobius flavimanus*) at the site.

In addition to the limited aquatic habitat data collected as part of several of the above fish investigations, a comprehensive stream habitat inventory was conducted in 1995 by GGNRA staff (Fong 2002). This inventory includes data on channel morphology, substrate, water temperature, habitat types, LWD, residual pool volume, streamside cover, riparian canopy density, and benthic macroinvertebrates for approximately five miles of Redwood Creek, from Big Lagoon upstream to Bridge 4 in Muir Woods National Monument. In a separate study, woody debris abundance and distribution in Redwood Creek from 1994–1996 were reported by Vore (1996) for reaches in and immediately downstream of Muir Woods.

Results of fish surveys are summarized below by three general reaches of Redwood Creek: the intermittently tidal lagoon, the backwater channel adjacent to the levee (near the parking lot) and just upstream of the footbridge.

D1.2 Intermittently Tidal Lagoon

The intermittently tidal lagoon at Big Lagoon was sampled in 1992 and 1993 by seining (PWA et al. 1994). Water quality data were also collected in the lagoon in 1992 and 1993; the results are discussed in the Water Quality section (including timing of the opening/closing of the mouth of the lagoon). The lagoon was sampled again in February 1995 by electrofishing and in March and October 1995 using a combination of beach seine and snorkel techniques to document use by juvenile salmonids and other fish (Fong 1996). In 2001 and 2002 the Big Lagoon estuary, including the tidal lagoon, was snorkeled repeatedly between March and December to document use by rearing salmonids over the course of each year (Laidig 2003). The estuary between the ocean and the footbridge at Muir Beach was surveyed 34 times in 2001 and 27 times in 2002, and salinity and water temperature data were collected throughout the survey periods.

1992 and 1993 surveys. In 1992 the size and depth of the lagoon varied substantially with sand bar formation and streamflow. The sand bar was closed by 23 June and the deepest part of the lagoon was probably about 1.25 m (PWA et al. 1994). However, streamflows declined over the summer, and by 19 September there was no inflow and maximum lagoon depth had dropped to only 0.65 m. On 23 June, with a recently closed sand bar and good streamflow, the lagoon was mostly freshwater (0.6 ppt salinity), except for a thin layer of more brackish water on the bottom (PWA et al. 1994). In August and September the shallow, wind mixed lagoon was brackish and unstratified. The sand bar was by breached by a late September storm, but reformed; in November the lagoon was again deeper, very salty and stratified (PWA et al. 1994).

In 1993 the lagoon was open, shallow and stratified on 4 June (PWA et al. 1994). Runoff from a heavy storm on that day lowered the partial sand bar. On 9 June and 24 June the lagoon was shallow and draining at the time of sampling; during that part of the tidal cycle the lagoon was freshwater. On 19 August the sand bar was in place, and the lagoon was relatively deep (1.2 m) and stratified (PWA et al. 1994). By September low streamflows had reduced the lagoon to a shallow (0.65 m), unstratified, freshwater pool. Inflows in excess of 0.5 cfs are probably needed to keep the summer lagoon over 1.2 m deep and to back water into the adjoining salt marsh (PWA et al. 1994).

Because of wind mixing, dissolved oxygen levels in the lagoon were generally good in 1992 and 1993 (PWA et al. 1994). However, when detrital kelp was present (14 November 1992) and during prolonged calm, overcast periods (10 September 1993) dissolved oxygen levels were lower. However, because the lagoon was shallow and unshaded, afternoon water temperatures were often quite high (PWA et al. 1994). On 23 June 1992 early evening water temperatures throughout the water column reached 23.5 oC (75 oF). When the lagoon was stratified for salinity, the highest water temperatures were within the salt water lens near the bottom (19 August 1993) (PWA et al. 1994).

Threespine stickleback (*Gasterosteus aculeatus*) were always abundant in the lagoon (PWA et al. 1994). In 1992 juvenile steelhead were common in the lagoon in August (PWA et al. 1994), despite the high afternoon water temperatures. Coho require cooler water, and none were collected in 1992. In 1993 both coho and steelhead were present on 4 June, but the storm on that day apparently flushed them from the shallow lagoon; none were seen in the lagoon during the remainder of the summer. In 1992 juvenile striped bass (*Morone saxatilis*) (to 7 inches long) were abundant in the lagoon. Other fishes collected in the lagoon in 1992 and 1993 were Pacific staghorn sculpin (*Leptocottus armatus*), starry flounder (*Platichthys stellatus*), and yellowfin goby (*Acanthogobius flavimanus*) (PWA et al. 1994).

No tidewater gobies (*Eucyclogobius newberryi*) were collected in either 1992 or 1993. Tidewater gobies tolerate a wide range of salinity, dissolved oxygen and temperature conditions and lagoon sizes, but require lagoons with some refuge from the high currents of winter floods. Big Lagoon presently has no backwater channels or salt marsh potholes to serve as winter refuges for gobies.

1995 Surveys. The mouth of the lagoon was reportedly open to the ocean during snorkel surveys on March 1 and March 30, 1995, and the mouth had closed by the time sampling occurred on October 31, 1995 (Fong 1996). No water quality data were reported for the 1995 lagoon surveys.

Two steelhead smolts (147 and 178 mm) were observed during the February electrofishing survey in the lagoon, but no coho salmon were reported. Juvenile coho salmon were observed during both March snorkel surveys, with maximum coho density (0.05 fish/m^2) reported on March 30 (Fong 1996). All coho salmon observed in the March surveys were < 35 cm in length. Juvenile steelhead were not observed on March 1 but were present in low numbers on March 30. The October 31 survey documented low numbers of juvenile steelhead in the lagoon but no coho salmon. Fong (1996) theorized that juvenile coho salmon found in the lagoon in spring 1995 may have been displaced from more favorable upstream rearing habitat by competition or high flows. It was also noted that juvenile coho salmon likely do not rear in the lagoon during summer due to poor water quality (PWA et al. 1994), predation, or other factors.

All steelhead observed in the lagoon were found in water approximately 1 m deep, in association with rubble substrate (Fong 1996). The majority (74 percent) of juvenile coho salmon observed in the late March surveys of the lagoon and upstream areas were associated with emergent or overhanging vegetation. Woody debris, including rootwads, (12 percent) and cobble substrates (7 percent) were the next most frequently used cover types, although it is unclear which of these features, if any, were present in the lagoon. Large amounts of filamentous green algae and decaying algae were noted on the bottom of the lagoon during the October snorkel survey (Fong 1996).

In addition to coho salmon and steelhead, Fong (1996) also observed or collected topsmelt (*Atherinops affinis*), Pacific staghorn sculpin (*Leptocottus armatus*), striped bass, and threespine stickleback in the lagoon.

2001 and 2002 Surveys. Salinity and water temperature data were collected in the lower portion of the Big Lagoon project area during snorkel surveys in 2001 and 2002 (Laidig 2003). Salinity in 2001 was low until late-May and fluctuated until early July in response to periodic salt water intrusion. Water in the estuary was largely fresh from early July through the end of 2001. In 2002 the estuary was freshwater until late April, after which the salinity fluctuated through November. Estuarine water temperatures in 2001 ranged from a low of 11°C in March to a high of 29.2°C in late August. In 2002, water temperatures followed a similar pattern, with a low of 12°C recorded in March and November and a high of 22°C in August.

In 2001, young-of-the-year (YOY) steelhead were first observed on June 12, and were present only in low numbers during the year (n=7) (Laidig 2003). Abundance of smolts and age 1+ steelhead in 2001 was highest when they were first seen on March 26, with smolt abundance declining through April and May and the last smolt observed on June 23. Abundance of 1+ steelhead was lowest in early May, with a brief increase in mid-June followed by a decline to zero by mid-July. In 2001, YOY coho were only observed in the upstream end of the lagoon, immediately downstream of the Muir Beach footbridge (see the following subsection, Redwood Creek, Pools Near Parking Lot). Coho smolts in 2001 were first observed on April 22, and abundance peaked in early May. Coho smolts remained in the estuary for a total of 31 days, and none were observed during or following the May 27 survey.

In 2002, YOY steelhead were observed from late April to mid-August, with the peak abundance reported in mid-June (Laidig 2003). Steelhead smolts and 1+ fish first appeared in the estuary in late March and early April, with peak smolt abundance in early May. Steelhead smolts were not observed after mid-June. Abundance of 1+ steelhead in 2002 peaked at nine fish in mid-June and declined to zero by mid-August. YOY coho were very abundant in 2002, with 150 fish observed during sampling in late May and numbers increasing to 900 fish by late April (Laidig 2003). YOY coho were observed in the estuary until early September, 2002. Coho smolts in 2002 were first observed in late March, with numbers peaking at 60 fish in late April and dropping to nearly zero until they were last observed in early August.

In 2001, threespine stickleback and sculpin were also observed in the Big Lagoon project area (Laidig 2003). Stickleback and sculpin were observed again in 2002, as well as striped bass, which were not seen in 2001. Striped bass, ranging in length from 100–150 mm, were present from April–June, and were believed to be feeding on YOY coho, steelhead, and possibly stickleback.

D1.3 Redwood Creek Backwater Channel (Near Parking Lot)

Immediately upstream of the intermittently tidal lagoon, a depositional delta, gabion bank protection, channel realignment and levee construction combine to produce a long, deep mid-channel pool and a backwater channel behind the creek levee (PWA et al. 1994). This portion of Big Lagoon was surveyed in 1992 and 1993 (PWA et al. 1994) and again in 1994 (Smith 1994b) and 1995 (Fong 1996). Aquatic habitat data were also collected in this reach in 1995 (Fong 1996, Fong 2002). In 2001 and 2002, this area of the estuary was snorkeled to document its use as rearing habitat by juvenile coho salmon and steelhead (Laidig 2003).

1992 and 1993 Surveys. Depth of the mid-channel pool during the 1992–1993 surveys was up to 1.2 m and depth of the backwater channel was up to 1.6 m. Neither habitat was well shaded, resulting in growth of abundant algae and rooted and floating aquatic plants. In addition, since the backwater channel is not scoured by winter flows, organic detritus up to 0.2 m thick accumulates on the bottom. Detrital algae, cattails and riparian leaves also accumulate in summer in the mid-channel pool.

The highest water temperatures in 1992 and 1993 briefly exceeded 20oC near the surface in late afternoon, but cooled off substantially (15–18°C) over night and during overcast periods. However, because of algal growth and detrital decomposition, the pools experienced low summer dissolved oxygen levels in morning and during cloudy periods (PWA et al. 1994). During 19 September 1992 sampling, the dissolved oxygen levels ranged between 2.0 and 4.3 mg/l in the morning (PWA et al. 1994), and because of overcast, they increased little from photosynthesis during the day. Juvenile steelhead were observed in the morning gulping at the surface to force more highly oxygenated boundary water over their gills. At the time, there was no surface inflow from Redwood Creek to the pools. Even in 1993, when surface inflows were present, morning dissolved oxygen levels were mostly below 6.0 mg/l during August and September sampling (PWA et al. 1994). Near the foot bridge at the tail of the large mid-channel pool, dissolved oxygen levels near the bottom were often very low, even in the afternoon. Bottom disturbance by swimming dogs was usually responsible; most unleashed dogs crossing the bridge jumped in the water for a swim, and on one afternoon four dogs were counted splashing in the water within 15 minutes.

In 1992 and 1993 both coho and steelhead were abundant in the pools in early summer (PWA et al. 1994). Not only were numerous fish caught by relatively inefficient deepwater electroshocking, but schools of coho and steelhead were regularly seen. In 1992, however, both species disappeared over the summer, presumably due to poor dissolved oxygen levels. In 1993 coho and steelhead also declined substantially over the summer, but some fish were still present in September (PWA et al. 1994). PWA et al. (1994) reported that the primary value of the pools for coho and steelhead was probably as feeding and resting areas in winter and spring for outmigrating smolts.

Threespine stickleback and prickly sculpin (*Cottus asper*) were common in the pools throughout the year. In both 1992 and 1993 yellowfin goby were also commonly collected. All gobies exceeded 80 mm standard length (adult size), so it is not known whether a reproducing population is established in the lagoon. In 1992 juvenile Sacramento blackfish (*Orthodon microlepidotus*) were present in the pools and in 1993 two Sacramento perch (*Archoplites interruptus*) were collected. Both species are present in a pond in Green Gulch, and occasional individuals probably enter the creek with pond overflow.

1994 and 1995 Surveys. Sampling in July 1994 documented use of the pools by steelhead, but no coho salmon were present in this area (Smith 1994b). A total of one YOY steelhead and three older juvenile steelhead (age 1+ or 2+) were found in the pools in July 1994. Whereas juvenile steelhead at all sites sampled were found to be considerably more abundant in 1994 than in 1992 or 1993, abundance of juvenile coho salmon in 1994 was lower and their distribution was more restricted throughout Redwood Creek and Big Lagoon than in the two previous years (Smith 1994b). Other species documented in July 1994 in the pools near the parking lot were threespine stickleback and prickly sculpin.

In 1995 the pools were sampled by seining and snorkeling (Fong 1996). The maximum depth of the pools during October 1995 sampling ranged from 0.25–0.9 m, with dense overhanging vegetation and abundant woody debris. Most coho were found during April and May surveys, with 250 and 152 juvenile coho observed, respectively. Although this area appeared to be suitable habitat for summer rearing by coho salmon, coho apparently did not rear in the pools through the summer. Only one juvenile coho salmon was found during the October sampling. Abundance of juvenile steelhead was generally very low, peaking during the May sample period. Age 1+ steelhead were present in the pools in low numbers, and most were found near the channel bottom, in dense cover. Most steelhead observed in this area and upstream reaches were associated with emergent and overhanging vegetation, woody debris, and cobble substrates (>64 mm). It is likely that the number of steelhead was underestimated during the snorkel surveys due to their behavior and poor visibility (Fong 1996).

Other fish species observed in the pools during the 1995 surveys were prickly sculpin, coastrange sculpin (*Cottus aleuticus*), and threeespine stickleback (Fong 1996).

2001 and 2002 Surveys. In 2001, a total of five YOY coho were observed in this part of the estuary, all of which were located in the upstream end of the lagoon, immediately downstream of the Muir Beach footbridge. YOY coho were first observed on April 28 and none were found after mid-July. Coho smolts in 2001 were also observed in the pools near the parking lot. As noted above for the intermittently tidal lagoon, coho smolts were first observed on April 22, and abundance peaked in early May. Coho smolts remained in the estuary for a total of 31 days, and none were observed during or following the May 27 survey. Steelhead YOY and smolts were also present in 2001 in this portion of the estuary (Laidig 2003). Details are described above in the Intermittently Tidal Lagoon section).

Distribution of rearing coho salmon and steelhead in the estuary in 2002 was not reported by Laidig (2003). Nevertheless, YOY coho salmon were reported to be “very abundant” in the estuary in 2002, and it can be assumed that YOY coho were present in the pools near the parking lot.

Laidig (2003) noted the presence of threespine stickleback and unidentified sculpin species in the estuary in both 2001 and 2002, and striped bass were observed in 2002. The exact location of these species was not reported, so their presence in the pools is speculative. Water quality data reported by Laidig (2003) for the estuary as a whole are summarized above (see the Intermittently Tidal Lagoon section).

D1.4 Redwood Creek—Upstream Of Footbridge

Systematic sampling of Redwood Creek upstream of the Muir Beach footbridge began in 1992 in association with the Big Lagoon restoration planning effort (PWA et al. 1994) and, with the exception of 1999, has taken place annually since then. Backpack electrofishing has been used each year to document fish distribution and abundance. Results are currently available through 2001 (Smith 1994b, 1995, 1996, 1997, 1998, 2000, 2001). In addition to these annual surveys, outmigrant trapping was used in 1996 to document outmigrating anadromous salmonids (Fong 1997a), and a coho salmon spawner and carcass survey was conducted in the winter of 1996–1997 (Fong 1997b).

Studies characterizing the aquatic and riparian habitat in portions of Redwood Creek upstream of the footbridge have also been conducted since 1994. These include a survey to document woody debris recruitment in and downstream of Muir Woods National Monument from 1994–1996 (Vore 1996), and a 1995 stream habitat and benthic macroinvertebrate inventory (Fong 2002). Daily water temperature at the Muir Beach footbridge (mid-February–mid-July) and daily Redwood Creek discharge (March–June) were also collected as part of the 1996 GGNRA salmonid outmigrant trapping program (Fong 1997a). The 1996-1997 spawner and carcass survey included information on habitat type distribution and substrate composition for Redwood Creek (Fong 1997b). Water temperature and water clarity were also apparently recorded during the spawner and carcass surveys but were not included in the report. The annual fall surveys to document distribution and abundance of juvenile coho salmon and steelhead in Redwood Creek have included limited information on dissolved oxygen and estimates of stream discharge (Smith 1995, 1996, 1997, 1998, 2000, 2001).

1992 and 1993 surveys. In 1992 and 1993 four stream sites, from the Muir Beach footbridge upstream to Muir Woods National Monument, were sampled by backpack electroshocker (PWA et al. 1994). In 1992 coho outnumbered steelhead in summer sampling at all four sites. In 1993 coho densities were similar to those of 1992, but steelhead densities substantially increased (PWA et al. 1994).

At the Pacific Way bridge, streamflows declined to only about 0.01 cfs in late summer 1992. Salmonid densities declined by almost 40 percent between July and November (PWA et al. 1994), apparently due to the loss of shallow run and riffle habitat for rearing. In 1993 collected coho were less abundant than in 1992, reducing total coho and steelhead density compared to 1992 (PWA et al. 1994). Part of the observed difference was due to inability in 1993 to sample a pool that in 1992 had both high fish densities and a high proportion of coho. Threespine stickleback and some prickly sculpin and coastrange sculpin were also collected at the site. Although the site has primarily fine gravel and sand substrate, some suitable steelhead and coho spawning sites are present.

Downstream of the agricultural and domestic diversions, Redwood Creek was reduced to isolated pools in 1992, although flows upstream of the diversion remained above 0.2–0.25 cfs. Dissolved oxygen levels were as low as 2.5 mg/l in some of the isolated pools, and coho density dropped by two thirds between September and November sampling (PWA et al. 1994). Total fish density at the end of the summer was probably less than 20 percent of that of the site upstream of the diversion, and less than 16 percent of the next site downstream, where summer flows dropped to only 0.01 cfs (PWA et al. 1994). In 1993 streamflows were maintained at the site and total coho and steelhead density was 9 times that of 1992 (PWA et al. 1994). In 1993 most of the fish present were steelhead. Threespine stickleback and some prickly sculpin and riffle sculpin were also collected. Substrate at the site includes more sand and finer gravel than upstream, but suitable coho and steelhead spawning sites are present. Pool development is also less than at upstream sites, possibly partly due to bank modifications.

Upstream of the third bridge on Redwood Creek, within Tamalpais State Park, fish densities were substantially less than at Muir Woods in both 1992 and 1993 (PWA et al. 1994), despite good pool and cover development and substrate conditions. The site is very heavily shaded (99 percent canopy), and fish production may be limited by food availability. Threespine stickleback, prickly sculpin and riffle sculpin were also collected.

At Muir Woods, coho salmon were very abundant (84 to 91 fish per 100 feet) in both 1992 and 1993, and in 1992 coho outnumbered steelhead by over 3 to 1 (PWA et al. 1994). The high fish abundance and dominance by coho reflect good pool and cover development and excellent substrate conditions. Riffle sculpin were also abundant at the site, and some prickly sculpin were also present.

1994–1998, 2000, and 2001 Surveys. Annual fall electrofishing surveys have been conducted by Dr. Jerry Smith of San Jose State University to document the distribution and abundance of coho salmon and steelhead in Redwood Creek (Table D-1). Results of these surveys have documented the regular presence of both coho salmon and steelhead at sites from the Pacific Way bridge upstream to Muir Woods, although not all sites were sampled in all years. Annual variability in the relative abundance of these salmonids has been attributed to differences in habitat conditions and life history traits (Smith 2001).

Table D-1 Habitats sampled and estimated mean number of coho and steelhead per 100 feet in Redwood Creek in 1994–1998, 2000, and 2001 (from Smith 2001).

Sample date	Number of sites	Habitat types sampled				Total length sampled (feet)	Fish/100 feet		
							Coho salmon[a]	Steelhead	
		Pool	Glide	Run	Riffle			0+	1+, 2+
Jul 1994	7	58	25	12	6	1,287	2	69	14
Oct 1994	5	83	10	4	3	1,018	2	34	6
Aug 1995	4	41	30	19	10	796	42	97	4
Nov 1996	3	51	31	11	7	604	39	33	11
Sept–Oct 1997	5	72	18	9	1	984	23	15	5
Oct 1998	5	58	25	15	1	1,174	32	47	4
Oct 2000	6	71	27	3	0	1,077	1.1	39	15
Oct 2001	5	78	15	0	7	956	27	6	6

[a] All coho salmon are assumed to be young-of-the-year (YOY)

Sampling has shown high juvenile coho salmon recruitment in 1992/1995/1998, as well as 1993/1996. Because female coho salmon in this part of their range generally spawn as 3-year olds (Shapovalov and Taft 1954), these year classes represent subsequent years in the 3-year cycle. Other year classes since 1992 (i.e., 1994/1997/2000) have been comparatively weak. Coho abundance was extremely low in 1994 and 2000, and about 50 percent lower in 1997 (Table 1D-1). Similar patterns have also been documented for coho salmon in Santa Cruz County and San Mateo County streams (Smith 2001).

Steelhead, due to their ability to return to the ocean after spawning and their tendency to spawn at a variety of ages, have not shown pronounced annual variability in abundance in Redwood Creek. Abundance of YOY steelhead, however, was particularly low in 1997 and 2001, and particularly high in 1995 (Table 4.2-9). Smith (1997, 2001) attributes low YOY steelhead abundance to loss of suitable rearing habitat and reduced food availability resulting from low summer and fall stream flows, especially at the most downstream sites. The impacts of low summer and fall flows on steelhead and coho salmon may also be exacerbated by groundwater pumping from the wells that supply the town of Muir Beach and impoundments at Green Gulch Farms, especially in years with low rainfall.

Survey data have indicated that coho salmon and steelhead year class success in Redwood Creek may be highly dependent on habitat and flow conditions (e.g., Smith 1997, 2001). By dewatering shallow habitats and reducing pool volume, low flows can reduce food availability by lowering benthic macroinvertebrate production and can limit the amount of suitable rearing habitat. Low flows may also result in poor water quality due to increased temperatures and reduced dissolved oxygen levels. Conversely, high winter flows can damage redds, reconfigure the stream channel, and displace rearing salmonids from preferred rearing habitat. The availability (i.e., distribution and abundance) of valuable instream cover, especially woody debris in upper stream reaches, is largely responsive to high flows. Vore (1996) found that woody debris in Redwood Creek appeared to be recruited to upstream reaches during the winter of 1994-95 and redistributed downstream in 1996 in response to storm events.

