CHAPTER 4

NATURAL DISTURBANCES

Natural disturbances have the potential the shift watershed conditions and processes in unprecedented ways, especially if the disturbance is sufficiently severe, frequent, widespread, or enduring. Climate scientists predict that the frequency and intensity of many natural disturbances will increase with global warming. This chapter considers four categories of natural disturbances in Bear Creek watershed: fire, geological hazards, floods, and drought. This chapter also describes the environmental and social impacts from these disturbances, and the efforts to manage them, and, in addition, outlines considerations for disturbances in the development of land uses. Gaps in information needed for managing or responding to natural disturbances are summarized at the end of the chapter.

4.1 Wildfire

Fire may extend landscape disturbances over tens of thousands of acres and interrupt ecosystem services that support human land uses. In some cases, fire is essential for maintaining biological diversity of native species, particularly plants species (Sweeny 1956, Keeley and Fotheringham 2000), or it can put species at risk by degrading or destroying habitat. It can variously control or spread invasive non-native species (di Tomaso and Johnson 2006; Keeley 2002). Controlling the destructive impacts of wildfire and facilitating vegetation regeneration after fires is a major management focus.

Fire Ecology

Impacts to water quality and supply, soil nutrient chemistry, soil erosion rates, air quality, vegetation, and animals may result from fires. Rapid loss of vegetation after intense and extensive fires can change how water moves through the watershed. Lost vegetation can no longer intercept rainfall and dissipate the force of rain on soils. Water from rain storms then moves with greater speed over land, often leading to high rates of soil erosion and stream sedimentation.

Situated at the juncture of the North Coast Bioregion and the Central Valley Bioregion (Hoshovksy 1992), the watershed shares traits of fire history and ecology from both bioregions. The oak savanna woodlands and semi-arid grasslands in the watershed are similar to those of Central Valley foothills and contrast with the chaparral and conifer woodland on steeper parts typical of the higher-elevation rugged terrain in the North Coast Range.

Fire Regimes

A fire regime consists of a set of factors that determine the severity of a fire: source of ignition, seasonality of fire, fire frequency ("fire-return interval"), existing fuel conditions in different vegetation communities, watershed topography, and weather. The Mediterranean climate naturally creates fire-prone conditions in Bear Creek watershed. Particularly during the summer and early autumn drought, total water in the watershed is at its lowest amount, and live vegetation and organic debris fuels are driest. In general, fire moves more quickly across the steeper topography of the west half and southern third of the watershed. Higher amounts of aboveground live and dead biomass contribute to larger fuel loads and greater fire hazard.

In the fire regime classification of Sugihara et al. (2006), Types I, II, and III are characteristic of different parts of Bear Creek watershed. The distribution of fire regime classes depends on vegetation types and fuel loading, i.e. the type, amount, and distribution of combustible matter. Chaparral vegetation, conifer woodlands, oak woodlands, and grasslands, all major vegetation types in Bear Creek watershed, are flammable, each in different ways.

Table 4.1 Fire regimes in Bear Creek watershed

Regime	Frequency	Severity
I	0-35 years	Low (mostly surface fires) – grasslands
II	0-35 years	High (mostly stand replacing fires) - chaparral
III	35-100+ years	Mixed (patches of low- and high-intensity fires) – woodland

Sources of Ignitions: Lightning and People

Lightning is the natural cause of fire in Bear Creek watershed. In the western half of California lightning is a comparatively rare phenomenon, comprising three percent or less of total ignitions in northern California west of the Sacramento River Valley (Keeley 2006; van Wagtendonk and Cayan 2008). In Bear Creek watershed between 1997 and 2007, lightning on three dates ignited five fires (Figure 4.2). CALFIRE and BLM fire crews quickly suppressed these fires.

People have probably been the major agents of fire in the watershed for millenia. Native Americans ignited fires in the region regularly until the 1840s (Stuart and Stephens 2006), accounting for most fires in the North Coast Range before European settlement. The fire ignitions displayed in Figure 4.2 do not include prescribed fires intentionally set for management purposes. Between 1997 and 2007, 32 ignitions (86 percent of the total displayed) not relating to prescribed burns resulted from human actions. Four of these ignitions were the acts of arson. The arson fires occurred along lower Bear Creek along Highway 16.

Transportation corridors are frequently points for ignitions. Records from the California Department of Forestry and Fire Protection (CALFIRE) show that motor vehicles were involved in at least eight of the 32 ignitions. CALFIRE estimated costs from these eight fires, totaling nine acres, at $42,000.00. Ignitions from other equipment burned 280 acres during the same period.

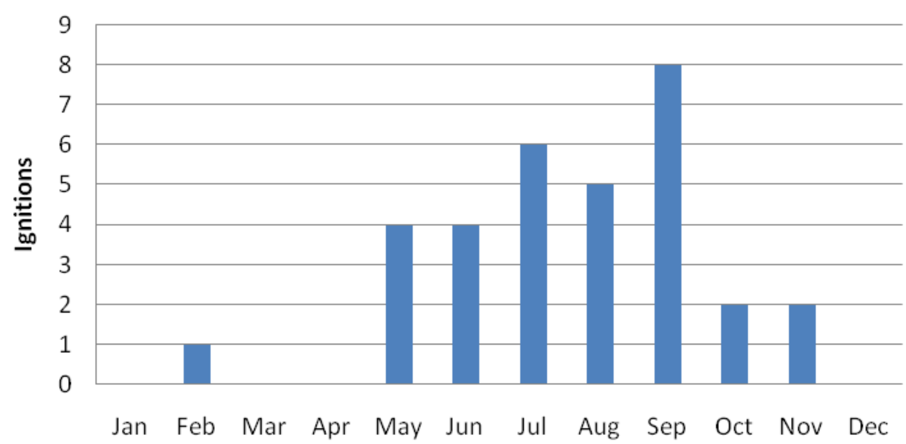
Most large fires since 1950 in the past have not originated in the watershed. For example, in June 2008, the 14,500-acre Walker Fire started outside Bear Creek watershed at the southern end of Indian Valley Reservoir when the metal undercarriage of a vehicle struck a rock on a road. The fire started in the Indian Valley, moved up the west side of Walker Ridge and down the east side into Bear Creek watershed, eventually burning more than 6,325 acres in the watershed.

Seasonality of Fire

Fires generally occur when fire hazard is greatest, under conditions of low humidity and soil moisture and high temperature and wind. These conditions tend to prevail from June through October in the watershed. Rare lightning events leading to fire are also seasonal. Between 1997 and 2007, lightning ignitions occurred in the months of July and September only.

Human alteration of fire regimes comes in part from human-caused ignitions outside the summer/autumn fire season. Most human-caused ignitions between 1997 and 2007 occurred in July and September, but other fires in February and November are well outside a natural fire regime based on lightning strikes.

Figure 4.1 - Distribution of Human Ignitions by Month, 1997 - 2007



Planned ignitions used by land managers and landowners often depart from the natural ignition pattern of lightning. For example, the Mendocino National Forest conducts most prescribed burns for fuels management once