Outmigrant trapping during spring of 1996 documented at least five fish species at the trap location in lower Redwood Creek. In addition to coho salmon (YOY, juveniles, and smolts) and steelhead (YOY, juveniles, smolts, and adults), threespine stickleback, prickly sculpin, and other unidentified sculpins were captured in the trap (Fong 1997a). The majority of fish captured were YOY coho salmon and steelhead, which together accounted for 87 percent of all fish trapped. Fry of both species appeared to emigrate downstream in response to high flows, with the peak capture of YOY fish occurring in mid- to late March when average flows were highest. In contrast, outmigration peaks for coho salmon and steelhead smolts did not appear to correspond with peak flow events (Fong 1997a). Peak capture of emigrating smolts occurred from late April through mid-May, at which time flows were relatively low. Coho salmon production for the Redwood Creek watershed was estimated at 60.5 fish/km. This falls within the lower end of the range reported for Waddell Creek in Santa Cruz County (34–1,120 coho/km) by Shapovalov and Taft (1954). Steelhead production was estimated at 1.3 fish/km. These estimates, however, could not be confirmed because trap efficiency was not assessed and the duration of the trapping period may not have captured the entire outmigration period.

The spawner and carcass survey in winter 1996–1997 documented spawning by coho salmon and steelhead in the Redwood Creek watershed. A total of 58 coho salmon (53 live and 15 carcasses) and 17 steelhead (all live) were observed (Fong 1997b). Coho were first observed in late November, but steelhead were not recorded until mid-January. Twelve of the steelhead spawners were observed in Fern Creek, which enters Redwood Creek in Muir Woods National Monument. As in the two previous survey years, all redds were located upstream of the Pacific Way bridge. This reflects the lack of suitable riffles and adequate hydraulic conditions in the most downstream portion of Redwood Creek. Size data indicate that up to 78 percent of spawning coho observed during the 1996-1997 surveys were jacks (males that have spent only one year in the ocean).

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Appendix E

Special-status and Non-native Invasive Plant Species Tables

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Table E-1. Special-status plants that have been observed or could potentially occur in the Redwood Creek watershed (NPS 2005, CNPS 2009, CDFG 2009).

Scientific name (Common name)	2009 Status (Federal, State, CNPS)	Habitat	Blooming period	Elevation range	Threats	Known locations	Source
Amorpha californica var. *napensis* (Napa false indigo)	–/–/1B.2	Coastal dunes, Coastal scrub	April–July	2–200 m	Threatened by development and habitat alteration.	2 collections in Mt Tamalpais, one from above cascade, north slope and another collection (Zeile1924) found between Ross Valley and Phoenix Lake [4]	CNPS 2009, CNDDB 2009
Arabis aculeolata (Waldo rock cress)	–/–/2.2	Coastal bluff scrub(rocky, outcrops)	May–July	15–155 m	Threatened by logging and mining. On watch list in Oregon	Known in California from fewer than ten occurrences. [3]	CNPS 2009
Arctostaphylos hookeri ssp. *montana* (Mt. Tamalpais manzanita)	–/–/1B.3	Coastal bluff scrub, Coastal scrub, Valley and foothill grassland/sandy or serpentinite	June–September	15–400 m		Mill Valley Air Fore Base (Mapped By GGNRA In 2001) [2] Numerous colonies mapped in the Mt. Tamalpais area from Panoramic Highway on the south side of Mt Tamalpais NNW to Green Hill (NE of Kent Lake)[mapped locations available][4]	NPS 2005, CNPS 2009 CNDDB 2009
Arctostaphylos virgata (Marin manzanita)	–/–/1B.2	Broadleafed upland forest, Chaparral, Cismontane woodland, Coastal scrub, Riparian woodland, Valley and foothill grassland	March–June	60–1,300 m	Threatened by fire suppression. .	Only known from about 20 Eos in Marin County. On sandstone or granitic soil. 60–700m, [mapped locations available][4]	CNPS 2009, CNDDB 2009
Aspidotis carlotta-halliae (Carlotta Hall's lace fern)	–/–/4.2	Serpentine slopes, crevices, and outcrops (Hickman 1993)	March–May	100–1,400 m		Bootjack area[2]	NPS 2005

Scientific name (Common name)	**2009 Status (Federal, State, CNPS)**	**Habitat**	**Blooming period**	**Elevation range**	**Threats**	**Known locations**	**Source**
Boschniakia hookeri (small groundcone)	–/–/2.3	Valley and foothill grassland/sometimes roadsides	April–November	20–560 m	Parasitic on *Gaultheria shallon* and *Vaccinium* spp. Possibly threatened by logging	Hoo-koo-e trail, east facing side of Mt. Tamalpais, above Baltimore Cyn just north of Knob Hill, northwest of Larkspur; Pipeline trail, Mt. Tamalpais; and West point, Mt. Tamalpais [mapped locations available][4].	NPS 2005, CNPS 2009, CNDDB 2009
Calochortus umbellatus (Oakland star tulip)	–/–/4.2	Open chaparral or woodlands, generally on serpentine (Hickman 1993)	March–May	100–700 m		Panoramic Hwy near Muir Woods Road intersection; Mill Valley Air Force Base (Johnson and Cushing 2001) mapped by GGNRA in 2001[2]	NPS 2005
Carex comosa (bristly sedge)	–/–/2.1	Chaparral, Valley and foothill grassland/serpentinite	April–July	5–370 m	Threatened by marsh drainage and road maintenance. Endangered in ID, endangered in Oregon, and state-listed as Sensitive in Washington.	In swamp near San Francisco [Bolander 1866][4] Location, rarity, and endangerment information needed; need historical quads for SFO Co. Fairly widely distributed, but apparently rarely collected. [3]	CNDDB 2009
Chorizanthe cuspidata var. *cuspidata* (San Francisco Bay spineflower)	–/–/1B.2	Coastal prairie, Coastal scrub, Valley and foothill grassland/often clay, sandy	June–October	10–220 m	Closely related to *C. pungens*. .	Exact location on Mt. Tamalpais is unknown. Mapped near the summit although actual site may have been on the lower slopes (Mclean 1970)[4].	CNPS 2009, CNDDB 2009
Chorizanthe valida (Sonoma spineflower)	FE/CE/1B.1	Closed–cone coniferous forest, Chaparral(maritime), Coastal dunes, Coastal scrub/sandy or gravelly, openings	April–September	10–200 m	Closely related to *C. pungens*.	Thought extinct for 77 years; only known extant occurrence was rediscovered in 1980 at Pt. Reyes NS. Experimental introduction work ongoing as of 2000. [3]	CNPS 2009

Scientific name (Common name)	2009 Status (Federal, State, CNPS)	Habitat	Blooming period	Elevation range	Threats	Known locations	Source
Cirsium andrewsii (Franciscan thistle)	–/–/1B.2	Broadleafed upland forest, Chaparral, Valley and foothill grassland/mesic openings, sandy	May–July	50–500 m	Threatened by development and non–native plants. .	Fort Cronkite Military Reservation and Marin Headlands.[4]	CNPS 2009, CNDDB 2009
Cirsium hydrophilum var. *vaseyi* (Mt. Tamalpais thistle)	–/–/1B.2	Coastal dunes, Coastal scrub(sandy)	March–July	0–60 m	Threatened by road construction and non–native plants.	Known from fewer than 20 occurrences on Mt. Tamalpais[3]	NPS 2005, CNPS 2009 CNDDB 2009
Cordylanthus maritimus ssp. *palustris* (Point Reyes bird's–beak)	–/–/1B.2	Coastal bluff scrub	April–July	0–100 m	Once rather common in proper habitat; now greatly reduced by development. Also threatened by foot traffic, non-native plants, hydrological alterations, cattle grazing and trampling. State listed as Endangered in Oregon. .	Richardson Bay, southeast of Mill Valley, Corte Madera Ecological Reserve, and San Rafael.[4]	CNPS 2009, CNDDB 2009
Cypripedium californicum (California lady's-slipper)	–/–/4.2	Moist slopes, streambanks, mixed evergreen or coniferous forest (Hickman 1993); serpentinite seeps	April–August	30–2,750 m		Noted by Howell (1970) in moist canyon on south side of Mt. Tamalpais above Muir Woods (current occurrence unknown).[2]	NPS 2005
Elymus californicus	–/–/4.3	Coniferous forest (Hickman 1993)	March–June	15–470 m		Muir Woods; mapped by GGNRA in 2001[2]	NPS 2005

Scientific name (Common name)	**2009 Status (Federal, State, CNPS)**	**Habitat**	**Blooming period**	**Elevation range**	**Threats**	**Known locations**	**Source**
Erysimum franciscanum	–/–/4.2	Serpentine outcrops, granitic cliffs, and sometimes coastal dunes (Hickman 1993)	March–June	0–550 m		Muir Beach[2]	NPS 2005
Eriogonum luteolum var. *caninum* (Tiburon buckwheat)	–/–/1B.2	Broadleafed upland forest, Coastal scrub, Lower montane coniferous forest, Valley and foothill grassland/clay, serpentinite	June–October	15–305 m	*E. luteolum* is similar to *E. gracile* to the south and *E. vimineum* to the northeast. Threatened by development, foot traffic, and non-native plants. .	Above Pan Toll Campground, Mt. Tamalpais; near rocky ridge, Mt. Tamalpais; on the Dipsea Trail, 2 miles W on Panoramic Highway from junction of Panoramic and Shoreline Highway 1; and around Ridgecrest Boulevard, Mt. Tamalpais[mapped locations available][4]	CNPS 2009, CNDDB 2009
Fissidens pauperculus (minute pocket moss)	–/–/1B.2	Chaparral, Valley and foothill grassland/usually serpentinite, often roadsides	July–October, sometimes June	100–500 m		Mt. Tamalpais sp, Dipsea Trail. [4]	CNPS 2009, CNDDB 2009
Fritillaria lanceolata var. *tristulis* (Marin checker lily)	–/–/1B.1	Broadleafed upland forest, Chaparral, Cismontane woodland, Valley and foothill grassland/rocky	March–May	45–825 m	Some occurrences threatened by grazing, and all by small size. Plants seem not to set seed, but to reproduce by offsets. .	1.5 miles up road to Mt. Tamalpais from Highway 1 (Lloyd 1963). [4]	CNPS 2009, CNDDB 2009
Gilia capitata ssp. *chamissonis* (blue coast gilia)	–/–/1B.1	Closed–cone coniferous forest, Cismontane woodland, Coastal scrub, Valley and foothill grassland	April–June, sometimes July	5–300 m	Threatened by urbanization, recreational development, and non–native plants. Possibly threatened by trampling. .		CNPS 2009

Scientific name (Common name)	2009 Status (Federal, State, CNPS)	Habitat	Blooming period	Elevation range	Threats	Known locations	Source
Gilia capitata ssp. *tomentosa* (woolly–headed gilia)	–/–/1B.1	Cismontane woodland, Lower montane coniferous forest, Meadows and seeps, Valley and foothill grassland, Vernal pools/mesic	April–July	5–1,740 m	Threatened by urbanization, road maintenance, and erosion. Intergrades with ssp. *capitata* in northeastern San Francisco Bay area.	Known from approximately 10 occurrences.[3]	CNPS 2009
Grindelia hirsutula var. *maritima* (San Francisco gumplant)	–/–/1B.2	Closed–cone coniferous forest, Chaparral/serpentinite, rocky	May–July	200–635 m	Threatened by coastal development and non-native plants. Can be difficult to identify. Many herbarium specimens need to be checked for correct id.	Oceanic bluffs, Point Lobos, San Francisco.[4]	CNPS 2009, CNDDB 2009
Helianthella castanea (Diablo helianthella)	–/–/1B.2	Cismontane woodland, Valley and foothill grassland(often serpentinite)	March–May	35–620 m	Threatened by urbanization, grazing, and fire suppression. Possibly threatened by roadside maintenance.	Mill Valley (Ramsey 1938)[4]	NPS 2005, CNPS 2009, CNDDB 2009
Hemizonia congesta ssp. *congesta* (pale yellow hayfield tarplant)	–/–/1B.2	Meadows and seeps(alkaline), Marshes and swamps(coastal salt)	March–May	15–180 m	Threatened by agriculture, development, and road construction. Possibly threatened by grazing.	Vicinity of Ross, Lake Lagunitas, and north slope of Mount Tamalpais.[4]	CNPS 2009, CNDDB 2009
Hesperolinon congestum (Marin western flax)	FT/CT/1B.1	Broadleafed upland forest, Meadows and seeps, North Coast coniferous forest/open areas, mesic	April–August	10–671 m	Threatened by development, non-native plants, and foot traffic.	Protected in part at Ring Mtn. Preserve, MRN Co.[3] North of Alpine Lake, near junction of Fairfax Bolinas Road with Pine Mountain Truck Road and San Rafael.[4]	CNPS 2009, CNDDB 2009
Holocarpha macradenia (Santa Cruz tarplant)	FT/CE/1B.1	Coastal prairie, Coastal scrub,	April–September	0–1,830 m	Seriously threatened by urbanization, agriculture,	Mapped in general vicinity of Mt. Tamalpais and Ross Valley.[4]	CNPS 2009,

Scientific name (Common name)	2009 Status (Federal, State, CNPS)	Habitat	Blooming period	Elevation range	Threats	Known locations	Source
		Lower montane coniferous forest			non-native plants, and lack of appropriate ecological disturbance.		CNDDB 2009
Horkelia cuneata ssp. *sericea* (Kellogg's horkelia)	–/–/1B.1	Marshes and swamps(coastal salt or brackish)	May–August, sometimes May and October	0–10 m	Threatened by coastal development.	Occurrence from the Crocker Hills probably last remaining location in S.F. Bay. Historical occurrences need field surveys.[3]	CNPS 2009, CNDDB 2009
Horkelia tenuiloba (thin-lobed horkelia)	–/–/1B.2	Lower montane coniferous forest	March–April	100–750 m	Threatened by development.	Historical occurrences need field surveys.[3] Mount Tamalpais, about 0.25 mile ssw and 0.25 miles southeast (at Willow Meadow) of serpentine point; Mount Tamalpais, Double Bowknot; and Mount Tamalpais, Matt Davis Trail between east peak and middle peak.[4].	NPS 2005, CNPS 2009, CNDDB 2009
Layia carnosa (beach layia)	FE/CE/1B.1	Marshes and swamps(freshwater, near coast)	April–September	3–75 m	Threatened by coastal development, foot traffic, vehicles, and non-native plants.	San Francisco sand dunes, San Francisco.[4]	CNDDB 2009
Leptosiphon rosaceus (rose leptosiphon)	–/–/1B.1	Chaparral(serpentinite)	May–June	50–430 m	Possibly threatened by competition and non-native plants. .	San Francisco.[4]	CNDDB 2009

Scientific name (Common name)	**2009 Status (Federal, State, CNPS)**	**Habitat**	**Blooming period**	**Elevation range**	**Threats**	**Known locations**	**Source**
Lessingia hololeuca (woolly–headed lessingia)	–/–/3	Broadleafed upland forest, Closed–cone coniferous forest, Chaparral, Coastal prairie, Coastal scrub, Valley and foothill grassland/open areas, sometimes serpentinite	April–May	10–500 m	Possibly threatened by grazing.	Probably more widespread in the southern Sacramento Valley, southern North Coast Ranges, and northern S.F. Bay. [3]	NPS 2005, CNPS 2009
Lessingia micradenia var. *micradenia* (Tamalpais lessingia)	–/–/1B.2	Closed-cone coniferous forest, Chaparral/serpentinite	April–July	305–650 m		Known from only four occurrences in the Mt. Tamalpais area. [3] Near Alpine Lake and along the Fairfax–Bolinas Road; Phoenix Lake; and San Anselmo Canyon. [4]	CNPS 2009, CNDDB 2009
Micropus amphibolus (Mt. Diablo cottonweed)	–/–/3.2	Chaparral, Valley and foothill grassland/serpentinite	May–July, sometimes August	150–800 m	Can be confused with *M. californicus*.	Many occurrences old; need current status information. [3]	CNPS 2009
Microseris paludosa (marsh microseris)	–/–/1B.2	Closed-cone coniferous forest, Cismontane woodland, Coastal scrub, Valley and foothill grassland	April–June, sometimes July	5–300 m	Similar to *M. laciniata* spp. *leptosepala*. .	Summit Ave. in Mt. Tamalpais and Corte Madera[4]	CNPS 2009, CNDDB 2009

Scientific name (Common name)	**2009 Status (Federal, State, CNPS)**	**Habitat**	**Blooming period**	**Elevation range**	**Threats**	**Known locations**	**Source**
Navarretia leucocephala ssp. *bakeri* (Baker's navarretia)	–/–/1B.1	Cismontane woodland, Lower montane coniferous forest, Meadows and seeps, Valley and foothill grassland, Vernal pools/mesic	April–July	5–1,740 m	Threatened by development, habitat alteration, road construction, and agriculture.	May be more widespread; need information. Need quads for COL Co. [3]	CNPS 2009
Navarretia rosulata (Marin County navarretia)	–/–/1B.2	Closed–cone coniferous forest, Chaparral/serpentinite, rocky	May–July	200–635 m	Possible trampling from hikers and bikes.	Known from fewer than twenty occurrences. [3] West slope of Mount Tamalpais, along Laurel Dell Road, just west of Barths Retreat; northwest slope of Mount Tamalpais, between east fork and Swede George Creek, west of Serpentine Ridge; northwest slope of Mount Tamalpais, along rocky ridge from just above Alpine Lake south about 1.25 miles; and north of Alpine Lake along Pine Mountain Truck Road, about 0.5 mile northeast of Liberty Gulch. [4]	NPS 2005, CNPS 2009, CNDDB 2009
Pentachaeta bellidiflora (white-rayed pentachaeta)	FE/CE/1B.1	Cismontane woodland, Valley and foothill grassland (often serpentinite)	March–May	35–620 m	Historical occurrences lost to development.	Known from fewer than twenty occurrences.[3] East of King Mountain, north of Larkspur Creek, Larkspur and Kentfield. [4]	CNPS 2009, CNDDB 2009
Plagiobothrys glaber (hairless popcorn-flower)	–/–/1A	Meadows and seeps(alkaline), Marshes and swamps(coastal salt)	March–May	15–180 m	Possibly a variety of *P. stipitatus.*	Last confirmed sighting in 1954. Possibly relocated near Antioch; identification uncertain. All collections since 1930's located in the Hollister area; plant should also be looked for there. [3]	CNPS 2009, CNDDB 2009

Scientific name (Common name)	2009 Status (Federal, State, CNPS)	Habitat	Blooming period	Elevation range	Threats	Known locations	Source
Pleuropogon hooverianus (North Coast semaphore grass)	–/CT/1B.1	Broadleafed upland forest, Meadows and seeps, North Coast coniferous forest/open areas, mesic	April–August	10–671 m	Threatened by roadside maintenance, timber harvest, feral pigs, and invasive species.	Lagunitas Meadows, north side of Mount Tamalpais and Ross Valley. [4]	CNPS 2009, CNDDB 2009
Polemonium carneum (Oregon polemonium)	–/–/2.2	Coastal prairie, Coastal scrub, Lower montane coniferous forest	April–September	0–1,830 m	Threatened by logging.	Fort Barry. [4]	CNPS 2009, CNDDB 2009
Polygonum marinense (Marin knotweed)	–/–/3.1	Marshes and swamps(coastal salt or brackish)	May–August, sometimes April and October	0–10 m	Threatened by coastal development and foot traffic.	Known from fewer than twenty occurrences. [3] Escalle Salt Marsh along Corte Madera Creek, 0.4 airmile southwest of top of Bon Air Hill, southwest of San Rafael. [4]	CNPS 2009, CNDDB 2009
Quercus parvula var. *tamalpaisensis* (Tamalpais oak)	–/–/1B.3	Lower montane coniferous forest. Shaded parts of Mt. Tamalpais.	March–April	100–750 m	Known only from Mt. Tamalpais. May hybridize with *Q. wislizeni* var. *frutescens*.	Possibly Matt Davis Trail[2] Pilot Knob Trail, e of the large madrone and w of the spur trail to Pilot Knob, n side of Mt Tamalpais; Se of Phoenix Lake, along'bill williams' trail from crown rd to se lake; International trail, N slope of Mount Tamalpais; Ridge E of Pantoll Campground, Redwood Creek Drainage; Ridge W of Mill Valley; and S of azalea meadow [flat].[4]	NPS 2005, CNPS 2009, CNDDB 2009
Sidalcea calycosa ssp. *rhizomata* (Point Reyes checkerbloom)	–/–/1B.2	Marshes and swamps(freshwater, near coast)	April–September	3–75 m	Threatened by non-native plants, road maintenance, foot traffic, and pipeline construction. .	San Anselmo Canyon and Lake Lagunitas. [4]	CNPS 2009, CNDDB 2009
Sidalcea hickmanii ssp. *viridis* (Marin checkerbloom)	–/–/1B.3	Chaparral (serpentinite)	May–June	50–430 m	Possibly threatened by development and fire suppression	About 0.5 mile east of junction of Highway 1 and Panoramic Highway, southwest of Mount Tamalpais. [4]	CNDDB 2009

Scientific name (Common name)	2009 Status (Federal, State, CNPS)	Habitat	Blooming period	Elevation range	Threats	Known locations	Source
Stebbinsoseris decipiens (Santa Cruz microseris)	–/–/1B.2	Broadleafed upland forest, Closed-cone coniferous forest, Chaparral, Coastal prairie, Coastal scrub, Valley and foothill grassland/open areas, sometimes serpentinite	April–May	10–500 m	Threatened by grazing. USFWS uses the name *Microseris decipiens*	Known from fewer than twenty occurrences. [3] Highway 1 roadcut, approx 2 miles south of Stinson Beach, just south of Dipsea Fire Road.and Mt Tamalpais, north of Ridgecrest Boulevard, south of Rifle Camp & east of Barths Retreat	CNPS 2009, CNDDB 2009
Streptanthus batrachopus (Tamalpais jewel-flower)	–/–/1B.3	Closed-cone coniferous forest, Chaparral/serpentinite	April–July	305–650 m	Similar plants from the southern North Coast Ranges may be an undescribed new taxon. Intergrades with S. barbiger.	Known from fewer than ten occurrences in the Mt. Tamalpais area.[3] Mt Tamalpais; along north side trail, between Rifle Camp & Collier Spring. 0.25 mi ne of Rifle Camp and n side of Mt Tamalpais. along Simmons Trail, from just south to 0.3 mi south of spring at Barths Retreat. [4]	CNPS 2009, CNDDB 2009
Streptanthus glandulosus ssp. *pulchellus* (Mount Tamalpais bristly jewel-flower)	–/–/1B.2	Chaparral, Valley and foothill grassland/serpentinite	May–July, sometimes August	150–800 m	Threatened by trampling and non-native plants. Possibly threatened by browsing.	Known only from the Mt. Tamalpais area.[3] Bootjack Camp (see mapped locations). [4]	NPS 2005, CNPS 2009, CNDDB 2009

Table E-2. GGNRA results from special-status plant surveys within Redwood Creek watershed, 1998–2004 (NPS 2009).

Subsite	Species name	Population #	1998	1999	2000	2001	2002	2003	2004	Survey notes
Muir Woods (Four Corners)	*Calochortus umbellatus*	1	--	--	--	--	--	approx. 470	No survey	The Calochortus umbellatus found here are the only populations found in the GOGA on non-serpentine soils. This new population was documented on non-serpentine soils, near the "Four Corners" intersection on Panoramic Highway in 2003. Several large patches were found. French broom threatens the populations in this area. Management recommendations: None at this time. Monitoring recommendations: None at this time. Recommended monitoring intervals: Calochortus umbellatus: Every 3 years.
Muir Woods	*Elymus californicus*:	all	Approx. 1,485	No survey	710	No survey	No survey	No survey	No survey	Count includes all sites in Muir Woods: visitor center, parking lots, west side of Redwood Creek below Bridge 1, Maple Meadow, upper shop area, "fallen tree", Bohemian Grove, Dipsea Trail, boundary sign-Frank Valley. Distinct clumps counted, when not distinct, stalks in some small areas counted as one plant. As of 2004, there is no GIS map layer for the ELCA at Muir Woods. Management recommendations: None at this time. Monitoring recommendations: *Elymus californicus*: Due to the widespread occurrence and numerous individuals found, mapping of population boundaries rather than individual census counts are acceptable for this species. The numbers listed above are rough estimates of the size of these populations. This is not a priority species. Populations should be briefly revisited every three years to monitor threats from invasive species. Recommended Monitoring Intervals *Elymus californicus*: Every 3 years
Mill Valley Air Force Base	*Arctostaphylos hookeri* ssp. *montana*	1	925	973	820	596	Established photopoint	No survey	No survey	Decrease due to differences in determining individual plants rather than an actual decline in number of individuals These populations do not appear to be under immediate threat (Continued on next page)

Subsite	Species name	Population #	1998	1999	2000	2001	2002	2003	2004	Survey notes	
Mill Valley Air Force Base	*Arctostaphylos hookeri* ssp. *montana*	2	--	--	306	624	Established photopoints	No survey	No survey		Monitoring Recommendations: Establishing line transects would capture absolute cover data for individual species and relative cover data for all species occurring within this community. To verify the presence of *S. decipiens* on MVAFB, another search should be conducted in mid to late April 2004 and a voucher specimen collected (provided there is more than 1 individual!). The observer recommends looking for the plant in the area indicated on the attached map. The search should be conducted before noon since flowers of members of the chicory tribe tend to close as the day progresses. Recommended Monitoring Intervals *Arctostaphylos hookeri* ssp. *montana*: Every 3 years *Calamagrostis ophitidis*: Every 3 years *Calochortus umbellatus*: Every 2 years *Eriogonum luteolum* var. *caninum*: Every 3 years *Streptanthus glandulosus* ssp. *pulchellus*: Every 3 years
	Arctostaphylos hookeri ssp. *montana*	3	--	--	--	--	79	No survey	No survey		
	Calamagrostis ophitidis	1	--	--	--	--	Surveyed, not censused	No survey	No survey		
	Calochortus umbellatus	1	102	1,162	1,851	1,117	1,276	No survey	No survey		
	Calochortus umbellatus	2	197	251	998	720	369	No survey	No survey		
	Calochortus umbellatus	3	--	--	--	--	Surveyed; not censused	No survey	No survey		
	Eriogonum luteolum var. *caninum*	1	17	31	33	587	Surveyed; not censused	No survey	531		
	Eriogonum luteolum var. *caninum*	2	--	--	--	346	Surveyed; not censused	No survey	298		
	Streptanthus glandulosus ssp. *pulchellus*	1	129	555	923	*Surveyed; not censused	**2,491	No survey	No survey	*too late in season to census; **larger area sampled in 2002 than previous years	
	Streptanthus glandulosus ssp. *pulchellus*	2**	0	No survey	1,122	*Surveyed; not censused	1,668	No survey	No survey	*too late in season to census; **combined populations 2 and 3 into 2 in 2002	

Source: GGNRA special-status plant inventory--NPS 2009

Table E-3. Special-status plant occurrences within the Redwood Creek watershed found during the 2004 surveys by Faden.

Location	Special-status plant occurrence	Survey notes
Green Gulch	*Erysimum franciscanum*	A population of *E. franciscanum*, in bloom, was found south of Muir Beach on bluffs overlooking Muir Beach. Flower color ranged from cream to almost white; plants ranged in size from robust and shrub-like to small single-stemmed individuals. No *A. blepharophylla* was found.
Four Corners	*Calochortus umbellatus*	Three patches of *C. umbellatus* were found on adjacent ridges, staring within about 30m of the road. The three patches were mapped as a single population. Invasive broom occurs toward the east and south; the Habitat Restoration Team is working to control it.
Coyote Ridge	*Arabis blepharophylla*	Two new, small populations of *Arabis blepharophylla* were found. Pop. 36 was found on the west bank of the Miwok Trail approximately 170 meters north of the intersection with the Coyote Ridge Trail.

Source: Faden 2004

Table E-4. Special-status plant occurrences within the Redwood Creek watershed found during the 2004 surveys of the Comprehensive Roads and Trails Management Plan for the Mt. Tamalpais watershed.

Trail or Road section	Special-status plant occurrence
Lagunitas Rock Spring Road from Ridgecrest Boulevard to Potrero Meadow	*Arctostaphylos hookerii* var. *montana* and *Streptanthus glandulosus* ssp. *pulchellus* (May 2004)
Old Stage from West Point Inn to Bootjack	*Streptanthus glandulosus* ssp. *pulchellus*, *Cirsium hydrophilum* var. *vaseyi*, *Calamagrostis ophitidis*, *Navarretia rosulata*, and *Calochortus umbellatus* (May 2004)
Rock Spring Trail	*Arctostaphylos hookeri* var. *montana* and *Quercus parvula* var. *tamalpaiensis* (May 2004)
Ridgecrest Boulevard from Mountain Theater parking lot to Lagunitas-Rock Spring Road intersection -	*Arctostaphylos hookeri* var. *montana*, *Streptanthus glandulosus* ssp. *pulchellus*, and *Aspidotis carlotta-halliae* (May 2004)

Source: MMWD 2004

Table E-5. Total area covered by non-native invasive plant species in the Redwood Creek watershed with targets of eradication and/or control efforts highlighted in bold.

Species name	Area infested (acres)	Area infested (hectares)	Relative percent cover*	Area as a percentage of total watershed area (5,696 acres)
Cirsium vulgare (bull thistle)	123.52	49.99	13.8%	2.17%
Conium maculatum (poison hemlock)	121.12	49.02	13.5%	2.13%
Myosotis latifolia **(forget-me-not)**	**82.07**	**33.21**	**9.2%**	**1.44%**
Carduus pycnocephalus (italian thistle)	77.25	31.26	8.6%	1.36%
Genista monspessulana **(French broom)**	**54.27**	**21.96**	**6.1%**	**0.95%**
Brassica spp. (mustards)	53.70	21.73	6.0%	0.94%
Phalaris aquatica (Harding Grass)	50.45	20.42	5.6%	0.89%
Eucalyptus globulus **(blue gum)**	**48.83**	**19.76**	**5.5%**	**0.86%**
Holcus lanatus (velvet grass)	48.61	19.67	5.4%	0.85%
Delairea odorata **(cape ivy)**	**34.00**	**13.76**	**3.8%**	**0.60%**
Pinus radiata **(Monterey pine)**	**30.74**	**12.44**	**3.4%**	**0.54%**
Festuca arundinaceae (tall fescue)	29.76	12.04	3.3%	0.52%
Foeniculum vulgare (fennel)	23.67	9.58	2.6%	0.42%
Cortaderia jubata **(pampass grass)**	**20.42**	**8.26**	**2.3%**	**0.36%**
Cupressus macrocarpa (Monterey cypress)	18.22	7.37	2.0%	0.32%
Silybum marianum (milk thistle)	17.94	7.26	2.0%	0.31%
Oxalis pes-caprae (Bermuda buttercup)	17.32	7.01	1.9%	0.30%
Cotoneaster pannosa (cotoneaster)	15.06	6.09	1.7%	0.26%
Centaurea solstitialis (yellow star thistle)	9.01	3.65	1.0%	0.16%
Cytisus scoparius **(Scotch broom)**	**7.28**	**2.95**	**0.8%**	**0.13%**
Acacia spp. (acacia)	2.15	0.87	0.2%	0.04%
Vinca major (periwinkle)	2.13	0.86	0.2%	0.04%
Pennisetum clandestinum (kikuyu grass)	1.87	0.76	0.2%	0.03%
Hedera helix (English ivy)	1.69	0.68	0.2%	0.03%

Species name	Area infested (acres)	Area infested (hectares)	Relative percent cover*	Area as a percentage of total watershed area (5,696 acres)
Rubus discolor (Himalaya blackberry)	1.66	0.67	0.2%	0.03%
Ammophila arenaria (European beachgrass)	1.24	0.50	0.1%	0.02%
Crocosmia x *crocosmiiflora* (montbretia)	0.11	0.04	0.0%	0.00%
Lathyrus latifolius (giant pea)	0.09	0.04	0.0%	0.00%
Echium spp. (echium)	0.08	0.03	0.0%	0.00%
Leucanthemum vulgare (ox-eye daisy)	0.06	0.02	0.0%	0.00%
Arctotheca calendula (capeweed)	0.05	0.02	0.0%	0.00%
Arundo donax (giant reed)	0.02	0.01	0.0%	0.00%
Totals	**894.39**	**361.93**	**NA**	**15.70%**

Relative to total area infested.
Source: NPS unpublished data.

Table E-6. Distribution of non-native invasive species with habitat types of particular management concern highlighted in bold.

Habitat type	Total area (acres)	Total area (hectares)	Relative percent cover*	Area as a percentage of total watershed area (5,696 acres)
Scrub/grassland	**261.3**	**105.7**	**27.3%**	**4.38%**
Grassland	**224.3**	**90.8**	**23.5%**	**3.76%**
Riparian (includes 34 acres of cape ivy)	**154.2**	**62.4**	**16.1%**	**2.58%**
Forest	91.9	37.2	9.6%	1.54%
Developed Area	65.3	26.4	6.8%	1.09%
Coastal Scrub	57.6	23.3	6.0%	0.97%
Woodland	26.9	10.9	2.8%	0.45%
Agricultural	16.8	6.8	1.8%	0.28%
Seasonal Wetland	5.3	2.1	0.6%	0.09%
Wetland	2.6	1.1	0.3%	0.04%
Chaparral	2.3	0.9	0.2%	0.04%
Dune Scrub/Foredune	1.2	0.5	0.1%	0.02%
Serpentine Grassland/chaparral	0.1	0.04	0.0%	0.00%
Other	39.0	15.8	4.1%	0.65%
Other: Roadside	6.8	2.8	0.7%	0.11%
Totals	**955.7**	**386.8**		**16.02**%

Relative to total area infested.
Source: NPS unpublished data.

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Table E-7. Control and eradication methods for mapped non-native invasive weeds within the Muir Woods five management areas (Baxter 2009).

Cal-IPC Rating	Scientific name	Common name	Control season	Removal method	Group type
Limited	*Acacia melanoxylon* *Eucalyptus globerata*	Blackwood Acacia Blue gum Eucalyptus	Year-round	Mechanical: Chainsaw cut with stump herbicide application.	NR
Moderate	*Ageratina adenophora*	Eupatory	Winter	Hand Removal: Plant is to be dug up by root. Piled at site if not in flower. Flowering and seeding plants are to be bagged and disposed.	VIP
				Chemical: Foliar application for large infestations (individuals <10 have been found in the Monument, action not required currently).	NR
Limited	*Brassica rapa* *Rhapnus sativa*	Mustard Wild radish	Mechanical: Winter and Spring	Hand Removal: Hand pull before seed pods develop. Best after heavy rain because of large taproot. Cut plants below taproot with pick or shovel before seed pods develop.	VIP, MW
				Mechanical: Control dense populations with a mixture of flaming and targeted application. Brush cut to control seeds.	NR
Moderate	*Carduus pycnocephalus* *Cirsium vulgare* *Erchtities minima*	Italian Thistle Bull Thistle Fireweed	Hand Removal: Winter and Spring	Hand Removal: Remove before flowering, dig up taproot. Plants may continue to develop seed if in advanced flowering stage. Material should not remain on site.	VIP, MW
Not-listed	*Carex pendula*	Sedge	Mechanical: Winter, Spring and Summer	Hand removal when soil is wet. Dig up plant with Pulaski. Leave plant material, roots exposed on site. Note: this is a new non-native to the park. One individual found in Redwood Creek, south of the dipsea trail foot bridge and behind Muir Woods nursery.	NR, MW

Cal-IPC Rating	Scientific name	Common name	Control season	Removal method	Group type
Moderate	*Conium maculatum*	Poison Hemlock	Mechanical: Spring	Hand removal when plant is in flowering stage, before seed set. Continued treatment in flowering stage for 3 years is required.	VIP, MW
			Flame: Winter-early Spring	Propane flaming of rosette stage in the winter.	NR, MW
High	*Cortaderia selloana* *Cortaderia jubata*	Pampas Grass and Jubata Grass	Mechanical: Year-round	Mechanical: Trim aboveground growth then dig up root mass.	VIP
			Chemical: Summer to Fall	Chemical: Foliar application in the spring through fall	NR
Moderate	*Cotoneaster pannosa* *Cotoneaster franchetii*	Cotoneaster	Mechanical: late Summer - early Fall	Hand Removal: Pull with weed wrench for trunks ½ inch or less in diameter.	VIP
				Mechanical: Cut back to 1 foot in height just after shrub has produced fruit. Cover 1-2 ft. around stump for a two years.	NR
				Chemical: cut stump to less than 6 inches height and paint with herbicide solution.	NR
Not listed	*Crocosmia Crocosmiiflora* *Watsonia meriana*	Montbretia	Hand Removal: Winter	Chemical: No known effective chemical treatment at this time.	VIP, MW
				Hand Removal: Bulbs and corms dug 1 ft deep. Soil requires shifting through to find broken pieces	NR
Not listed	*Cupressus macrocarpa*	Monterey Cypress	Hand Removal: Winter	Mechanical: Chainsaw cut	VIP, MW
				Hand Removal: Seedlings are to be pulled with weed wrench or by hand	NR
Limited *Moderate* *Moderate*	*Dactylis glomerata* *Phalaris aquatica* *Festuca arundinaceae*	Orchard Grass Harding Grass Tall Fescue	Hand Removal: Year-round Chemical: Spring	Hand Removal: Individual infestations are to be hand removed	VIP, MW
				Mechanical: Brushcut monotypic stands, followed by chemical treatment within a month	VIP, MW
				Chemical: Foliar application to be done in early spring	NR

Cal-IPC Rating	Scientific name	Common name	Control season	Removal method	Group type
High	*Delairea odorata*	Cape-ivy	Mechanical: Fall/Winter	Mechanical: Cut back infested vegetation with hand and power tools (non-bird nesting season, August to February).	Hired crew NR
				Woody material to be separated out and placed cleared of ivy in pile at site. Leafy material to be piled on site or hauled away. Piled material to be covered with landscape material.	VIP, MW
				Chemical: Foliar application treatment 3 times a year	NR
Not-listed	*Duchesnea indica*	Mock strawberry	Hand Removal: Winter, Spring	Hand removal: Dig up plant below soil surface 2inches. Remove runners.	NR, VIP, MW
Moderate	*Ehrharta erecta*	Veldt Grass	Hand Removal: Year-round Mechanical: HMO: Fall Flame: Winter Chemical: Year-round	Initial Treatment:	VIP, MW
				Hand Removal (small scale): Remove mature plants and roots. Plant in flower nearly year-round. Plants with flower and seeds are to be bagged and disposed. Method should be limited due to disturbance increasing germination of seedbank.	
				Hydro-mechanical obliteration (landscape scale): A high powered pressure washer to be applied in late summer to fall in riparian zone.	Hired contractor
				Follow-up treatment:	NR
				Propane flaming of seedlings in cotyledon stage is to be applied in late fall through winter to wet sites only on a monthly basis, ideally 3 times in winter.	
				Chemical: Foliar application of mature and seedling plants to be treated five to six times a year. Treatment may be reduced in summer in dry locations.	NR
Not listed	*Erigeron karvinskianus*	Fleabane, Mexican daisy	Winter and Spring	Hand Removal: Pull roots out with handpicks.	NR

Cal-IPC Rating	Scientific name	Common name	Control season	Removal method	Group type
				Chemical: Foliar application annually.	
High	*Foeniculum vulgare*	Fennel	Mow: Spring Spray: Spring	Hand Removal: Pull seedlings by hand. Dig out with shovels, or top 3-6 inches of crown and root.	VIP, MW
				Mechanical: Brushcut 4 times a year beginning March and April. Do not cut while in seed.	NR
				Chemical: Brushcut plant and allow re-growth before treating with foliar application.	NR
High	*Genista monspessulana*	French Broom	Hand Removal: Winter/Spring Cut: Summer	Hand Removal: Remove mature and immature plants with weed wrench. Remove taproot or will resprout from base. Conduct while soil moist in winter and spring before flowers set seed.	VIP, MW
				Mechanical: Cut shrub above ground during dry season so stumps become stressed in July or August. Cut above ground and girdle stumps with paint scraper (ideal on med-large plants). Scrape seedlings with a hula hoe.	VIP, MW
				Chemical: Cut stump application for mature plants.	NR
				Propane flame: Flame one year old seedlings in the winter and early spring.	NR, MW
				Prescribe fire: Prescribe fire applied every 2 years for several years will exhaust the seed bank.	Fire Division
High	*Hedera helix*	English ivy	Year-round	Hand Removal: Remove seedlings by hand.	VIP, NR
				Mechanical: Rake with McCloud and cut vines with loppers.	NR
				Chemical: Cut and remove 1 foot section of stem and treat with herbicide. Monitor for resprouts.	
High	*Helichrysium pedulatum*	Licorice plant	Hand Removal: yearround, or Fall	Hand Removal: Hand pull plant with roots. Larger plants require cutting and raking to pile. Pile on site or dispose in bag.	NR, VIP, MW

Cal-IPC Rating	**Scientific name**	**Common name**	**Control season**	**Removal method**	**Group type**
Limited	*Myosotis latifolia*	Forget-me-not	Hand Removal: Winter and Spring	Hand Removal: Hand pull plant with roots. Pile on site or dispose in bag.	VIP, MW
Limited	*Pennisetum clandestinum*	Kikuyu grass	Chemical: Spring, Summer	Hand Removal: Not effective Chemical: Foliar application to reduce thatch. Treat before dormancy in the fall.	NR
Native	*Pinus radiata*	Monterey Pine	Hand Removal: Winter	Hand Removal: Weed wrench, lopping and cutting. Usually does not re-sprout.	VIP, MW
			Mechanical: Fall	Mechanical: Chainsaw after bird nesting season.	NR
Limited	*Prunus* sp.	Fruit Tree	Mechanical: Winter	Hand Removal: Pull or weed wrench seedlings. Mechanical: Cut and cover stump with fabric. Chemical: Cut and apply herbicide to stump.	NR
High	*Rubus discolor*	Armenian Blackberry	Mechanical: Spring/ Summer Chemical: Summer	Hand Removal: Cut stem and dig up root mass. Remove as much of root as possible.	VIP, MW
				Mechanical: Brush cut canes and use McClouds to clear vegetation. Idea time is in spring when in flower.	NR
				Chemical: Cut stems to one foot and treat with herbicide.	NR
Moderate	*Vinca major*	Periwinkle	Mechanical: late summer/ early fall Chemical: Spring	Hand Removal: For small patches >10m2, pull up dense vegetation and underlying stolons. Pull up roots from base and dig up all roots.	VIP, MW
				Mechanical: Brush cut vines close to ground and cover with weed fabric, black plastic, or cardboard. Leave covered for one to two years.	NR
				Chemical: Brushcut in the fall when driest. Foliar application of resprouts 3 weeks - 1 month later.	NR

Source of table Baxter et al. 2009

Key: **NR**- Natural Resources staff**, HC**- Hired crew or contractor**, VIP**- volunteer groups, **MW-** Muir Woods docents, interns, and interpretive staff

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Appendix F

Species Detections and Predictions:
Birds and Mammals

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Table F-1. Bird species predictions and detections in the Redwood Creek watershed

Order	Family	Common name	Scientific name	Status[1]	Habitat association							Detection[2]	Source[3]
					Redwood/ Doug-Fir	Mixed hard-wood	Grass-land	Coastal scrub	Riparian woodland	Seasonal wetland	Open water		
Gaviiformes	Gaviidae	red-throated loon	*Gavia stellata*								+	+	C,D
		Pacific loon	*Gavia pacifica*								+	+	C,D
		common loon	*Gavia immer*								+	+	C,D
Podicipediformes	Podicipedidae	pied-billed grebe	*Podilymbus podiceps*							+	+	+	A,C
		horned grebe	*Podiceps auritus*							+	+	+	B,C
		eared grebe	*Podiceps nigricollis*							+	+	+	A,C
		western grebe	*Aechmophorus occidentalis*							+	+	+	A,C,D
		Clark's grebe	*Aechmophorus clarkii*							+	+	+	A,C,D
Pelecaniformes	Pelecanidae	brown pelican	*Pelecanus occidentalis*	FD							+	+	A,B,C,D
	Phalacrocoracidae	double-crested cormorant	*Phalacrocorax auritus*								+	+	A,B,C,D
		Brandt's cormorant	*Phalacrocorax penicillatus*								+	+	A,C
		pelagic cormorant	*Phalacrocorax pelagicus*								+	+	A,C,D
Ciconiiformes	Ardeidae	American bittern	*Botaurus lentiginosus*							+		-	A
		great blue heron	*Ardea herodias*							+	+	+	A,B,C
		great egret	*Ardea alba*							+	+	+	A,B,C,D
		snowy egret	*Egretta thula*							+	+	+	A,B,C
		cattle egret	*Bubulcus ibis*							+	+	+	A,C
		green heron	*Butorides striatus*							+	+	+	B,C,E
		black-crowned night heron	*Nycticorax nycticorax*						+	+	+	+	A,B,C
Anseriformes	Anatidae	tundra swan	*Cygnus columbianus*								+	-	A
		greater white-fronted goose	*Anser albifrons*								+	-	A
		snow goose	*Chen caerulescens*								+	-	A

Table F-1. Bird species predictions and detections in the Redwood Creek watershed

Order	Family	Common name	Scientific name	Status[1]	Habitat association							Detection[2]	Source[3]
					Redwood/ Doug-Fir	Mixed hard-wood	Grass-land	Coastal scrub	Riparian woodland	Seasonal wetland	Open water		
		Ross' goose	*Chen rossii*								+	-	A
		brant	*Branta bernicla*								+	+	A,B
		Canada goose	*Branta canadensis*								+	+	A,B,C
		wood duck	*Aix sponsa*						+	+	+	+	A,C
		gadwall	*Anas strepera*							+	+	+	A,C
		Eurasian wigeon	*Anas penelope*							+	+	+	A,B,C
		American wigeon	*Anas americana*							+	+	+	A,B,C
		mallard	*Anas platyrhynchos*			+			+	+	+	+	A,B,C,D,E,G
		blue-winged teal	*Anas discors*								+	-	A
		cinnamon teal	*Anas cyanoptera*							+	+	+	A,B,C
		northern shoveler	*Anas clypeata*							+	+	+	A,C
		northern pintail	*Anas acuta*							+	+	+	A,C
		green-winged teal	*Anas crecca*							+	+	+	A,B,C
		canvasback	*Aythya valisineria*								+	-	A
		redhead	*Aythya americana*	SSC							+	-	A
		greater scaup	*Aythya marila*								+	+	A,C
		lesser scaup	*Aythya affinis*								+	+	A,C
		bufflehead	*Bucephala albeola*							+	+	+	A,B,C
		surf scoter	*Melanitta perspicillata*								+	+	C,D
		Barrow's goldeneye	*Bucephala islandica*								+	+	B
		common goldeneye	*Bucephala clangula*								+	+	B,C
		common merganser	*Mergus merganser*								+	+	B
		red-breasted merganser	*Mergus serrator*						+		+	+	A,C
		ruddy duck	*Oxyura jamaicensis*		+	+					+	-	A

Table F-1. Bird species predictions and detections in the Redwood Creek watershed

Order	Family	Common name	Scientific name	Status[1]	Habitat association							Detection[2]	Source[3]
					Redwood/ Doug-Fir	Mixed hard-wood	Grass-land	Coastal scrub	Riparian woodland	Seasonal wetland	Open water		
Falconiformes	Cathartidae	turkey vulture	*Cathartes aura*			+	+					+	A,B,C,D
	Accipitridae	osprey	*Pandion haliaetus*		+						+	+	A,B,C
		white-tailed kite	*Elanus leucurus*	FP			+					+	A,B,C
		bald eagle	*Haliaeetus leucocephalus*	FD, SE, BGEPA	+						+	-	A
		northern harrier	*Circus cyaneus*	SSC			+			+		+	A,B,C,H
		sharp-shinned hawk	*Accipiter striatus*		+							+	A,C,D
		Cooper's hawk	*Accipiter cooperii*		+	+						+	A,B,C,D
		red-shouldered hawk	*Buteo lineatus*			+			+			+	A,B,C,D
		red-tailed hawk	*Buteo jamaicensis*		+	+	+	+	+	+		+	A,B,C,D, G
		ferruginous hawk	*Buteo regalis*				+		+			+	A,C
		rough-legged hawk	*Buteo lagopus*		+		+					-	A
		golden eagle	*Aquila chrysaetos*	BGEPA	+		+					-	A
	Falconidae	American kestrel	*Falco sparverius*			+	+					+	A,B,C,G
		merlin	*Falco columbarius*			+	+			+		+	A,C
		peregrine falcon	*Falco peregrinus*	FD,SE		+	+			+		+	A,B,C
		prairie falcon	*Falco mexicanus*				+			+		-	A
Galliformes	Phasianidae	chukar	*Alectoris chukar*	Intro			+					+	A, H
		ring-necked pheasant	*Phasianus colchicus*				+			+		-	A
		wild turkey	*Meleagris gallopavo*	Intro		+						+	A,H
		California quail	*Callipepla californica*				+	+	+			+	A,B,C,D, E,G

Table F-1. Bird species predictions and detections in the Redwood Creek watershed

Order	Family	Common name	Scientific name	Status[1]	Habitat association							Detection[2]	Source[3]
					Redwood/ Doug-Fir	**Mixed hard-wood**	**Grass-land**	**Coastal scrub**	**Riparian woodland**	**Seasonal wetland**	**Open water**		
Gruiformes	Rallidae	California black rail	*Laterallus jamaicensis coturniculus*	ST						+		-	A
		California Clapper rail	*Rallus longirostris*	FE,SE						+		-	A
		Virginia rail	*Rallus limicola*							+		+	A,B,C,G
		sora	*Porzana carolina*							+		+	A,C,G
		American coot	*Fulica americana*							+	+	+	A,B,C
Charadriiformes	Charadriidae	black-bellied plover	*Pluvialis squatarola*							+		+	A,C
		semipalmated plover	*Charadrius semipalmatus*							+		+	C
		killdeer	*Charadrius vociferus*				+			+		+	A,B,C
	Haematopodidae	black oystercatcher	*Haematopus bachmani*								+	+	B,C
	Recurvirostridae	black-necked stilt	*Himantopus mexicanus*							+		-	A
		American avocet	*Recurvirostra americana*							+		-	A
Charadriiformes	Scolopacidae	greater yellowlegs	*Tringa melanoleuca*							+		+	A,C
		lesser yellowlegs	*Tringa flavipes*							+		+	A,B
		willet	*Catoptrophorus semipalmatus*							+		+	A,B,C
		wandering tattler	*Heteroscelus incanus*							+		+	B,C
		spotted sandpiper	*Actitis macularia*							+		+	A,B,C
		whimbrel	*Numenius phaeopus*							+		+	A,B,C
		long-billed curlew	*Numenius americanus*							+		+	A,C,D
		marbled godwit	*Limosa fedoa*							+		+	A,B,C
		ruddy turnstone	*Arenaria interpres*							+		+	C
		black turnstone	*Arenaria*							+		+	C

Table F-1. Bird species predictions and detections in the Redwood Creek watershed

Order	Family	Common name	Scientific name	Status[1]	Habitat association							Detection[2]	Source[3]
					Redwood/ Doug-Fir	**Mixed hard-wood**	**Grass-land**	**Coastal scrub**	**Riparian woodland**	**Seasonal wetland**	**Open water**		
			melanocephala										
		surfbird	*Aphriza virgata*								+	+	C
		sanderling	*Calidris alba*							+		+	C
Charadriiformes	Scolopacidae	western sandpiper	*Calidris mauri*							+		+	A,C
		least sandpiper	*Calidris minutill* *Calidris alpinaa*							+		+	A,C
		dunlin	*Calidris alpina*							+		+	A,C
		short-billed dowitcher	*Limnodromus griseus*							+		-	A
		long-billed dowitcher	*Limnodromus scolopaceus*							+		+	A,C
		common snipe	*Gallinago gallinago*							+		+	A,B
	Phalaropodidae	Wilson's phalarope	*Phalaropus tricolor*							+		-	A
		red-necked phalarope	*Phalaropus lobatus*							+		+	A,B,C
		red phalarope	*Phalaropus fulicaria*							+		+	A,C
	Laridae	Bonaparte's gull	*Larus philadelphia*							+	+	+	A,C
		Heermann's gull	*Larus heermanni*							+	+	+	C,D
		ring-billed gull	*Larus delawarensis*							+	+	+	A,B,C
		California gull	*Larus californicus*							+	+	+	A,B,C
		herring gull	*Larus argentatus*							+	+	+	B,C
		mew gull	*Larus canus*							+	+	+	B,C
		Thayer's gull	*Larus thayeri*							+	+	+	C
		western gull	*Larus occidentalis*							+	+	+	A,B,C,D
		glaucous-winged gull	*Larus glaucescens*							+	+	+	C,D
		black-legged kittiwake	*Rissa tridactyla*								+	+	D
		Caspian tern	*Sterna caspia*								+	+	A,C,D

Table F-1. Bird species predictions and detections in the Redwood Creek watershed

Order	Family	Common name	Scientific name	Status[1]	Habitat association							Detection[2]	Source[3]
					Redwood/ Doug-Fir	Mixed hard-wood	Grass-land	Coastal scrub	Riparian woodland	Seasonal wetland	Open water		
		elegant tern	*Sterna elegans*								+	+	A,C
		common tern	*Sterna hirundo*								+	-	A
		Forster's tern	*Sterna forsteri*								+	+	A,C
	Alcidae	common murre	*Uria aalge*								+	+	C,D
		pigeon guillemot	*Cepphus columba*								+	+	C,D
		marbled murrelet	*Brachyramphus marmoratus*	FE	+						+	-	A
		rhinoceros auklet	*Cerorhinca monocerata*								+	-	A
Columbiformes	Columbidae	rock pigeon	*Columba livia*									+	A,B,C
		band-tailed pigeon	*Columba fasciata*		+							+	A,C,D
		mourning dove	*Zenaida macroura*			+	+					+	A,B,C,D, E
Strigiformes	Tytonidae	barn owl	*Tyto alba*				+			+		+	A,C
		barred owl	*Strix varia*	Intro	+	+			+			+	H,J
		western screech owl	*Otus kennicottii*			+			+			-	A
		great horned owl	*Bubo virginianus*		+	+	+		+			+	A,B,C
		northern pygmy owl	*Glaucidium californicum*			+						-	A
		burrowing owl	*Speotyto cunicularia*	SSC			+					-	A
		northern spotted owl	*Strix occidentalis caurina*	FT	+	+						+	A,C
		long-eared owl	*Asio otus*	SSC	+	+						-	A
		short-eared owl	*Asio flammeus*	SSC		+	+			+		-	A
		northern saw-whet owl	*Aegolius acadicus*		+	+				+		+	A
Caprimulgiformes	Caprimulgidae	common poorwill	*Phalaenoptilus nuttallii*				+	+				-	A
Apodiformes	Apodidae	black swift	*Cypseloides niger*	SSC	+							-	A
		chimney swift	*Chaetura pelagica*									-	A

Table F-1. Bird species predictions and detections in the Redwood Creek watershed

Order	Family	Common name	Scientific name	Status[1]	Habitat association							Detection[2]	Source[3]
					Redwood/ Doug-Fir	Mixed hard-wood	Grass-land	Coastal scrub	Riparian woodland	Seasonal wetland	Open water		
		Vaux's swift	*Chaetura vauxi*	SSC	+	+			+			-	A
		white-throated swift	*Aeronautes saxatalis*									+	A,C,D
	Trochilidae	Anna's hummingbird	*Calypte anna*			+		+	+			+	A,B,C,D, E,G
		Calliope hummingbird	*Stellula calliope*		+	+			+			-	A
		Rufous hummingbird	*Selasphorus rufus*			+	+	+	+	+		-	A
		Allen's hummingbird	*Selasphorus sasin*		+	+		+	+	+		+	A,C,D,E, G
Coraciiformes	Alcedinidae	belted kingfisher	*Ceryle alcyon*			+			+	+	+	+	A,B,C,D, F,G
Piciformes	Picidae	Lewis's woodpecker	*Melanerpes lewis*		+	+			+			-	A
		acorn woodpecker	*Melanerpes formicivorus*		+	+						+	A,C,D
		red-breasted sapsucker	*Sphyrapicus ruber*		+				+			+	A,C
		Nuttall's woodpecker	*Picoides nuttallii*			+			+			+	A,C
		downy woodpecker	*Picoides pubescens*			+			+			+	A,B,C,D, E,F,G
		hairy woodpecker	*Picoides villosus*		+	+			+			+	A,B,C,D, E,F,G
		northern flicker	*Colaptes auratus*		+	+			+			+	A,B,C,D, E,F,G, I
		pileated woodpecker	*Dryocopus pileatus*		+	+			+			+	A,C,D,G
Passeriformes	Tyrannidae	olive-sided flycatcher	*Mionectes olivaceus*	SSC	+		+					+	A,B,C,F, G
		western wood-pewee	*Contopus sordidulus*		+	+			+			+	A,C,E,F
		willow flycatcher	*Empidonax hammondii*	SE					+			+	A,C
		Hammond's	*Empidonax*		+							-	A

Table F-1. Bird species predictions and detections in the Redwood Creek watershed

Order	Family	Common name	Scientific name	Status[1]	Habitat association							Detection[2]	Source[3]
					Redwood/ Doug-Fir	**Mixed hard-wood**	**Grass-land**	**Coastal scrub**	**Riparian woodland**	**Seasonal wetland**	**Open water**		
		flycatcher	*hammondii*										
		least flycatcher	*Empidonax minimus*		+	+			+			+	C
		gray flycatcher	*Empidonax wrightii*					+				+	A,C
		dusky flycatcher	*Empidonax oberholseri*		+			+				-	A
		Pacific-slope flycatcher	*Empidonax difficilis*		+	+			+			+	A,C,D,E,F,G
		black phoebe	*Sayornis nigricans*						+	+		+	A,B,C,D,F,G
		say's phoebe	*Sayornis saya*				+			+		+	A,C
		ash-throated flycatcher	*Myiarchus cinerascens*					+	+			+	A,C,D,F
Passeriformes	Tyrannidae	western kingbird	*Tyrannus verticalis*				+					+	A,C
	Laniidae	loggerhead shrike	*Lanius ludovicianus*	SSC		+	+					+	A,C
	Vireonidae	solitary vireo	*Vireo solitarius*						+			+	A,C
		Cassin's vireo	*Vireo cassinii*			+						-	A
		Hutton's vireo	*Vireo huttoni*		+				+			+	A,C,D,E,F
		warbling vireo	*Vireo gilvus*		+	+			+			+	A,C,D,E,F
	Corvidae	Steller's jay	*Cyanocitta stelleri*		+	+			+			+	A,B,C,D,E,F
		western scrub-jay	*Aphelocoma californica*		+	+	+	+	+	+		+	A,B,C,E,F,G
		American crow	*Corvus brachyrhynchos*		+	+	+	+	+	+		+	A,B,C,D
		common raven	*Corvus corax*		+	+	+	+	+	+		+	A,C,D,E,F,H
	Alaudidae	horned lark	*Eremophila alpestris*				+					-	A
	Hirundinidae	purple martin	*Progne subis*	SSC	+						+	-	A

Table F-1. Bird species predictions and detections in the Redwood Creek watershed

Order	Family	Common name	Scientific name	Status[1]	Habitat association							Detection[2]	Source[3]
					Redwood/ Doug-Fir	Mixed hard-wood	Grass-land	Coastal scrub	Riparian woodland	Seasonal wetland	Open water		
		tree swallow	*Tachycineta bicolor*		+				+	+	+	+	A,B,C,D,E,G
		violet-green swallow	*Tachycineta thalassina*			+						+	A,B,C,D,E
		northern rough-winged swallow	*Stelgidopteryx serripennis*						+			+	A,B,C,D
		bank swallow	*Riparia riparia*	ST					+			-	A
		cliff swallow	*Hirundo pyrrhonota*									+	A,B,C,D
		barn swallow	*Hirundo rustica*						+			+	A,B,C,D,E
	Paridae	chestnut-backed chickadee	*Parus rufescens*		+	+			+			+	A,B,C,D,E,F,G
		oak titmouse	*Baeolophus inornatus*			+						-	A
	Aegithalidae	bushtit	*Psaltriparus minimus*			+		+				+	A,B,C,E,F,G
	Sittidae	red-breasted nuthatch	*Sitta canadensis*		+				+			+	A,C,D
Passeriformes	Sittidae	pygmy nuthatch	*Sitta pygmaea*		+	+			+			+	A,B,C,D,F,G
		white-breasted nuthatch	*Sitta carolinensis*			+						-	A,B
	Certhiidae	brown creeper	*Certhia americana*		+	+			+			+	A,B,C,D,F
	Troglodytidae	Bewick's wren	*Thryomanes bewickii*			+		+	+			+	A,B,C,D,E,F,G,H
		house wren	*Troglodytes aedon*		+	+			+			+	A,B,C
		winter wren	*Troglodytes troglodytes*		+							+	A,C,D,E,F
		marsh wren	*Cistothorus palustris*							+		+	A,B,C
	Muscicapidae	golden-crowned kinglet	*Regulus satrapa*		+							+	A,C,D

Table F-1. Bird species predictions and detections in the Redwood Creek watershed

Order	Family	Common name	Scientific name	Status[1]	Habitat association							Detection[2]	Source[3]
					Redwood/ Doug-Fir	Mixed hard-wood	Grass-land	Coastal scrub	Riparian woodland	Seasonal wetland	Open water		
		ruby-crowned kinglet	*Regulus calendula*		+	+			+			+	A,B,C,H
		blue-gray gnatcatcher	*Polioptila caerulea*			+		+				-	A
		western bluebird	*Sialia mexicana*		+	+	+		+			+	A,C,F, I
		mountain bluebird	*Sialia currucoides*			+	+					-	A
		Swainson's thrush	*Catharus ustulatus*			+			+			+	A,B,C,D, E,F,G
		hermit thrush	*Catharus guttatus*		+	+			+			+	A,B,C,D
		American robin	*Turdus migratorius*		+	+			+			+	A,B,C,D, E,F,G
		varied thrush	*Ixoreus naevius*		+				+			+	A,C
		wrentit	*Chamaea fasciata*					+				+	A,C,D,E, F,H
	Mimidae	northern mockingbird	*Mimus polyglottos*				+	+				+	A,C
		California thrasher	*Toxostoma redivivum*					+	+			-	A
	Sturnidae	European starling	*Sturnus vulgaris*	Intro		+	+	+	+	+		+	A,B,C,E, G
	Motacillidae	American pipit	*Anthus rubescens*				+			+		+	A,C
	Bombycillidae	cedar waxwing	*Bombycilla cedrorum*		+	+			+			+	A,B,C
Passeriformes	Emberizidae	black and white warbler	*Mniotilta varia*			+						+	C
		orange-crowned warbler	*Vermivora celata*			+		+	+			+	A,C,D,E, F,G
		Audubon's warbler	*Dendroica auduboni*			+						+	A,B,D
		Nashville warbler	*Vermivora ruficapilla*			+			+			+	A,C
		yellow warbler	*Dendroica petechia*	SSC				+	+			+	A,B,C,E

Table F-1. Bird species predictions and detections in the Redwood Creek watershed

Order	**Family**	**Common name**	**Scientific name**	**Status**[1]	**Habitat association**							**Detection**[2]	**Source**[3]
					Redwood/ Doug-Fir	**Mixed hard-wood**	**Grass-land**	**Coastal scrub**	**Riparian woodland**	**Seasonal wetland**	**Open water**		
		Cape May warbler	*Dendroica tigrina*									+	C
		yellow-rumped warbler	*Dendroica coronata*		+				+	+		+	A,C,D
		black-throated gray warbler	*Dendroica nigrescens*		+	+			+			+	A,B,C,D
		Townsend's warbler	*Dendroica townsendi*					+				+	A,B,C
		hermit warbler	*Dendroica occidentalis*		+				+			+	A,C,D
		palm warbler	*Dendroica palmarum*						+			+	C
		American redstart	*Setophaga ruticilla*						+			+	A,B,C
		MacGillivray's warbler	*Oporornis tolmiei*			+			+			+	A,C,E
		common yellowthroat	*Geothlypis trichas*						+	+		+	A,C,E,G
		Wilson's warbler	*Wilsonia pusilla*		+	+		+	+			+	A,B,C,D, E,F,G
		yellow-breasted chat	*Icteria virens*	SSC				+	+			-	A
		western tanager	*Piranga ludoviciana*		+							+	A,C
		spotted towhee	*Pipilo maculatus*		+			+				+	A,B,C,D, E,F,H
		California towhee	*Pipilo crissalis*					+	+			+	A,B,C,D, E,F,G
		rufous-crowned sparrow	*Aimophila ruficeps*					+				-	A
Passeriformes	Emberizidae	chipping sparrow	*Spizella passerina*			+	+					+	A,C
		black-chinned sparrow	*Spizella atrogularis*					+				-	A
		Vesper sparrow	*Pooecetes gramineus*				+					-	A
		lark sparrow	*Chondestes grammacus*				+	+				-	A

Table F-1. Bird species predictions and detections in the Redwood Creek watershed

Order	Family	Common name	Scientific name	Status[1]	Habitat association							Detection[2]	Source[3]
					Redwood/ Doug-Fir	Mixed hard-wood	Grass-land	Coastal scrub	Riparian woodland	Seasonal wetland	Open water		
		sage sparrow	*Amphispiza belli*					+				-	A
		savannah sparrow	*Passerculus sandwichensis*				+	+		+		+	A,C,E,G,H
		grasshopper sparrow	*Ammodramus savannarum*	SSC			+					-	A
		fox sparrow	*Passerella iliaca*			+			+			+	A,B,C
		song sparrow	*Melospiza melodia*			+	+	+	+	+		+	A,B,C,D,E,F,G,H
		Lincoln's sparrow	*Melospiza lincolnii*				+	+	+	+		+	A,C
		Swamp sparrow	*Melospiza georgiana*							+		+	C
		white-throated sparrow	*Zonotrichia albicollis*					+		+		+	A,C
		Harris's sparrow	*Zonotrichia querula*			+	+					-	A
		white-crowned sparrow	*Zonotrichia leucophrys*				+	+				+	A,B,C,E,G,H
		golden-crowned sparrow	*Zonotrichia atricapilla*				+	+	+			+	A,B,C
		dark-eyed junco	*Junco hyemalis*		+	+			+			+	A,C,D,G
		Lapland longspur	*Calcarius lapponicus*				+					-	A
		black-headed grosbeak	*Pheucticus melanocephalus*			+						+	A,B,C,E,F,G
		Lazuli bunting	*Passerina amoena*					+	+			+	A,E
		indigo bunting	*Passerina cyanea*					+				-	A
		red-winged blackbird	*Agelaius phoeniceus*						+	+		+	A,B,C,E,G
		tricolored blackbird	*Agelaius tricolor*	SSC						+		+	A,B
Passeriformes	Emberizidae	western meadowlark	*Sturnella neglecta*				+			+		+	A,C
		yellow-headed blackbird	*Xanthocephalus xanthocephalus*	SSC						+		+	A,C

Table F-1. Bird species predictions and detections in the Redwood Creek watershed

Order	Family	Common name	Scientific name	Status[1]	Habitat association							Detection[2]	Source[3]
					Redwood/ Doug-Fir	Mixed hard-wood	Grass-land	Coastal scrub	Riparian woodland	Seasonal wetland	Open water		
		brewer's blackbird	*Euphagus cyanocephalus*				+		+			+	A,B,C,E, G
		brown-headed cowbird	*Molothrus ater*	Intro			+	+	+			+	A,C,E,F, G
	Icteridae	hooded oriole	*Icterus cucullatus*						+			-	A
		northern oriole	*Icterus galbula bullockii*			+						+	A,C
	Fringillidae	purple finch	*Carpodacus purpureus*		+				+			+	A,B,C,D, E,F
		house finch	*Carpodacus mexicanus*				+	+	+	+		+	A,B,C,F, G
		red crossbill	*Loxia curvirostra*		+							+	A,C,D
		pine siskin	*Carduelis pinus*		+	+						+	A,B,C,D
		lesser goldfinch	*Carduelis psaltria*			+			+			+	A,B,C,E
		Lawrence's goldfinch	*Carduelis lawrencei*			+	+	+	+			-	A
		American goldfinch	*Carduelis tristis*				+	+				+	A,B,C,D, E,F,G,H
		evening grosbeak	*Coccothraustes vespertinus*		+	+						-	A
	Passeridae	house sparrow	*Passer domesticus*	Intro			+	+				+	A,C

[1] **Status**: FE=Federally Endangered
FD=Federally Delisted
SE=State Endangered
ST=State Threatened
SSC=California Species of Special Concern;
FP=California Fully Protected
BGEPA=protected by the Bald and Golden Eagle Protection Act
Intro=Introduced

[2] **Detection:** Species Detected (+); Species Not Detected (-): Detection = species that have been observed and documented in Redwood Creek watershed since the early 1990s. If a species is categorized as Not Detected (-), there is either a historical record for the species in the watershed, suitable habitat for the species in the watershed, or both.

[3] **Source**

(A) California Wildlife Habitat Relationships System Version 8.2, 2008 (primarily used for habitat associations and range overlap, along with the Cornell Lab of Ornithology bird website http://www.allaboutbirds.org)
(B) PWA et al. 1994
(C) Stallcup 1995
(D) Gardali and Geupel 2000
(E) Holmes et al. 1999
(F) Scoggin et al. 2000
(G) Gardali and Geupel 1997
(H) Shulzitski et al. 2003
(I) Humple and Gardali 2004
(J) Jensen et al. 2007

Table F-2. Mammal species predictions and detections in the Redwood Creek watershed.

Order	Family	Common name	Scientific name	Status[1]	Habitat association						Detection[2]	Source[3]
					Redwood/Doug-Fir	**Mixed hard-wood**	**Grass-land**	**Coastal scrub**	**Riparian woodland**	**Seasonal wetland**		
Marsupialia	Didelphidae	Virginia opossum	*Didelphis marsupialis*	Intro	+				+		+	A,B,D
Insectivora	Soricidae	vagrant shrew	*Sorex vagrans*		+						+	A,B,D
		fog shrew	*Sorex sonomae*		+	+		+	+		-	A,B
		ornate shrew	*Sorex ornatus*				+	+		+	-	A,B
		Trowbridge's shrew	*Sorex trowbridgii*		+	+			+		+	B,D
	Talpidae	shrew-mole	*Neurotrichus gibbsii*						+		+	A,B,D
		broad-footed mole	*Scapanus latimanus*						+		+	A,B,D
Chiroptera	Vespertillionidae	pallid bat	*Antrozous pallidus*	SSC					+		-	A,B,E
		big brown bat	*Eptesicus fuscus*		+						+	A,B,E
		silver-haired bat	*Lasionycteris noctivagans*		+	+			+		+	A,B,E
		western red bat	*Lasiurus blossevillii*	SSC	+	+			+		+	A,B,E
		hoary bat	*Lasiurus cinereus*						+		+	A,B,E
		California myotis	*Myotis californicus*			+		+			+	A,B,E
		long-eared bat	*Myotis evotis*		+			+			-	A,B,E
		little brown bat	*Myotis lucifugus*					+	+		-	A
		fringed myotis	*Myotis thysanodes*		+						+	A,B,E
		long-legged myotis	*Myotis volans*		+						+	B,E
		Yuma myotis	*Myotis yumanensis*		+				+		+	A,B,E
		Townsend's long-eared bat	*Corynorhinus townsendii*	SSC	+						+	A,B,E
		guano (=Brazilian free-tailed) bat	*Tadarida brasiliensis*		+						+	A,B,E

Order	Family	Common name	Scientific name	Status[1]	Habitat association						Detection[2]	Source[3]
					Redwood/Doug-Fir	Mixed hard-wood	Grass-land	Coastal scrub	Riparian woodland	Seasonal wetland		
Carnivora	Canidea	Coyote	*Canis latrans*		+	+	+	+	+		+	A,B,D
		Domestic dog	*Canis familiaris*	Intro	+		+				+	D
		Gray fox	*Urocyon cinereoargenteus*		+	+	+	+	+		+	A,B,C,D
	Procyonidae	Ringtail	*Bassariscus astutus*	FP	+				+		-	A,B
		Raccoon	*Procyon lotor*		+	+			+		+	A,B,D
	Mustelidae	River otter	*Lontra canadensis*		+				+	+	+	B,G
		Short-tailed weasel	*Mustela erminea*		+						-	B
		Long-tailed weasel	*Mustela frenata*		+	+	+	+			-	A,B
		Badger	*Taxidea taxus*	SSC			+				-	A,B
	Mephitidae	Striped skunk	*Mephitis mephitis*		+	+	+	+	+	+	+	A,B,D
		Spotted skunk	*Spilogale gracilis*		+	+	+	+	+	+	+	A,B,D
	Felidae	Feral cat	*Felis silvestris*	Intro	+	+	+	+	+	+	+	D
		Mountain lion	*Puma concolor*		+	+		+	+		+	A,B,G
		Bobcat	*Lynx rufus*		+	+	+	+	+		+	A,B,C,D
Artiodactyla	Cervidae	Black-tailed deer	*Odocoileus hemionus*		+	+	+	+	+		+	A,B,C,D
Rodentia	Sciuridae	California ground squirrel	*Spermophilus beecheyi*			+	+				-	A,B
		Western gray squirrel	*Sciurus griseus*			+					+	A,B,D
		Douglas's squirrel	*Tamiasciurus douglasii*		+						-	A,B
		Sonoma chipmunk	*Tamias sonomae*		+			+			+	A,B,D
	Dipodidae	Pacific jumping mouse	*Zapus trinotatus*				+				-	A,B
	Geomyidae	Botta's pocket gopher	*Thomomys bottae*				+	+			-	A,B
	Heteromyidae	California kangaroo rat	*Dipodomys californicus*					+			-	A,B
	Muridae	Dusky-footed woodrat	*Neotoma fuscipes*			+		+	+	+	+	A,B,D
		Brush mouse	*Peromyscus boylii*			+		+			-	B
		Deer mouse	*Peromyscus*		+	+	+	+	+	+	+	A,B,D,F

Order	Family	Common name	Scientific name	Status[1]	Habitat association						Detection[2]	Source[3]
					Redwood/Doug-Fir	Mixed hard-wood	Grass-land	Coastal scrub	Riparian woodland	Seasonal wetland		
			maniculatus									
		Pinyon mouse	*Peromyscus trueii*		+	+					-	A,B
		Western harvest mouse	*Reithrodontomys megalotis*				+		+	+	+	A,B,D,F
		California red-backed vole	*Clethrionomys californicus*		+						-	A,B
		California meadow vole	*Microtus californicus*				+	+	+	+	+	A,B,D,F
		House mouse	*Mus musculus*	Intro			+	+			-	A,B
		Norway rat	*Rattus norvegicus*	Intro	+	+	+	+	+		-	A,B
		Black rat	*Rattus rattus*	Intro	+	+	+	+	+		+	A,B,F
Lagomorpha	Leporidae	Brush rabbit	*Sylvilagus bachmani*					+	+		+	A,B,D
		Black-tailed jackrabbit	*Lepus californicus*				+	+			-	A,B

[1] **Status**: SSC=California Species of Special Concern;
FP=California Fully Protected
Intro=Introduced

[2] **Detection:** Species Detected (+); Species Not Detected (-): Detection = species that have been observed and documented in Redwood Creek watershed since the early 1990s. If a species is categorized as Not Detected (-), there is either a historical record for the species in the watershed, suitable habitat for the species in the watershed, or both.

[3] **Source**

(A) California Wildlife Habitat Relationships System Version 8.2, 2008 (primarily used for habitat associations and range overlap)
(B) Jameson and Peeters 1988 (primarily used for habitat associations and range overlap)
(C) PWA et al. 1994
(D) Howell et al. 1999
(E) Heady and Frick 2004
(F) Takegawa 2003
(G) Bill Merkle, pers. comm.

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Appendix G

Tier One Prioritization Scoring for Action Issues

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Table G-1. Tier One Prioritization Scoring for Action Issues

Priority	DFC Reference Number and Subject Area	Priority Action Issue Description	Scores (1-3)**		Notes
			Ecological Significance (ES)	Threat Severity (TS)	
High	Issue 9 Aquatic Species	**Minimize effects of water withdrawal on fish populations** *Summary:* The greatest withdrawals from the main stem supply the Muir Beach Community through the MBCSD well near the Banducci property. A recent study indicates that pumping during dry water years increases the number of disconnected pools and results in lower dissolved oxygen levels. The study concludes that dry year low flow conditions could result in a 10 percent reduction in watershed fish production. The MBCSD Adaptive Management Plan of 2005 introduces several alternative dry-season water source options, including tank storage in Frank Valley and desalination. In addition, the restoration of Lower Redwood Creek at Muir Beach, initiated in August of 2010, includes removal of fish barriers to the Green Gulch tributaries. Renewed availability of this habitat will require that water withdrawal and impoundment by the Green Gulch Zen Center be tailored to minimize impacts on aquatic habitat, particularly during late summer and early fall. *Benefits:* Aquatic habitat, salmonid and other aquatic species, human water users, water quality *Primary Actions:* Provide assistance in developing alternative water source options for Lower Redwood Creek, including consideration of desalination, additional conservation measures, and additional storage of high winter flows. Alternative storage location(s) for winter flows along the mainstem will be considered, along with identification of potential negative impacts of storage options and ways to minimize or mitigate these effects. Also priority actions include identification of potential impacts and means to avoid impacts associated with withdrawals from Green Gulch and the unnamed tributary to its south and implement water use measures to ensure optimal ecological flows.	3	3	ES: Low late summer flows associated with water withdrawal have been linked to reduced salmonid success. TS: Low summer flows shown to reduce high quality late summer salmonid habitat could directly, negatively impact salmonid populations. Projected increase in extreme events, including droughts, could exacerbate this problem unless alternative solutions are identified and enacted.
High	Issue 20 Vegetation	**Limit introduction and spread of invasive plant species through systematic monitoring and public outreach** *Summary:* Invasive non-native plant species reduce biodiversity, degrade habitat quality. Most invasive species enter the watershed via transportation corridors or as garden escapes. Public outreach and education could reduce invasive species introductions along trails, roads, and from lawns and gardens. With new invasive species being continually introduced and established species spreading, a monitoring program is critical for detecting new and for tracking established invasive species so that a control program is based on informed priorities and the best available information. Monitoring is not currently performed in a coordinated fashion throughout the watershed. *Benefits:* Wildlife and avian habitat; plant communities; aquatic communities *Primary Actions:* Develop coordinated monitoring program for all lands in the watershed; perform public outreach; develop and disseminate education materials.	3	3	ES: Invasive plant species negatively affect native plant populations, wildlife and aquatic habitat; there are enough invasive species that a tracking system is needed to ensure that resources are targeted at reducing introduction and spread, and control of most problematic species TS: This is high because if invasives are slow to respond to control, invasives will spread rapidly, increasing impacts and cost and labor of required management.
High	Issue 14 Water Quality	**Reduce nutrient enrichment of lower Redwood Creek** *Summary:* Seasonal occurrences of low dissolved oxygen levels occur within lower Redwood Creek and could be associated with observed downstream increases in stream water nutrient [Nitrogen] concentrations. As with bacterial inputs, equestrian use of Redwood Creek trail could result in important nutrient inputs to lower Redwood Creek. *Benefits:* Salmonid populations, water quality, aquatic habitat, benthic macro-invertebrates *Primary Actions:* Implement actions to reduce nutrient inputs from known or highly likely sources, such as Redwood Creek trail crossing.	3	3	ES: Contributes to low DO in late summer/ fall, particularly during dry years, which has been linked to reduced salmonid success TS: Left untreated, these sources could get worse with increased frequency of extreme events projected for watershed due to climate change. Threat to fish is very imminent and time-sensitive.
High	Issue 30 Wildlife	**Halt declines in wetland and riparian bird species by restoring suitable habitat**. *Summary:* Riparian areas and wetlands are extremely valuable habitat for bird species; including many special-status species such as tricolored and yellow-headed blackbirds, willow flycatcher, and the yellow warbler. However, loss of historical riparian areas and wetlands in the watershed has decreased suitable habitat for riparian and wetland bird species, affecting abundance, productivity and distribution in the Redwood Creek watershed. For some wetland and riparian bird species, this watershed is believed to be acting as a sink rather than source for the regional population. Conversion of riparian woodland habitat to emergent wetlands through the Restoration of Lower Redwood Creek at Muir Beach will mark an important shift in abundance of these habitats in the watersheds, however additional riparian forests and wetlands are needed in other areas of the watershed, adjacent to healthy uplands for foraging, to help recover and support these bird species populations. Adjacent chaparral communities also provide important forage habitat and need to be included in restoration plans *Benefits:* Wetland and riparian bird species and other associated wildlife, wetland and riparian plant communities; aquatic community; water quality *Primary Actions*: Implement restoration of riparian and wetland areas, and associated adjacent chaparral, and monitor population trends in relation to restored and existing wetland and riparian habitat characteristics perform adaptive management.	3	3	ES: Actions would affect sensitive species (riparian focal species, especially Wilson's warbler); increases resilience; doesn't support natural processes; or connectivity; does foster diversity TS: Wilson's warbler population is declining and Redwood Creek is a sink. Brood parasitism has been shown to be an important factor. Untreated, Redwood Creek will continue to be a sink and the population will continue to decline.
High	Issue 21 Vegetation	**Improve invasive non-native plant species control and eradication** *Summary:* Control of invasive plants through herbicide application, mechanical treatments, and controlled burning can have negative effects on other resources. Research and monitoring, adaptive management, communication and coordination among resource managers is needed to ensure that all weed control activities are as effective as possible and have minimal effects on other resources. Control/eradication is usually labor intensive and very expensive; so that collaboration among agencies might offer opportunities for increased efficiency and for sharing lessons learned regarding control techniques. *Benefits:* Native plant communities and dependant wildlife species *Primary Actions:* Increase monitoring, research, communication and coordination among resource staff within and among agencies through annual or more frequent meetings, reduced spread rate and extent of invasive plant species; public outreach and education.	2	2	ES: Indirectly affects sensitive species but directly affects habitat; increases resilience by increasing biodiversity; indirect support of natural processes; can increase connectivity by creating higher quality habitat in riparian corridors; does foster diversity TS: Effective treatments need to be identified and shared among land managers to minimize spread and cost of control. Each species requires slightly different control methods.

Table G-1. Tier One Prioritization Scoring for Action Issues

Priority	DFC Reference Number and Subject Area	Priority Action Issue Description	Scores (1-3)**		Notes
			Ecological Significance (ES)	Threat Severity (TS)	
High	Issue 2 Hydrology/ Geomorphology	**Reconnect Frank Valley floodplain to Redwood Creek mainstem** *Summary:* Past channel realignment, floodplain regrading, and incision has isolated Redwood Creek from its floodplain along Frank Valley. Since reconnecting and regrading are expensive, the extent of floodplain disconnection and its implications on salmon and steelhead rearing habitat should be better understood as the basis for prioritizing cost-effective restoration measures. *Benefits:* Aquatic habitat (e.g., coho salmon winter habitat), water quality, riparian community extent and composition, and flood conveyance. *Primary Actions:* Develop field-based estimates of floodplain inundation frequency, duration, and extent under current conditions during different return period flows in relation to existing and potential aquatic habitat distribution as a basis for selecting priority restoration areas. Second stage actions include implementation of restoration projects along selected reaches in Frank Valley.	3	3	ES: Reconnecting floodplain would provide a bundle of ecosystem services, aquatic and riparian habitat, flood control, reduced sediment input, and probably others, and improves resilience, connectivity, diversity. TS: The situation is likely to get better over (geologic) time physically; however the threat severity of impacts on fish if no actions are taken has the potential to be extreme. This would argue that the biological threat severity is high (3).
Med	Issue 13 Water Quality	**Identify sources of bacterial contamination of lower Redwood Creek and Muir Beach** *Summary:* Bacterial contamination periodically occurs along lower Redwood Creek and Muir Beach due to unidentified contamination sources. Local observations of equestrian use along Redwood Creek Trail, particularly where the trail crosses the creek multiple times, suggest that horse use along these creek crossings could be an important source of bacterial contamination to lower Redwood Creek. *Benefits:* Water quality; residential and visitor use of Muir beach (MB); aquatic habitat and species. *Primary Actions:* Move Redwood Creek trail out of the channel to minimize equestrian nutrient and bacterial inputs and work with the Muir Beach community to improve septic systems, work with dog and horse owners to minimize potential inputs.	2	2	ES: Shown to be a problem for beach-goers, the fish, frogs and riparian plants are not apparently affected. TS: High bacteria levels have not been shown to threaten natural resources. However, left untreated, these sources could get worse with increased frequency of extreme events projected for watershed due to climate change.
Med	Issue 25 Wildlife	**Increase California red-legged frog breeding areas in watershed** *Summary:* Red-legged frog population is extremely small and confined to the Big Lagoon area. *Benefits:* Red-legged frogs; other wetland and riparian-dependant species *Primary Actions:* Implementation of Lower RWC restoration at MB with 'frog pond' followed by monitoring and adaptive management to optimize conditions for the RLF.	3	3	ES: Directly affects a federally listed species; increases resilience; supports natural processes/disturbance (flooding); fosters diversity TS: Especially high for CA red-legged frogs, which may become extirpated if habitat becomes unsuitable
Med	Issue 8 Hydrology/ Geomorphology	**Remove constraints on natural processes by existing structures and parking lots** *Summary:* Existing structures and infrastructure, including Pacific Way Bridge, Muir Woods Road along Upper Frank Valley, Muir Woods road bridge, rockwork along channel banks within Muir Woods and downstream of the Highway 1 bridge, buildings and parking lots, and buried infrastructure (e.g. underground utilities) can constrain or impinge upon natural processes such as flooding, channel migration, and wildlife behavior. *Benefits:* Aquatic and riparian habitat and species; water quality. *Primary Actions:* Identify and implement actions necessary to remove or minimize constraints these structures on natural processes on a case by case basis. Action examples include restructuring Pacific Way Bridge, moving Muir Woods parking lot and concession buildings away from the channel and floodplain; realigning Muir Woods road along reaches where it impinges on channel migration, and removing or minimizing extent of bank revetments in Muir Woods and in the reach between the Highway 1 and Pacific Way bridges.	3	3	ES: Resizing and relocating the Pacific Way Bridge, as well as MB and MuWo parking lots to allow channel access to floodplain and removing stone revetments would directly affect salmonid habitat/survival, as well as regeneration and diversity in MuWo ancient redwood forest. TS: Timing to improve salmonid winter refugia and red legged frog habitat along lower Redwood Creek is critical and needs will increase with climate change
Med	Issue 23 Aquatic Species	**Increase amount of winter refugia for rearing Coho salmon and steelhead**. *Summary:* Reduced large woody debris (LWD) frequency, aquatic habitat complexity, and floodplain connectivity in the watershed have likely diminished the amount of winter refuge habitat for rearing Coho salmon and steelhead. *Benefits:* Coho and steelhead populations; other aquatic and riparian species and communities, sediment storage; flood attenuation. *Primary Actions:* Increase winter refugia, support adaptive management informed by field survey and mapping of fish habitat, fish use, in-stream LWD, and LWD sources. The restoration of Lower RWC at MB includes adding a lot of winter refugia; so issue now needs monitoring to be sure this project has positive and significant effects.	3	3	ES: Lateral connectivity with floodplain offers many benefits to salmonids and other aquatic and riparian species TS: Salmonid populations need help now.
Med	Issue 6 Hydrology/ Geomorphology	**Reduce flood hazard during high flow events along Pacific Way** *Summary:* Flood discharges overtop the left bank and flow through the lower central portion of the floodplain to lower RWC, crossing Pacific Way. The result is extended periods of flooding on Pacific Way during relatively wet water years; likely to have increasing importance with climate change. *Benefits:* Muir beach and MB community access; sediment transport; aquatic habitat; adjacent riparian and wetland communities *Primary Actions:* Move channel to natural valley bottom position (issue #2); widen Pacific Way bridge; post-implementation monitoring for bed aggradation (see Lower RWC Restoration at MB)	3	3	ES: Making this portion of lower Redwood Creek highly supportive for fish refugia and frogs (as well as riparian habitat) is very important. While flooding along these lower reaches would be expected to improve frog, salmonid and riparian habitat, channel avulsions could have important negative effects on salmonids by creating inadequate fish passage. Solutions would increase resilience, support natural processes, and foster diversity. TS: Will likely get worse if untreated; and likely to get worse with climate change.

Table G-1. Tier One Prioritization Scoring for Action Issues

Priority	DFC Reference Number and Subject Area	Priority Action Issue Description	Scores (1-3)**		Notes
			Ecological Significance (ES)	Threat Severity (TS)	
Med	Issue 11 Water Quality	**Implement best management practices to minimize negative water quality effects from storm water runoff from parking lots and roads** *Summary:* Storm water runoff from roads and parking lots is known to release ecologically harmful levels of contaminants to downstream aquatic ecosystems. The proximity of roads and parking lots to the channel and anticipated increase in visitor use suggests minimal natural filtering occurs and likely future increases in pollutant loads could occur. *Benefits:* Water quality; Aquatic habitat and species; riparian species dependant on aquatic food sources *Primary Actions:* Implement known best management practices to minimize storm water runoff input directly to aquatic systems, including construction of settling ponds or riparian/wetland filter strips between compacted surface and stream channel.	3	2	ES: Good water quality is essential for life; however historical sampling for toxins and heavy metals associated with stormwater runoff do not indicate high levels (water quality criteria have been met for all but ammonia and bacterial inputs). Lack of event-driven sampling associated with likely sources makes it difficult to conclude no effects associated with stormwater runoff are occurring. Location of Redwood Creek Road, Muir Beach and Muir Woods parking lots and intersections of the road network with Redwood Creek at multiple locations suggest stormwater runoff could be occurring at ecologically important levels. TS: Low non-event associated metal numbers suggest storm and unmeasured organic pollutants associated with metals like PAH's could also low; use of the Muir Woods shuttle should decrease traffic and runoff. Other threats to aquatic system seem to be greater and more imminent.
Low	Issue 15 Vegetation	**Allow for regeneration and natural disturbance regimes in Muir Woods and other Redwood forests in watershed** *Summary:* Historical fire and flood regimes have been changed in Muir woods and the other redwood forests in RWC watershed and suspension of frequent low intensity fires and floods could have increased vulnerability to pests and disease, reduced frequency of pulse nutrient inputs to soil, and reduced availability of mineral soil for redwood regeneration. *Benefits:* Redwood forest; wildlife and plant species dependant on redwood forest *Primary Actions:* Restore, through prescribed burns and restoration of channel banks and floodplain, fire and flooding to redwood forests in Muir Woods and Kent Canyon.	3	2	ES: Direct effect of actions on wildlife habitat mostly positive; indirect effects include increased resilience; support of natural processes; increased connectivity (flooding); increased structural and species diversity. TS: Changes due to SOD on wildlife habitat and forest processes (fire, nutrient cycling) could be important and imminent, particularly regarding wildfire potential, and spotted owl effects. Impacts associated suppressed disturbance regimes are exacerbated by SOD. This is given a 2 over a 3 since redwood forest response to change/stress occurs over decades rather than months or years (as with fish and amphibian species).
Low	Issue 21 Wildlife	**Minimize impacts of non-native animals and native "pest" animal species on native species** *Summary:* Non-native pest species can threaten visitors or negatively affect other native species (e.g. turkeys and Chukar partridges) and some native animals, such as raccoons and ravens, crows, and jays, are more prevalent and impacting other species through excessive populations. *Benefits:* native animal and plant species *Primary Actions:* Assess distribution and effects of 'pest' species; identify and implement control measures.	2	3	ES: Indirectly affects sensitive species; increases resilience by increasing biodiversity; does not support natural physical processes; does not increase connectivity; does foster diversity TS: Turkey population likely to be on verge of expanding greatly in the near future. The impacts of a bursting turkey population on resident native species and habitat conditions are likely to be significant, by sheer numbers at least. Other non-native species populations could follow similar path (e.g., bullfrogs, corvids, chukars).
Low	Issue 31 Wildlife	**Halt decline of local native song bird populations due to nest predation and brood parasitism by non-native predator birds** *Summary:* Studies have attributed declines in local native songbirds (Wilson's warble or WW) to brood parasitism and nest predation by other species, such as brown-headed cowbirds; Redwood creek a 'sink' population for WW in the region; WW population in decline in CA as well as several other western states. *Benefits:* Song-birds, local invertebrates Primary Actions: Implement protections for brood parasitism and predation and assess song bird status in relation to these measures for adaptive management.	2	3	ES: Actions would affect sensitive species (riparian focal species, especially Wilson's warbler); increases resilience; doesn't support natural processes; or connectivity; does foster diversity TS: Wilson's warbler population is declining and Redwood Creek is a sink. Brood parasitism has been shown to be an important factor. Untreated, Redwood Creek will continue to be a sink and the population will continue to decline.
Low	Issue 7 Hydrology/ Geomorphology	**Increase flood capacity in existing culverts** *Summary:* Numerous culverts through the watershed have insufficient capacity to pass flood flows, resulting in local upstream flooding, downstream hydraulic erosion, potential culvert failure and site erosion, and impacts on sediment delivery to downstream aquatic systems. MMWD has addressed several of the undersized culverts within their jurisdiction, but more needs t o be accomplished on these and other lands in the watershed. Existing studies have identified specific sites in need of improvement. *Benefits:* Local and downstream aquatic habitat; reduced cumulative sediment loading; improved roadways and passage *Primary Actions:* Identification and replacement of undersized culverts through funding and multi-agency commitment	2	2	ES: Fine sediment from culvert blow-outs during storm events could negatively affect downstream aquatic resources, however might not be as acute a problem as others, such as reduced water availability and quality/ TS: Sediment pulses could occur if culvert is blocked, then by passed or broken in a storm event, delivering potentially important but temporary slugs of sediment downstream.
Low	Issue 5 Hydrology/ Geomorphology	**Quantify and reduce excessive sediment yields due to mainstem and tributary incision in Frank Valley that impact water quality, fish habitat, and flood conveyance** *Summary:* Land use and channel management in Frank Valley have resulted in incision of the Redwood Creek mainstem causing sediment yields estimated to account for one-quarter of the sediment input to Big Lagoon. High fine sediment inputs are impacting downstream aquatic habitat and water quality. *Benefits:* Water quality, aquatic species and habitat; riparian communities, flood conveyance *Primary Actions:* Fill data gaps regarding the extent to which Redwood Creek is shifting from a degrading to an aggrading system, and the likelihood of associated bank erosion and increased fine sediment output. In this way, land and/or water uses that increase storm-related sediment loading from channel erosion can be identified and avoided. Perform in coordination with geomorphology baseline study (Issue 3).	2	2	ES: Fine sediment inputs could be importantly and negatively affecting the fish by making it hard to find winter refugia in the form of unfilled-in boulders - high flow refuge habitat is severely limited in the incised reach (hence the low weirs) TS: Overall quantity of sediment is 10 times greater than background, but not clear that fine sediment is more limiting that water (DO) to fish.

Table G-1. Tier One Prioritization Scoring for Action Issues

Priority	**DFC Reference Number and Subject Area**	**Priority Action Issue Description**	**Scores (1-3)****		**Notes**
			Ecological Significance (ES)	**Threat Severity (TS)**	
Low	Issue 4 Hydrology/ Geomorphology	**Quantify and reduce high potential sediment yields resulting from human actions in tributaries, including Conlon Canyon** *Summary:* Excess sediment from headwater areas, partly derived from human activities, has the potential to cause short-term sediment pulses or long-lasting periods of aggradation which may adversely affect downstream restoration actions and aquatic habitat *Benefits:* Water quality, fish and amphibian species, aquatic habitat *Primary Actions:* Perform study to establish tributary sediment yields in exceedance of natural rates and actions or changes in land use that reduce inputs. Developing Best Management Practices for sediment conservation; second stage involves implementing these actions or land use changes. Perform in coordination with geomorphology baseline study (Issue 3).	2	2	ES: If fine and/or polluted sediment from headwaters is significantly impacting fish habitat, then the ES should be high. Fine sediment reduces boulder cover (winter refugia for fish) which suggests this should be 2 or 3 TS: Sediment pulses could occur, but would they be a major problem to fish or other species? It is likely there are numerous other measures (e.g. Lower Redwood Creek Restoration at Muir Beach and Frank Valley restoration measures) that may be more critical.
Low	Issue 10 Aquatic Species	**Reduce vulnerability of lower Redwood Creek to additional water diversions**. *Summary:* Water resources in the watershed have not been declared “fully appropriated” by the state water board, leaving the watershed vulnerable to future additional claims for water diversions *Benefits:* Provides means of assuring water allocations are known and manageable. *Primary Actions:* Detail all existing used and unused water rights in the watershed and removal of currently unused water rights from the possibility of future use.	3	1	ES: If there was/is a real threat of increased withdrawal, this would be very important, especially if it could happen during late summer/fall. TS: Additional water diversions are unlikely.
Low	Issue 29 Wildlife	**Reduce habitat fragmentation associated with trails, roads and development** *Summary:* Existing land uses, trails, fire roads, lack of wilderness areas, invasive species and fire suppression all contribute to habitat fragmentation for both plant and animal species. *Benefits:* Native wildlife and plant species *Primary Actions:* Analyze and map wildlife and native plant species use of potential corridors and determine locations for successful corridor design/placement; implement findings and monitor to ensure population dispersal occurs.	2	1	ES: Fosters connectivity and diversity; supports natural processes; wildlife affected are primarily common species, though also may include sensitive species (e.g., California red-legged frog); TS: Doesn’t seem too imminent and not likely to get worse rapidly (could improve if other issue actions are implemented)

Appendix H

Tier Two Prioritization Scoring for Action Issues

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Table H-1. Tier Two Prioritization Scoring for Action Issues

Priority number	Issue number	Issue description	Scoring (1 -3)**			Notes
			Natural resource enhance ment value	Benefit to other NR DFCs (BNR)	Benefit to other non-NR DFCs (B-Oth)	
High	Issue 9	**Minimize effects of water withdrawal on fish populations** *Summary:* The greatest withdrawals from the main stem supply the Muir Beach Community through the MBCSD well near the Banducci property. A recent study indicates that pumping during dry water years increases the number of disconnected pools and results in lower dissolved oxygen levels. The study concludes that dry year low flow conditions could result in a 10 percent reduction in watershed fish production. The MBCSD Adaptive Management Plan of 2005 introduces several alternative dry-season water source options, including tank storage in Frank Valley and desalination. In addition, the restoration of Lower Redwood Creek at Muir Beach, initiated in August of 2010, includes removal of fish barriers to the Green Gulch tributaries. Renewed availability of this habitat will require that water withdrawal and impoundment by the Green Gulch Zen Center be tailored to minimize impacts on aquatic habitat, particularly during late summer and early fall. *Benefits:* Aquatic habitat, salmonid and other aquatic species, human water users, water quality *Primary Actions:* Provide assistance in developing alternative water source options for Lower Redwood Creek, including consideration of desalination, additional conservation measures, and additional storage of high winter flows. Alternative storage location(s) for winter flows along the mainstem will be considered, along with identification of potential negative impacts of storage options and ways to minimize or mitigate these effects. Also priority actions include identification of potential impacts and means to avoid impacts associated with withdrawals from Green Gulch and the unnamed tributary to its south and implement water use measures to ensure optimal ecological flows.	3	3	3	EV: Benefits seem fairly certain as well as sustainable; response time is 1-3 yr; geographic extent is medium (mostly Franks reach and below) BNR: Positive effects on salmonid, amphibian, riparian bird species, as well as riparian and aquatic habitat B-Oth: Actions would be highly beneficial for MBCSD water users, protecting fish and other aquatic species would improve visitor experience.
High	Issue 20	**Limit introduction and spread of invasive plant species through systematic monitoring and public outreach** *Summary:* Invasive non-native plant species reduce biodiversity, degrade habitat quality. Most invasive species enter the watershed via transportation corridors or as garden escapes. Public outreach and education could reduce invasive species introductions along trails, roads, and from lawns and gardens. With new invasive species being continually introduced and established species spreading, a monitoring program is critical for detecting new and for tracking established invasive species so that a control program is based on the best available information. Monitoring is not currently performed in a coordinated fashion throughout the watershed. *Benefits:* Wildlife and avian habitat; plant communities; aquatic communities *Primary Actions:* Develop coordinated monitoring program for all lands in the watershed; perform public outreach; develop and disseminate education materials;	3	3	3	EV: Since all the weeds cannot be controlled all of the time, monitoring and public outreach are the firsts step in developing best strategies for weed control; certainty of benefits is high IV: High information value due to points made under NRE BNR: Provides protection of native plant communities and special status species, wildlife habitat, riparian habitat and associated bird species; minimization of negative impacts due to surrounding land uses B-Oth: Supports visitor experience and ability of resident community to act as active stewards and minimally impact their environment
High	Issue 14	**Identify sources and reduce nutrient enrichment of lower Redwood Creek** *Summary:* Seasonal occurrences of low dissolved oxygen levels occur within lower Redwood Creek and could be associated with observed downstream increases in stream water nutrient [Nitrogen] concentrations. As with bacterial inputs, equestrian use of Redwood Creek trail could result in nutrient inputs to lower Redwood Creek, septic tank leakage from the Muir Beach Community is another possible source. *Benefits:* Water quality, Aquatic habitat, benthic macro-invertebrates; salmonids *Primary Actions:* Identify sources of nitrogen in watershed, describe and implement	3	3	2	NRE: Benefit high because reducing nutrients would help DO which directly and importantly affects local salmonid populations, particularly in dry years; response time could be 1 to 3 years; geographic extent limited to lower RWC BNR: Salmon and other aquatic species, aquatic habitat B-Oth: Visitor enjoyment for both supporting healthy fish runs and maintaining clean waters for Muir Beach visitors

Table H-1. Tier Two Prioritization Scoring for Action Issues

Priority number	Issue number	Issue description	Scoring (1 -3)**			Notes
			Natural resource enhancement value	**Benefit to other NR DFCs (BNR)**	**Benefit to other non-NR DFCs (B-Oth)**	
		actions to reduce nutrient inputs from critical sources.				
High	Issue 30	**Halt declines in wetland and riparian bird species by restoring suitable habitat**. *Summary:* Riparian areas and wetlands are extremely valuable habitat for bird species; including many special-status species such as tricolored and yellow-headed blackbirds, willow flycatcher, and the yellow warbler. However, loss of historical riparian areas and wetlands in the watershed has decreased suitable habitat for riparian and wetland bird species, affecting abundance, productivity and distribution in the Redwood Creek watershed. For some wetland and riparian bird species, this watershed is believed to be acting as a sink rather than source for the regional population. Conversion of riparian woodland habitat to emergent wetlands through the Restoration of Lower Redwood Creek at Muir Beach will mark an important shift in abundance of these habitats in the watersheds, however additional riparian forests and wetlands are needed in other areas of the watershed, adjacent to healthy uplands for foraging, to help recover and support these bird species populations. Adjacent chaparral communities also provide important forage habitat and need to be included in restoration plans *Benefits:* Wetland and riparian bird species and other associated wildlife, wetland and riparian plant communities; aquatic community; water quality *Primary Actions*: Implement restoration of riparian and wetland areas, and associated adjacent chaparral, and monitor population trends in relation to restored and existing wetland and riparian habitat characteristics perform adaptive management.	3	3	2	NRE: Benefit certainty is quite high (likely birds will come if we build it and they will have greater reproductive success); sustainable, biological response time is 5-10 yr or less BNR: Supports native plant community health (riparian); B-Oth: Supports visitor experience (improved birder experience with potential increased diversity and abundance of wetland bird species)
High	Issue 2	**Reconnect Frank Valley floodplain to Redwood Creek mainstem** *Summary:* Past channel realignment, floodplain regrading, and incision has isolated Redwood Creek from its floodplain along Frank Valley. Since reconnecting and regrading are expensive, the extent of floodplain disconnection and its implications on salmon and steelhead rearing habitat should be better understood as the basis for prioritizing cost-effective restoration measures. *Benefits:* Aquatic habitat (e.g., coho salmon winter habitat), water quality, riparian community extent and composition, and flood conveyance. *Primary Actions:* Develop field-based estimates of floodplain inundation frequency, duration, and extent under current conditions during different return period flows in relation to existing and potential aquatic habitat distribution as a basis for selecting priority restoration areas. Second stage actions include implementation of restoration projects along selected reaches in Frank Valley.	3	3	3	NRE: Benefits certain and scale of benefit depends on how critical the aquatic and riparian songbird habitat is along Frank Valley (likely valuable); sustainable; extent is fairly local; biological response time is within 5 yr. BNR: Riparian habitat/birds, water quality, flood control, fish B-Oth: Flood control, human use
Med	Issue 13 Water Quality	**Identify sources of bacterial contamination of lower Redwood Creek and Muir Beach** *Summary:* Bacterial contamination periodically occurs along lower Redwood Creek and Muir Beach due to unidentified contamination sources. Local observations of equestrian use along Redwood Creek Trail, particularly where the trail crosses the creek multiple times, suggest that horse use along these creek crossings could be an important source of bacterial contamination to lower Redwood Creek. *Benefits:* Water quality; residential and visitor use of MB; aquatic habitat and species. *Primary Actions:* Move Redwood Creek trail out of the channel to minimize equestrian nutrient and bacterial inputs and work with the Muir Beach community to improve septic systems, work with dog and horse owners to minimize potential inputs.	2	1	3	NRE: Bacterial contamination does not have large negative effect on aquatic or riparian species or other natural resource DFCs. Benefit would go to human use-related DFCs, such as visitation experience. BNR: No established effect on aquatic and riparian fish and frogs B-Oth: Visitor experience (Muir Beach closings linked to bacterial exceedances)

Table H-1. Tier Two Prioritization Scoring for Action Issues

Priority number	Issue number	Issue description	Scoring (1 -3)**			Notes
			Natural resource enhance ment value	**Benefit to other NR DFCs (BNR)**	**Benefit to other non-NR DFCs (B-Oth)**	
Med	Issue 25	**Increase California red-legged frog breeding areas in watershed** *Summary:* Red-legged frog population is extremely small and confined to the Big Lagoon area. *Benefits:* Red-legged frogs; other wetland and riparian-dependant species *Primary Actions:* Implementation of Lower RWC restoration at MB with 'frog pond' followed by monitoring and adaptive management to optimize conditions for the RLF.	3	3	1	NRE: Benefits to RLF seem quite certain; sustainability also high for RLF BNR: Monitoring of RLF could help restoration of lower Redwood Creek at Muir Beach B-Oth: Visitor experience
Med	Issue 8	**Remove constraints on natural processes by existing structures and parking lots** *Summary:* Existing structures and infrastructure, including Pacific Way Bridge, Muir Woods Road along Upper Frank Valley, Muir Woods road bridge, rockwork along channel banks within Muir Woods and downstream of the Highway 1 bridge, buildings and parking lots, and buried infrastructure (e.g. underground utilities) can constrain or impinge upon natural processes such as flooding, channel migration, and wildlife behavior. *Benefits:* Aquatic and riparian habitat and species; water quality. *Primary Actions:* Identify and implement actions necessary to remove or minimize constraints these structures on natural processes on a case by case basis. Action examples include restructuring Pacific Way Bridge, moving Muir Woods parking lot and concession buildings away from the channel and floodplain; realigning Muir Woods road along reaches where it impinges on channel migration, and removing or minimizing extent of bank revetments in Muir Woods and in the reach between the Highway 1 and Pacific Way bridges. .	3	3	1	NRE: Benefits are quite certain; sustainable; response time 1-3 yr for parking lots, bridges, and road sections; BNR: Moving Muir Beach and Muir Woods parking lots and sections of Muir Woods roads will have sizeable impact on ecology/processes B-Oth: None apparent
Med	Issue 23	**Increase amount of winter refugia for rearing Coho salmon and steelhead**. *Summary:* Reduced large woody debris (LWD) frequency, aquatic habitat complexity, and floodplain connectivity in the watershed have likely diminished the amount of winter refuge habitat for rearing Coho salmon and steelhead. *Benefits:* Coho and steelhead populations; other aquatic and riparian species and communities, sediment storage; flood attenuation. *Primary Actions:* Increase winter refugia, support adaptive management informed by field survey and mapping of fish habitat, fish use, in-stream LWD, and LWD sources. The restoration of Lower RWC at MB includes adding a lot of winter refugia; so issue now needs monitoring to be sure this project has positive and significant effects.	3	1	2	NRE: Benefit certainty is high and sustainable; biological response time is 2-5 yrs; geographic extent is lower RWC and Muir Beach BNR: Supports geomorphic and hydrologic processes, aquatic and riparian habitat, frog and riparian bird species B-Oth: Supports visitor experience
Med	Issue 31	**Halt decline of local native song bird populations due to nest predation and brood parasitism by non-native predator birds**. *Summary:* Studies have attributed declines in local native songbirds (Wilson's warbler or WW) to brood parasitism and nest predation by other species, such as brown-headed cowbirds; Redwood creek a 'sink' population for WW in the region; WW population in decline in CA as well as several other western states. *Benefits:* song-birds, local invertebrates Primary Actions: Implement protections for brood parasitism and predation and assess song bird status in relation to these measures for adaptive management.	2	3	1	NRE: Benefit certainty quite high for WW but not as clear for other species or resources BNR: Supports non-native species control DFCs B-Oth: Supports visitor experience

Table H-1. Tier Two Prioritization Scoring for Action Issues

Priority number	Issue number	Issue description	Scoring (1 -3)** Natural resource enhancement value	Benefit to other NR DFCs (BNR)	Benefit to other non-NR DFCs (B-Oth)	Notes
Med	Issue 6	**Reduce flood hazard during high flow events along Pacific Way** *Summary:* Flood discharges overtop the left bank and flow through the lower central portion of the floodplain to lower RWC, crossing Pacific Way. The result is extended periods of flooding on Pacific Way during relatively wet water years; likely to have increasing importance with climate change. *Benefits:* Muir beach (MB) and MB community access; sediment transport; aquatic habitat; adjacent riparian and wetland communities *Primary Actions:* Move channel to natural valley bottom position (issue #2); widen Pacific Way bridge; post-implementation monitoring for bed aggradation (see Lower RWC Restoration at MB)	2	1	3	NRE: Very certain (more so if issue#1 is addressed); response time is soon; benefits are sustainable; geographic extent is fairly local BNR: Helps aquatic and riparian habitat near by and down stream by reducing chances of avulsion B-Oth: Beach and MB community access for MB visitors and residents
Med	Issue 11	**Implement best management practices to minimize negative water quality effects from storm water runoff from parking lots and roads** *Summary:* Storm water runoff from roads and parking lots is known to release ecologically harmful levels of contaminants to downstream aquatic ecosystems. The proximity of roads and parking lots to the channel and anticipated increase in visitor use suggests minimal natural filtering occurs and likely future increases in pollutant loads could occur. *Benefits:* Water quality; Aquatic habitat and species; riparian species dependant on aquatic food sources *Primary Actions:* Implement known best management practices to minimize storm water runoff input directly to aquatic systems, including construction of settling ponds or riparian/wetland filter strips between compacted surface and stream channel.	2	3	3	NRE: Benefits not certain; geographic extent mostly in Muir Woods and Muir Beach BNR: Fish. Amphibians, and other species associated with the aquatic foodweb B-Oth: Residential community (cleaner drinking water)
Low	Issue 15	**Allow for regeneration and natural disturbance regimes in Muir Woods and other Redwood forests in watershed** *Summary:* Historical fire and flood regimes have been changed in Muir woods and the other redwood forests in RWC watershed and suspension of frequent low intensity fires and floods could have increased vulnerability to pests and disease, reduced frequency of pulse nutrient inputs to soil, and reduced availability of mineral soil for redwood regeneration. *Benefits:* Redwood forest; wildlife and plant species dependant on redwood forest *Primary Actions:* Restore, through prescribed burns and restoration of channel banks and floodplain, fire and flooding to redwood forests in Muir Woods and Kent Canyon.	3	3	1	NRE: Careful use of prescribed burns and restoring flooding in Muir Woods and Kent Canyon could address concerns re: understory, SOD fuel loading; habitat and structural diversity; effects could occur in 1 to 5 year time span. BNR: Supports restoration of full hydrologic functions; aquatic ecosystem (flood pulse and food webs, winter refugia), wildlife, and riparian systems and bird species B-Oth: Improves visitor experience
Low	Issue 22	**Minimize impacts of non-native animals and native "pest" animal species on native species** *Summary:* Non-native pest species can threaten visitors or negatively affect other native species (e.g. turkeys and Chukar partridges) and some native animals, such as raccoons and birds (e.g. ravens, crows, and jays) are more prevalent and impacting other species through excessive populations. *Benefits:* native animal and plant species *Primary Actions:* Assess distribution and effects of ‘pest’ species; identify and implement control measures.	2	1	1	NRE: Certainty of benefits is moderate (lots of pests ‘leaking in’ from watershed edges); sustainability moderate; response time (5+ yrs for native spp. pops to rebound); geographic extent moderate (‘hot spots’ per spp.) BNR: Supports some native animals B-Oth: No apparent nexus with non-natural resource DFCs

Table H-1. Tier Two Prioritization Scoring for Action Issues

Priority number	**Issue number**	**Issue description**	**Scoring (1 -3)****			**Notes**
			Natural resource enhancement value	**Benefit to other NR DFCs (BNR)**	**Benefit to other non-NR DFCs (B-Oth)**	
Med	Issue 21	**Improve invasive non-native plant species control and eradication** *Summary:* Control of invasive plants through herbicide application, mechanical treatments, and prescribed burning can have negative effects on other resources. Research and monitoring, adaptive management, communication and coordination among resource managers is needed to ensure that all weed control activities are as effective as possible and have minimal effects on other resources. Control/eradication is usually labor intensive and very expensive; so that collaboration among agencies might offer opportunities for increased efficiency and for sharing lessons learned regarding control techniques. *Benefits:* Native plant communities and dependant wildlife species *Primary Actions:* Increase monitoring, research, communication and coordination among resource staff within and among agencies through annual or more frequent meetings, reduced spread rate and extent of invasive plant species; public outreach and education.	3	3	3	NRE: This is a difficult problem with a constantly moving target with high ecological value; certainty of benefits is high BNR Supports protection of native plant communities and special status species, wildlife habitat, minimizes negative impacts of surrounding land uses B-Oth: Supports improved visitor experience, and resident community ability to act as active stewards to minimally impact environment
Med	Issue 7	**Increase flood capacity in existing culverts** *Summary:* Numerous culverts through the watershed have insufficient capacity to pass flood flows, resulting in local upstream flooding, downstream hydraulic erosion, potential culvert failure and site erosion, and impacts on sediment delivery to downstream aquatic systems. MMWD has addressed several of the undersized culverts within their jurisdiction, but more needs t o be accomplished on these and other lands in the watershed. Existing studies have identified specific sites in need of improvement. *Benefits:* Local and downstream aquatic habitat; reduced cumulative sediment loading; improved roadways and passage *Primary Actions:* Identification and replacement of undersized culverts through funding and multi-agency commitment	1	1	3	NRE: Benefits are not clear since cutting off tributaries from sediment delivery could also be beneficial; response time is next big event; resized culverts are durable/sustainable; geographic extent is upper watershed and possibly Frank Valley BNR: Some erosion and sediment downstream B-Oth: Visitor access (car passage); damage to existing infrastructure (culverts and adjacent road areas)
Med	Issue 5	**Quantify and reduce excessive sediment yields due to mainstem and tributary incision in Frank Valley impact water quality, fish habitat, and flood conveyance** *Summary:* Land use and channel management in Frank Valley have resulted in incision of the Redwood Creek mainstem causing sediment yields estimated to account for one-quarter of the sediment input to Big Lagoon. High fine sediment inputs are impacting downstream aquatic habitat and water quality. *Benefits:* Water quality, aquatic species and habitat; riparian communities, flood conveyance *Primary Actions:* Fill data gaps regarding the extent to which Redwood Creek is shifting from a degrading to an aggrading system, and the likelihood of associated bank erosion and increased fine sediment output. In this way, land and/or water uses that increase storm-related sediment loading from channel erosion can be identified and avoided. Perform in coordination with geomorphology baseline study.	2	1	2	NRE: Moderately certain benefit; response time is next major event; increases sustainability; geographic extent is lower half of watershed BNR: Fish, frog and bird habitat B-Oth: Infrastructure, reduced likelihood of culvert failure and/or avulsion associated with excess sediment deposition around bridges at Pacific Way and Highway 1.
Med	Issue 4	**Quantify and reduce high potential sediment yields resulting from human actions in tributaries, including Conlon Canyon** *Summary:* Excess sediment from headwater areas, partly derived from human activities, has the potential to cause short-term sediment pulses or long-lasting periods of aggradation which may adversely affect downstream restoration actions and aquatic habitat *Benefits:* Water quality, fish and amphibian species, aquatic habitat	2	1	2	NRE: Moderately certain benefit; response time is next major event; increases sustainability; BNR: B-Oth: Infrastructure, reduced likelihood of culvert failure and/or avulsion

Table H-1. Tier Two Prioritization Scoring for Action Issues

Priority number	Issue number	Issue description	Scoring (1 -3)**			Notes
			Natural resource enhance ment value	Benefit to other NR DFCs (BNR)	Benefit to other non-NR DFCs (B-Oth)	
		Primary Actions: Perform study to establish tributary sediment yields in exceedance of natural rates and actions or changes in land use that reduce inputs. Developing Best Management Practices for sediment conservation; second stage involves implementing these actions or land use changes. Perform in coordination with geomorphology baseline study.				associated with excess sediment deposition around bridges at Pacific Way and Highway 1.
Med	Issue 10	**Reduce vulnerability of lower Redwood Creek to additional water diversions**. *Summary:* Water resources in the watershed have not been declared “fully appropriated” by the state water board, leaving the watershed vulnerable to future additional claims for water diversions *Benefits:* Provides means of assuring water allocations are known and manageable. *Primary Actions:* Detail all existing used and unused water rights in the watershed and removal of currently unused water rights from the possibility of future use.	1	2	2	NRE: Certainty of benefits is low since it is unlikely that other water rights will be activated; removing this low level threat would increase likelihood of sustainable management of watershed; geographic extent of potential impacts likely linked to lower Redwood Creek. BNR: Aquatic resources, potential effects could benefit salmonids and other aquatic species, amphibians and riparian bird species B-Oth: Potential effects could be beneficial for MBCSD and other existing water users, protecting fish and other aquatic species would improve visitor experience.
Med	Issue 29	**Reduce habitat fragmentation associated with trails, roads and development** *Summary:* Existing land uses, trails, fire roads, lack of wilderness areas, invasive species and fire suppression all contribute to habitat fragmentation for both plant and animal species. *Benefits:* Native wildlife and plant species *Primary Actions:* Analyze and map wildlife and native plant species use of potential corridors and determine locations for successful corridor design/placement; implement findings and monitor to ensure population dispersal occurs.	2	2	1	NRE: Certainty of benefits is moderate, but sustainable BNR: Supports native plant community (riparian) and special status spp. B-Oth: No apparent nexus

Appendix I

Prioritization Scoring for Study Issues

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Table I-1. Prioritization Scoring for Study Issues

Priority position	DFC reference number and subject area	Study issue description	Scores (1-3)**			Notes
			Actionable information value (AIV)	Ecological significance (ES)	Threat severity (TS)	
First	Issue 17 Vegetation	**Characterize Sudden Oak Death effects on plant community composition and structure**. *Summary:* Changes in the forest canopy structure due to the die-off of tanoak and other species from SOD is creating canopy openings that may increase risk of Douglas-fir encroachment and non-native plant invasion. *Benefits:* Ancient redwoods and other redwood stands in Kent Canyon, avian and wildlife species *Primary Actions:* Identify and assess SOD induced changes in stand structure, composition and potential fire behavior; identify potential actions to reduce or minimize the effects.	3	3	3	ES: This may be the main issue for Muir Woods: SOD associated changes affect resilience; natural processes, connectivity (vertical); and diversity; information would be highly useful for rest of coastal redwood region, since MUWO is on the leading edge of the SOD infestation. TS: Getting worse rapidly now – threat is fire (with ladder fuels) as well as change in species composition and community structure and secondary effects on wildlife habitat AIV: Information would be directly useful for any prescribed burn or understory replanting plans, for wildlife management in affected areas, and for minimizing invasion of exotic plant species in gaps created by SOD.
First	Issue 1 Hydrology/ Geomorphology	**Gather sufficient information on stream flow for lower Redwood to assess water use/availability, habitat conditions/effects, and flood control needs** *Summary:* Addressing this issue would create a clear hydrologic record for the watershed in place of one based on gauging records of uneven quality from the current Highway One gauge. Insufficient high flow data (and limited validation of high flow data) is currently limiting the ability to assess Lower RWC restoration at MB. Development of hydrologic flow data for the creek should be done in concert with development of the geomorphic baseline described in Issue 3. *Benefits:* Provides basis for furthering understanding of current and future management, water withdrawals or other land use/restoration impacts on aquatic habitat, flood conveyance, sediment transport and storage. *Primary Actions:* Investigate options for installing a reliable flow gauge at or near Hwy 1, install, and collect sufficient field data to develop a stage-discharge curve for high to low flows.	3	3	3	ES: Ecologically significant information, TS: Incorrect and/or unfortunate decisions and designs could be implemented in multiple areas of the watershed if land managers are forced to continue making management decisions on incomplete knowledge (guessing); geographic extent: watershed AIV: Would directly inform existing, planned, future restoration and culvert/infrastructure improvement actions
First	Issue 19 Vegetation	**Characterize extent of and threats to native serpentine communities and species** *Summary:* The upper reaches of Redwood Creek watershed host many valuable endemic plant communities and listed species that are especially adapted to thrive on serpentine soils. The extent and distribution of these host communities and species populations are not mapped or monitored by a coherent program; although the Marin California Native Plant Society maintains records of species sitings and locations, which are also reported in the state CNDDB database. Many of these endemic communities and serpentine species are likely under stress induced by high visitor traffic and management of invasive non-native species through prescribed burns and other methods. A series of focused studies and monitoring programs are needed in order to describe the extent, health, and threats to these valuable communities and populations, and to serve as a basis for protecting and nurturing them in the future. *Benefits:* Native plant communities and animal dependants; special status plant species; visitor experience. *Primary Actions:* Map extent, location, and health of all existing native serpentine grassland, chaparral, and seep communities; identify existing and potential threats to communities; monitor every 2 to 3 years; identify potential actions to minimize negative impacts on communities.	3	3	3	ES: Very important resource; increase in resilience needed TS: Without some monitoring system in place, some endemic species could disappear or diminish to beyond recovery. Fairly high likelihood that some named potential threats are, in fact, occurring. AIV: Information would be extremely effective in addressing potential threats/improving species and community status.
First	Issue 16 Vegetation	**Determine baseline structure and composition of the redwood forest in Muir Woods** *Summary:* Muir Woods is an iconic stand of old growth coastal redwoods enjoyed by millions of visitors each year; earlier studies the structure and composition of Muir Woods need to be updated and expanded to cover more of the forest so that a baseline on the composition and structure of this forest can be established from which to identify responses to stressors such as climate change, SOD, human disturbance, and non-native species invasions. This baseline would be essential for early detection of changes in the rate and distribution of redwood regeneration, recruitment, encroachment of the redwood forest by adjacent Douglas fir stands, effects of Sudden Oak Death on understory composition and structure, effects of new diseases on plant species, and the changes in the distribution and character of snags and log. *Benefits:* Ancient redwood forest; avian and wildlife species; visitor enjoyment. *Primary Actions:* Survey stand structure and composition, including understory, logs and snags, of Muir Woods ancient redwoods as well as adjacent Douglas fir stands.	3	3	3	ES: Muir Woods ancient redwood forest is important for many wildlife species and represents a unique resource in and of itself. Establishing baseline information on stand structure, composition and habitat elements such as logs and snags will allow for early detection of threats to stand health and resilience. TS: The range of imminent threats on the ancient Muir Woods redwoods includes SOD, climate change, invasive non-native species, and human/visitor impacts. AIV: Project would directly inform prescribed burns, understory replanting, non-native species control, and other actions.
First	Issue 3 Hydrology/ Geomorphology	**Establish baseline and perform on-going monitoring of channel geomorphic structure for Redwood Creek Watershed** *Summary:* Information on channel size, structure, gradient, and bed composition at permanent transects along the upper, mid, and lower reaches of Redwood Creek could provide an essential point of reference for understanding overall condition and trends in channel incision and aggradation, as well as for detecting changes in response to restoration and/or stressors (e.g. undersized culverts; changes in flow and storm size/frequency associated with climate change; upland erosion) in channel condition, sediment input and routing, aquatic habitat quality and distribution. Identification and tracking of headcuts, nickpoints, and grade controls along the mainstem and major tributaries would also provide essential baseline information on channel existing conditions.	3	3	2	ES: Would provide fundamental understanding of trajectory and processes controlling condition of aquatic and riparian habitat in watershed. TS: This STUDY issue addresses channel and riparian areas of most of watershed; imminent threats associated with geomorphic processes include lack of winter refugia and heavy sediment loading and potential 'blow outs' from tributaries.

Table I-1. Prioritization Scoring for Study Issues

Priority position	**DFC reference number and subject area**	**Study issue description**	**Scores (1-3)****			**Notes**
			Actionable information value (AIV)	**Ecological significance (ES)**	**Threat severity (TS)**	
		Benefits: Hydraulic and geomorphic function; aquatic habitat and species; riparian habitat and dependant species; water quality; infrastructure *Primary Actions:* Establish permanent cross-sections and perform baseline survey of channel structure and composition at cross-sections; survey and document locations of headcuts, nickpoints, and grade controls; update surveys following large storm events and every 5 to 10 years.				AIV: Could provide essential information for detecting changes in response to restoration and/or stressors (e.g. undersized culverts; changes in flow and storm size/frequency associated with climate change; upland erosion) in channel condition, sediment input and routing, aquatic habitat quality and distribution that would fundamentally direct management actions.
First	Issue 33 Wildlife	**Comprehensive study on Coho salmon and steelhead populations** *Summary:* Although surveys have been performed on fish in the watershed, a comprehensive study on fish populations and habitats is needed to identify and fill important knowledge gaps. Examples of likely important knowledge gaps include assessment of winter refugia in upper portions of watershed, performance of spawning gravels, effects of exotic aquatic species (such as crayfish) on food availability (food web). *Benefits:* Fish, other aquatic species, geomorphic processes, water quality *Primary Actions:* Synthesize existing knowledge on aquatic habitats in watershed and identify knowledge gaps. Perform field studies and establish on-going monitoring programs as necessary to address gaps.	3	3	2	ES: Would provide comprehensive review of coho and steelhead habitat in watershed to nail down what aspects of life cycle/habitat are / not working for the fish. TS: This STUDY issue addresses conditions for listed fish species populations. AIV: Could provide essential information for improving management actions to support fish populations in watershed.
First	Issue 5 Hydrology/ Geomorphology	**Quantify excessive sediment yields due to mainstem and tributary incision in Frank Valley that impact water quality, fish habitat, and flood conveyance** *Summary:* Land use and channel management in Frank Valley have resulted in incision of the Redwood Creek mainstem causing sediment yields estimated to account for one-quarter of the sediment input to Big Lagoon. High fine sediment inputs are impacting downstream aquatic habitat and water quality. *Benefits:* Water quality, aquatic species and habitat; riparian communities, flood conveyance *Primary Actions:* Fill data gaps regarding the extent to which Redwood Creek is shifting from a degrading to an aggrading system, and the likelihood of associated bank erosion and increased fine sediment output. In this way, land and/or water uses that increase storm-related sediment loading from channel erosion can be identified and avoided. Perform in coordination with geomorphology baseline study (Issue 3).	3	3	1	ES: Fine sediment inputs could be importantly and negatively affecting the fish by making it hard to find winter refugia in the form of unfilled-in boulders - high flow refuge habitat is severely limited in the incised reach (hence the low weirs) TS: Since the channel is thought to be aggrading, seems like incision is not a big threat, as long as the understanding holds that the bed will keep coming up or will get more complex over time. AIV: Once identified, not all sources of fine sediment are easily controlled (but roadway culverts can help along with control of sedimentation from streams like Conlon Ave???).
Second	Issue 18 Vegetation	**Describe composition and distribution of native grasslands and determine methods to slow or reverse conversion of native grasslands to shrub-dominated plant communities** *Summary:* There has been a sharp reduction in the area occupied by grassland and an increase in shrub-dominated plant communities relative to historical conditions. Lack of information on the current extent, location, and condition of native grasslands limits the ability to assess current conditions, prioritize actions and action areas, and implement strategic monitoring. Uncertainties regarding the natural range of variability in the distribution of these ecosystem types and the mechanisms by which grasslands convert to shrub lands and forests makes it difficult to develop management goals and to target methods for restoring native grasslands. *Benefits:* Native grasslands; rare plant and animal species dependent on grasslands. *Primary Actions:* Study regional historical natural range of variability in grassland, shrubland, and forested lands and the mechanisms by which these cover types shift over time. Based on this information and desired conditions for watershed, determine management goals for balance among grassland, shrubland and forest land. Produce basin-wide maps of existing distribution based on field surveys of native versus non-native grasslands, and of woody species encroachment on pre-existing and existing grasslands and document plant community response to various types of control methods (grazing; prescribed burns); identify best strategies for restoring native grasslands if that is a management goal.	2	3	1	ES: Understanding shrub conversion of native grasslands is relevant along much of north coastal California so information here could be applied in many other areas. Native grasslands support range of native wildlife species, increases resilience to fire/floods/erosion; support disturbance regimes (fire) and diversity TS: Shrub encroachment will likely continue and with it loss of native grassland habitat and native grass populations; but it just doesn't seem like a big imminent threat – slow conversion AIV: Information would direct actions, but actions likely to be expensive and difficult to implement (e.g. repeated prescribed burns likely required unless some other ultimate mechanism for conversion is identified and reversed).
Second	Issue 11Water Quality	**Characterize negative water quality effects from storm water runoff from parking lots and roads** *Summary:* Storm water runoff from roads and parking lots could release ecologically harmful levels of contaminants to downstream aquatic ecosystems. No data collection during or directly after storm events has occurred in the watershed to assess contamination from runoff storm water; however the proximity of roads and parking lots and intersections of the road net work with Redwood Creek at multiple locations, as well as the anticipated increase in visitor use, suggest that storm water runoff is, and if left unchanged, will continue to be, occurring at ecologically important levels. However, BMI community metrics, which integrate responses to water quality over time, were indicative of minimal disturbance in all locations other than Green Gulch tributary. Thus, monitoring should include focus along Green Gulch tributary and the un-named tributary to its south. *Benefits:* Water quality; aquatic habitat and species; riparian species dependant on aquatic food sources *Primary Actions:* Event-driven survey of storm runoff inputs, analysis of effects on water quality and aquatic communities, followed by identification of potential targeted management actions and subsequent monitoring/adaptive plans to control identified source areas.	3	2	1	ES: Copper and PAH's (derived from oils and other organic pollutants) are likely major contaminants from storm water runoff. Neither of these bioaccumulate; however both are known to be toxic to a range of aquatic organisms. Toxicity could in particular impact red-legged frog populations. TS: In areas other than Green Gulch, BMI indicators and low non-event associated metal numbers suggest storm and unmeasured organic pollutants associated with metals like PAH's could also low. Other threats to aquatic system seem to be greater and more imminent. AIV: Identification of sources would be directly used to target set of known BMP's to minimize inputs.

Table I-1. Prioritization Scoring for Study Issues

Priority position	DFC reference number and subject area	Study issue description	Scores (1-3)**			Notes
			Actionable information value (AIV)	**Ecological significance (ES)**	**Threat severity (TS)**	
Second	Issue 26 Wildlife	**Characterize potential long-term negative threats to local northern spotted owl population**. *Summary:* The Marin County population of spotted owls is isolated from populations farther north and is threatened by urban development, increased potential for catastrophic wildfires, habitat alterations caused by Sudden Oak Death (SOD). The population is further threatened by displacement due to continued range expansion of the barred owl and susceptibility to West Nile Virus (WNV). *Benefits:* northern spotted owl; forest community; visitor experience *Primary Actions:* In coordination with land managers throughout the county and region, perform annual monitoring of northern spotted owl populations to identify trends in species abundance, distribution, reproductive success, foraging and nesting in relation to SOD-affected areas, and causes of mortality. Study barred owl populations, habitat preferences and behavior to identify areas of overlap or competition with spotted owl, including coordinated efforts throughout Marin county and region to monitor barred owl populations, map roosting, breeding, and foraging habitat quality and extent.	2	1	3	ES: Information and management of the few individuals breeding in Muir Woods would have little actual impact on the overall genetic diversity within the regional population; improved management of the MuWo pairs and others in Marin would increase species resilience. TS: Effects of SOD, WNV, and barred owl range expansion can worsen in the face of no action and this information would be relevant to spotted owl management throughout northern California, with Muir Woods on the forefront of SOD. AIV: Information on ~four spotted owl pairs in RWC would only be effective as one/several data point(s) among many for the region.
Third	Issue 25 Wildlife	**Examine potential reintroduction of Foothill yellow-legged frog in watershed** *Summary:* Foothill yellow-legged frog is a California Species of Special Concern that has been apparently extirpated from the watershed, but could be re-introduced. This species is believed to be extirpated from up to 45% of its range, particularly south of Monterey along the coast and south of Highway 80 in the foothills (CaliforniaHerps.com website; accessed 1/31/10 at http://www.californiaherps.com/frogs/pages/r.boylii.html). However, reintroductions need to be done very carefully, with thorough consideration given to potential negative impacts of reintroduction to the meta-population gene pool, spread of disease, and other ecological issues. *Benefits:* Yellow-legged frogs; other wetland and riparian-dependant species *Primary Actions:* Study of genetic diversity of Marin County meta-population of yellow-legged frogs, disease risks associated with reintroduction, and of broader ecological issues associated with reintroduction foothill yellow-legged frog to the Redwood Creek Watershed.	2	2	1	ES: Directly affects a California Species of Special Concern; if re-instated, local population could increase resilience of regional meta-population; and foster diversity TS: Local threat is past since this is an extirpated population; however species is believed to be extirpated from up to 45% of its range, particularly south of Monterey along the coast and Highway 80 in the foothills (CaliforniaHerps.com website; accessed 1/31/10 at http://www.californiaherps.com/frogs/pages/r.boylii.html). AIV: If studies show reintroduction would be ecologically desirable and feasible, uncertain success of actions (e.g. reintroduction of extirpated species can be very difficult)
Third	Issue 12 Water Quality	**Quantify dissolved metal and other contaminant levels throughout the watershed** *Summary:* Periodic exceedances of hardness-based water quality criteria for dissolved copper within lower Redwood Creek may have adverse effects upon sensitive aquatic species. The source of dissolved copper is uncertain, but could include 1. air-deposited metals; 2. Serpentine soil derived runoff; 3. leaching of copper used in stable operations (although recently halted use of copper-based hoof treatment); 4. septic leachate from Muir Beach community, Green Gulch Farms, and other residences in the watershed; 5. Mill Valley Air Force Station and State Parks Gun Range; 6. Storm water runoff of copper released from brake pads. Levels of other contaminants, such as chlorpyrifos and diazinon (ingredients to common household pesticides such as ant poison) are also unknown. *Benefits:* Water quality; aquatic species *Primary Actions:* Establish systematic sampling program, focusing on likely sources and storm events, and implement for at least one year to identify extent of exceedances, sources, and measures to reduce inputs to acceptable levels	2	2	1	ES: See comments for Issue 10. TS: See comments for Issue 10. AIV: See comments for Issue 10; however known effective actions would primarily pertain to storm water runoff. It would be difficult to take actions that would counter inputs from atmospheric deposition, leachates from serpentine soils and/or the Air Force Station n the upper watershed.
Third	Issue 32 Wildlife	**Characterize effects of human-caused sound, light, and activity disturbances on wildlife** *Summary:* Disturbances associated with human actions can impact behavior and breeding success of wildlife species, however the extent to which this is occurring within the Redwood Creek watershed is unknown. *Benefits:* Wildlife populations in RWC watershed *Priority Actions:* Survey watershed wildlife and human behaviors/disturbances to identify timing and location of activities with clear disturbing effects on wildlife. Propose potential rules and or educational materials to elicit changes in human behavior so that impacts on wildlife are minimized.	2	2	1	ES: Assumabley affects sensitive species (although undemonstrated), and could indirectly increase resilience through positive effects on species diversity/population vigor; no natural processes directly supported; connectivity not supported; diversity indirectly supported; TS: No apparently imminent effects on any known species; not getting better through time though either AIV: Human behavior can be difficult to control.
Third	Issue 27 Wildlife	**Survey distribution of and disturbance to native bat populations in the watershed** *Summary:* At least twelve species of bats, four of which are California Species of Special concern, occur or are expected to occur in the Redwood Creek watershed. Bats may be impacted by habitat removal or through human disturbance, particularly at hibernacula and maternity roost sites. Many human activities could affect bat behavior, survival and reproduction. *Benefits:* Bat populations and species dependant on bats. *Primary Actions:* Map distribution of bat colonies with associated potential disturbances (location and timing); identify critical areas and disturbances; provide recommendations for removing or minimizing disturbances	3	1	1	ES: Bats include sensitive species; protecting bats and habitat increases resilience of ecosystem and fosters native wildlife populations TS: Studies have not yet confirmed loss of bat populations, though threats do exist AIV: Implementation of actions to protect critical bat areas once disturbance sources are identified appears straight-forward and achievable.

Table I-1. Prioritization Scoring for Study Issues

Priority position	DFC reference number and subject area	Study issue description	Scores (1-3)**			Notes
			Actionable information value (AIV)	Ecological significance (ES)	Threat severity (TS)	
Third	Issue 24 Wildlife	**Survey suitable habitat for listed butterfly species** *Summary:* Changes in landscape vegetation patterns may have adversely impacted the habitat suitability for listed butterflies, namely the Myrtle's silverspot and Mission blue butterfly, by reducing abundance of larval host plants and native nectar sources. Through recent surveys for both species in the watershed, managers found no individuals, but what appeared to be suitable habitat. Better information on the habitat quality in the watershed and the species' habitat needs is needed in order to develop and implement a plan to encourage or engineer repopulation of the watershed by these species. *Benefits:* Butterflies and other terrestrial invertebrates; native plant communities and wildlife dependants *Primary Actions:* Field surveys and mapping of the extent and native plant species composition of appropriate habitat for each species, including lupine for the Mission blue, and coastal dune, scrub and grasslands supporting violet species for the Myrtle's silverspot; comparative study of existing/potential habitat in Redwood Creek watershed versus existing habitat in order to identify needs to increase habitat extent/quality.	1	1	1	ES: Main effect would be on these terrestrial invertebrate species which we are not sure occur in the watershed TS: This is an information gap, but not apparently linked to other issues AIV: No clear path towards introducing and maintaining two butterfly populations, once appropriate habitat conditions are described.
Third	Issue 28 Wildlife	**Assess potential for marbled murrelet (MAMU) habitat in watershed** *Summary:* Marbled murrelet have not been detected in the watershed or off-shore marine habitat, however vegetation types might create appropriate habitat in RWC watershed. Fostering marbled murrelet habitation of Redwood Creek watershed would need to be viewed from a broader, regional population perspective and any management of such population would be done in coordination with other managers working with the greater north coast California population. Any management decisions need to be based on specific information on the regional population needs and capacity of Muir Woods to provide suitable nesting habitat for marbled murrelets in its old-growth forests. *Benefits:* Marbled murrelet *Primary Actions:* Assess potential habitat quality for marbled murrelet within the watershed and how such a nesting pair would affect the greater regional population of northern coastal California. If potential habitat is considered high quality, and a nesting pair in Muir Woods would be sustained by and perhaps contribute to the regional population, assess steps for encouraging habitation and supporting a nesting pair. If positive determination is made, identify potential management actions needed to maintain high habitat quality and attract marbled murrelets to nest in watershed.	1	1	1	ES: Federally listed species affected; actions would support old-growth habitat; foster native wildlife populations; however, MAMU is not in watershed now. TS: May be okay to delay efforts to manage specifically for marbled murrelet, since species has not been detected, however still important to preserve old-growth habitats AIV: Reintroducing MAMU into Muir Woods could be difficult and could fail for reasons beyond control of the land managers (e.g. ocean related food source issues) in spite of excellent information on Muir Woods habitat, and MAMU natural history.

Appendix J

Tier Three Prioritization Scoring for Action Issues

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Table J-1. Tier Three Prioritization Scoring for Action Issues

Sum Tier 3 score	Issue number	Issue description (in order of priority based on Tier 1 and 2 scores)	Scoring (1–3)**			Notes
			Funding sources and costs (F&C)	Technical feasibility (TF)	Community support (CS)	
9	Issue 23	**Increase amount of winter refugia for rearing coho salmon and steelhead**. *Summary:* Reduced large woody debris (LWD) frequency, aquatic habitat complexity, and floodplain connectivity in the watershed have likely diminished the amount of winter refuge habitat for rearing coho salmon and steelhead. *Benefits:* Coho and steelhead populations; other aquatic and riparian species and communities, sediment storage; flood attenuation. *Primary Actions:* Increase winter refugia, support adaptive management informed by field survey and mapping of fish habitat, fish use, in-stream LWD, and LWD sources. The restoration of Lower RWC at MB includes adding a lot of winter refugia; so issue now needs monitoring to be sure this project has positive and significant effects.	3	3	3	F&S: Funding for a lot of this is already in place and acquiring additional needed funds should not be difficult due to the extent of work and momentum of the Lower Redwood Creek Restoration at Muir Beach. TF: This is technically feasible. CS: Community support for the fish is high.
9	Issue 20	**Limit introduction and spread of invasive plant species through systematic monitoring and public outreach** *Summary:* Invasive non-native plant species reduce biodiversity, degrade habitat quality. Most invasive species enter the watershed via transportation corridors or as garden escapes. Public outreach and education could reduce invasive species introductions along trails, roads, and from lawns and gardens. With new invasive species being continually introduced and established species spreading, a monitoring program is critical for detecting new and for tracking established invasive species so that a control program is based on the best available information. Monitoring is not currently performed in a coordinated fashion throughout the watershed. *Benefits:* Wildlife and avian habitat; plant communities; aquatic communities *Primary Actions:* Develop coordinated monitoring program for all lands in the watershed; perform public outreach; develop and disseminate education materials;	3	3	3	F&S: Programs already exist within GGNRA, MMWD and the State Parks, although additional funding for the State Parks is needed. Volunteerism is also a potential resource for this issue. TF: Coordination of efforts can be done through the existing GGNRA Golden Gate Weed Watchers Program. CS: This is an excellent means for building support for broader natural resource goals with the community
9	Issue 30	**Halt declines in wetland and riparian bird species by restoring suitable habitat**. *Summary:* Riparian areas and wetlands are extremely valuable habitat for bird species; including many special-status species such as tricolored and yellow-headed blackbirds, willow flycatcher, and the yellow warbler. However, loss of historical riparian areas and wetlands in the watershed has decreased suitable habitat for riparian and wetland bird species, affecting abundance, productivity and distribution in the Redwood Creek watershed. For some wetland and riparian bird species, this watershed is believed to be acting as a sink rather than source for the regional population. Conversion of riparian woodland habitat to emergent wetlands through the Restoration of Lower Redwood Creek at Muir Beach will mark an important shift in abundance of these habitats in the watersheds, however additional riparian forests and wetlands are needed in other areas of the watershed, adjacent to healthy uplands for foraging, to help recover and support these bird species populations. Adjacent chaparral communities also provide important forage habitat and need to be included in restoration plans *Benefits:* Wetland and riparian bird species and other associated wildlife, wetland and riparian plant communities; aquatic community; water quality *Primary Actions*: Implement restoration of riparian and wetland areas, and associated adjacent chaparral, and monitor population trends in relation to restored and existing wetland and riparian habitat characteristics perform adaptive management.	3	3	3	F&S: Some restoration projects might be expensive, but multiple potential funding sources exist. TF: Restoration designs exist for some parts of Frank Valley, and the technology is well understood for other areas. CS: PRBO and Marin CNPS along with other users of watershed would be highly supportive.

Table J-1. Tier Three Prioritization Scoring for Action Issues

Sum Tier 3 score	Issue number	Issue description (in order of priority based on Tier 1 and 2 scores)	Scoring (1–3)** Funding sources and costs (F&C)	Technical feasibility (TF)	Community support (CS)	Notes
9	Issue 2	**Reconnect Frank Valley floodplain to Redwood Creek mainstem** *Summary:* Past channel realignment, floodplain regrading, and incision has isolated Redwood Creek from its floodplain along Frank Valley. Since reconnecting and regrading are expensive, the extent of floodplain disconnection and its implications on salmon and steelhead rearing habitat should be better understood as the basis for prioritizing cost-effective restoration measures. *Benefits:* Aquatic habitat (e.g., coho salmon winter habitat), water quality, riparian community extent and composition, and flood conveyance. *Primary Actions:* Develop field-based estimates of floodplain inundation frequency, duration, and extent under current conditions during different return period flows in relation to existing and potential aquatic habitat distribution as a basis for selecting priority restoration areas. Second stage actions include implementation of restoration projects along selected reaches in Frank Valley.	3	3	3	F&S: Some restoration projects might be expensive, but multiple potential funding sources exist. TF: Restoration designs exist for some parts of Frank Valley, and the technology is well understood for other areas. CS: PRBO and Marin CNPS along with other users of watershed would be highly supportive.
9	Issue 25	**Increase California red-legged frog breeding areas in watershed** *Summary:* Red-legged frog population is extremely small and confined to the Big Lagoon area. *Benefits:* Red-legged frogs; other wetland and riparian-dependant species *Primary Actions:* Implementation of Lower RWC restoration at MB with 'frog pond' followed by monitoring and adaptive management to optimize conditions for the RLF.	3	3	3	F&S: A major part of the restoration has been funded, along with monitoring. TF: This is technically feasible. CS: Ecological importance of supporting the red-legged frog population is easily communicated and understood.
9	Issue 21	**Improve invasive non-native plant species control and eradication** *Summary:* Control of invasive plants through herbicide application, mechanical treatments, and prescribed burning can have negative effects on other resources. Research and monitoring, adaptive management, communication and coordination among resource managers is needed to ensure that all weed control activities are as effective as possible and have minimal effects on other resources. Control/eradication is usually labor intensive and very expensive; so that collaboration among agencies might offer opportunities for increased efficiency and for sharing lessons learned regarding control techniques. *Benefits:* Native plant communities and dependant wildlife species *Primary Actions:* Increase monitoring, research, communication and coordination among resource staff within and among agencies through annual or more frequent meetings, reduced spread rate and extent of invasive plant species; public outreach and education.	3	3	3	F&S: This is likely to have a low cost and large increase in efficiency; use of volunteers might also increase with increased collaboration among agencies and land owners. TF: This is technically feasible (although labor-intensive). CS: This provides high community support and agencies are likely to be supportive of increased collaboration as long as it results in increased efficiencies.
5 (9)	Issue 15	**Allow for regeneration and natural disturbance regimes in Muir Woods and other Redwood forests in watershed** *Summary:* Historical fire and flood regimes have been changed in Muir woods and the other redwood forests in RWC watershed and suspension of frequent low intensity fires and floods could have increased vulnerability to pests and disease, reduced frequency of pulse nutrient inputs to soil, and reduced availability of mineral soil for redwood regeneration. *Benefits:* Redwood forest; wildlife and plant species dependant on redwood forest *Primary Actions:* Restore, through prescribed burns and restoration of channel banks and floodplain, fire and flooding to redwood forests in Muir Woods and Kent Canyon.	1 (2)	3	1 (3)	F&S: Funding for controlled burns might be difficult to attain due to potential high costs and resistance from regulatory agencies and local communities (score = 1). Restoration of flooding in parts of the watershed are already underway with the Muir Woods parking lot /floodplain regeneration (score = 2). TF: Controlled burns have been performed in the area already and technology and ecological effects are fairly well understood. Similarly, general concepts of restoring floodplain access are also fairly well understood. CS: Community support for controlled burns might be limited due to potential local air quality effects and perceived increase in wildfire risk (score = 1). Community support for floodplain regeneration would likely be much greater (score = 3).

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Sum Tier 3 score	Issue number	Issue description (in order of priority based on Tier 1 and 2 scores)	Scoring (1–3)**			Notes
			Funding sources and costs (F&C)	Technical feasibility (TF)	Community support (CS)	
8	Issue 9	**Minimize effects of water withdrawal on fish populations** *Summary:* The greatest withdrawals from the main stem supply the Muir Beach Community through the MBCSD well near the Banducci property. A recent study indicates that pumping during dry water years increases the number of disconnected pools and results in lower dissolved oxygen levels. The study concludes that dry year low flow conditions could result in a 10 percent reduction in watershed fish production. The MBCSD Adaptive Management Plan of 2005 introduces several alternative dry-season water source options, including tank storage in Frank Valley and desalination. In addition, the restoration of Lower Redwood Creek at Muir Beach, initiated in August of 2010, includes removal of fish barriers to the Green Gulch tributaries. Renewed availability of this habitat will require that water withdrawal and impoundment by the Green Gulch Zen Center be tailored to minimize impacts on aquatic habitat, particularly during late summer and early fall. *Benefits:* Aquatic habitat, salmonid and other aquatic species, human water users, water quality *Primary Actions:* Provide assistance in developing alternative water source options for Lower Redwood Creek, including consideration of desalination, additional conservation measures, and additional storage of high winter flows. Alternative storage location(s) for winter flows along the mainstem will be considered, along with identification of potential negative impacts of storage options and ways to minimize or mitigate these effects. Also priority actions include identification of potential impacts and means to avoid impacts associated with withdrawals from Green Gulch and the unnamed tributary to its south and implement water use measures to ensure optimal ecological flows.	3	3	2	F&S: While desalination is likely far beyond reach; other solutions, such as additional storage and conservation measures, are likely within reach and might have multiple potential funding sources. TF: Construction of additional storage and/or conservation measures can be implemented without advanced or cutting edge technology. CS: Some resistance to additional storage might occur and conservation measures are already being implemented; therefore additional requirements might not be popular.
8	Issue 13 Water Quality	**Identify sources of bacterial contamination of lower Redwood Creek and Muir Beach** *Summary:* Bacterial contamination periodically occurs along lower Redwood Creek and Muir Beach due to unidentified contamination sources. Local observations of equestrian use along Redwood Creek Trail, particularly where the trail crosses the creek multiple times, suggest that horse use along these creek crossings could be an important source of bacterial contamination to lower Redwood Creek. *Benefits:* Water quality; residential and visitor use of MB; aquatic habitat and species. *Primary Actions:* Move Redwood Creek trail out of the channel to minimize equestrian nutrient and bacterial inputs and work with the Muir Beach community to improve septic systems, work with dog and horse owners to minimize potential inputs.	2	3	3	F&S: Funds for this are likely available through the EPA and other agencies, particularly if it can be linked to recreational use. TF: There are known technologies for addressing this issue. CS: Assurances would be needed that addressing these issues would not preclude set of uses from the watershed, but everyone would be in support of reducing the threat of potential future beach closures.
8	Issue 6	**Reduce flood hazard during high flow events along Pacific Way** *Summary:* Flood discharges overtop the left bank and flow through the lower central portion of the floodplain to lower RWC, crossing Pacific Way. The result is extended periods of flooding on Pacific Way during relatively wet water years; likely to have increasing importance with climate change. *Benefits:* Muir beach (MB) and MB community access; sediment transport; aquatic habitat; adjacent riparian and wetland communities *Primary Actions:* Move channel to natural valley bottom position (issue #2); widen Pacific Way bridge; post-implementation monitoring for bed aggradation (see Lower RWC Restoration at MB)	3	3	2	F&S: Funding for a lot of this is already in place and acquiring additional needed funds should not be difficult due to the extent of work and momentum of the Lower Redwood Creek Restoration at Muir Beach. TF: Construction of the wider bridge is technically feasible. CS: Some community resistance exists due to the scale of the planned new bridge.
8	Issue 11	**Implement best management practices to minimize negative water quality effects from storm water runoff from parking lots and roads** *Summary:* Storm water runoff from roads and parking lots is known to release ecologically harmful levels of contaminants to downstream aquatic ecosystems. The proximity of roads and parking lots to the channel and anticipated increase in visitor use suggests minimal natural filtering occurs and likely future increases in pollutant loads could occur. *Benefits:* Water quality; Aquatic habitat and species; riparian species dependant on aquatic food sources *Primary Actions:* Implement known best management practices to minimize storm water runoff input directly to aquatic systems, including construction of settling ponds or riparian/wetland filter strips between compacted surface and stream channel.	2	3	3	F&S: Funding sources might exist for this work (EPA and/or state sources). TF: Many BMPs and guidelines for reducing storm water effects on water quality exist. CS: This is likely to be moderate to high since, although invisible, the idea of clean water is well understood and appreciated.

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Sum Tier 3 score	**Issue number**	**Issue description (in order of priority based on Tier 1 and 2 scores)**	**Scoring (1–3)****			**Notes**
			Funding sources and costs (F&C)	**Technical feasibility (TF)**	**Community support (CS)**	
8	Issue 7	**Increase flood capacity in existing culverts** *Summary:* Numerous culverts through the watershed have insufficient capacity to pass flood flows, resulting in local upstream flooding, downstream hydraulic erosion, potential culvert failure and site erosion, and impacts on sediment delivery to downstream aquatic systems. MMWD has addressed several of the undersized culverts within their jurisdiction, but more needs t o be accomplished on these and other lands in the watershed. Existing studies have identified specific sites in need of improvement. *Benefits:* Local and downstream aquatic habitat; reduced cumulative sediment loading; improved roadways and passage *Primary Actions:* Identification and replacement of undersized culverts through funding and multi-agency commitment	2	3	3	F&S: Multiple funding sources could be identified to address specific, documented problems. TF: This is technically feasible. CS: Local and out of area users would be in support of improved roadways and passage.
8	Issue 29	**Reduce habitat fragmentation associated with trails, roads and development** *Summary:* Existing land uses, trails, fire roads, lack of wilderness areas, invasive species and fire suppression all contribute to habitat fragmentation for both plant and animal species. *Benefits:* Native wildlife and plant species *Primary Actions:* Analyze and map wildlife and native plant species use of potential corridors and determine locations for successful corridor design/placement; implement findings and monitor to ensure population dispersal occurs.	2	3	3	F&S: This might not be an expensive project but funding source would need to be identified. TF: This is technically feasible CS: Local and out of area users would be in support of/neutral towards this sort of study/survey
7	Issue 14	**Identify sources and reduce nutrient enrichment of lower Redwood Creek** *Summary:* Seasonal occurrences of low dissolved oxygen levels occur within lower Redwood Creek and could be associated with observed downstream increases in stream water nutrient [Nitrogen] concentrations. As with bacterial inputs, equestrian use of Redwood Creek trail could result in nutrient inputs to lower Redwood Creek, septic tank leakage from the Muir Beach Community is another possible source. *Benefits:* Water quality, Aquatic habitat, benthic macro-invertebrates; salmonids *Primary Actions:* Identify sources of nitrogen in watershed, describe and implement actions to reduce nutrient inputs from critical sources.	2	3	2	F&S: Funds for this are likely available through the EPA and other agencies, particularly if it can be linked to recreational use. TF: There are known technologies for addressing this issue. CS: Assurances would be needed that addressing these issues would not preclude sets of uses from the watershed.
7	Issue 5	**Quantify and reduce excessive sediment yields due to mainstem and tributary incision in Frank Valley impact water quality, fish habitat, and flood conveyance** *Summary:* Land use and channel management in Frank Valley have resulted in incision of the Redwood Creek mainstem causing sediment yields estimated to account for one-quarter of the sediment input to Big Lagoon. High fine sediment inputs are impacting downstream aquatic habitat and water quality. *Benefits:* Water quality, aquatic species and habitat; riparian communities, flood conveyance *Primary Actions:* Fill data gaps regarding the extent to which Redwood Creek is shifting from a degrading to ban aggrading system, and the likelihood of associated bank erosion and increased fine sediment output. In this way, land and/or water uses that increase storm-related sediment loading from channel erosion can be identified and avoided. Perform in coordination with geomorphology baseline study.	1	3	3	F&S: This might be an expensive project; funding source would need to be identified. TF: This is technically feasible CS: Local and out of area users would be in support of/neutral towards this sort of study/survey.
7	Issue 4	**Quantify and reduce high potential sediment yields resulting from human actions in tributaries, including Conlon Canyon** *Summary:* Excess sediment from headwater areas, partly derived from human activities, has the potential to cause short-term sediment pulses or long-lasting periods of aggradation which may adversely affect downstream restoration actions and aquatic habitat *Benefits:* Water quality, fish and amphibian species, aquatic habitat *Primary Actions:* Perform study to establish tributary sediment yields in exceedance of natural rates and actions or changes in land use that reduce inputs. Developing Best Management Practices for sediment conservation; second stage involves implementing these actions or land use changes. Perform in coordination with geomorphology baseline study.	1	3	3	F&S: This might be an expensive project; funding source would need to be identified. TF: This is technically feasible CS: Local and out of area users would be in support of/neutral towards this sort of study/survey.

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Sum Tier 3 score	Issue number	Issue description (in order of priority based on Tier 1 and 2 scores)	Scoring (1–3)**			Notes
			Funding sources and costs (F&C)	Technical feasibility (TF)	Community support (CS)	
7	Issue 10	**Reduce vulnerability of lower Redwood Creek to additional water diversions**. *Summary:* Water resources in the watershed have not been declared "fully appropriated" by the state water board, leaving the watershed vulnerable to future additional claims for water diversions *Benefits:* Provides means of assuring water allocations are known and manageable. *Primary Actions:* Detail all existing used and unused water rights in the watershed and removal of currently unused water rights from the possibility of future use.	1	3	2	F&S: Some of the options for resolving this issue might be expensive and exterenal funding source would need to be identified. TF: This is technically feasible CS: Local and out of area users would be in support of this if funding sources were available.
6	Issue 8	**Remove constraints on natural processes by existing structures and parking lots** *Summary:* Existing structures and infrastructure, including Pacific Way Bridge, Muir Woods Road along Upper Frank Valley, Muir Woods road bridge, rockwork along channel banks within Muir Woods and downstream of the Highway 1 bridge, buildings and parking lots, and buried infrastructure (e.g. underground utilities) can constrain or impinge upon natural processes such as flooding, channel migration, and wildlife behavior. *Benefits:* Aquatic and riparian habitat and species; water quality. *Primary Actions:* Identify and implement actions necessary to remove or minimize constraints these structures on natural processes on a case by case basis. Action examples include restructuring Pacific Way Bridge, moving Muir Woods parking lot and concession buildings away from the channel and floodplain; realigning Muir Woods road along reaches where it impinges on channel migration, and removing or minimizing extent of bank revetments in Muir Woods and in the reach between the Highway 1 and Pacific Way bridges. .	2	2	2	F&S: Very high costs of addressing Muir Woods road and potentially other structures; although federal and state funding sources might exist. TF: Balancing the complexity and cost of the solution with its effectiveness and durability might be challenging. CS: The lane closure along Muir Woods Road are inconvenient, however people will be highly sensitive to changes in the 'downhome, country' experience of driving through this watershed. Therefore, solutions to the Muir Woods Road/channel meander problem will gain support depending on the scale and design of the solution.
5	Issue 31	**Halt decline of local native song bird populations due to nest predation and brood parasitism by non-native predator birds**. *Summary:* Studies have attributed declines in local native songbirds (Wilson's warble or WW) to brood parasitism and nest predation by other species, such as brown-headed cowbirds; Redwood creek a 'sink' population for WW in the region; WW population in decline in CA as well as several other western states. *Benefits:* song-birds, local invertebrates Primary Actions: Implement protections for brood parasitism and predation and assess song bird status in relation to these measures for adaptive management.	2	1	2	F&S: There might be financial sources for this type of program (however see feasibility). TF: It has been shown that trapping and exporting or outright extermination of local predatory species populations is difficult because individuals from neighboring areas simply fill in the created 'spaces'. CS: Moderate support, however some method that works must be identified.
5	Issue 22	**Minimize impacts of non-native animals and native "pest" animal species on native species** *Summary:* Non-native pest species can threaten visitors or negatively affect other native species (e.g. turkeys and Chukar partridges) and some native animals, such as raccoons and birds (e.g. ravens, crows, and jays) are more prevalent and impacting other species through excessive populations. *Benefits:* native animal and plant species *Primary Actions:* Assess distribution and effects of 'pest' species; identify and implement control measures.	2	1	2	F&S: There might be financial sources for this type of program (however see feasibility). TF: It has been shown that trapping and exporting or outright extermination of local pest species populations is difficult because individuals from neighboring areas simply fill in the created 'spaces'. CS: Moderate support, however some method that works must be identified.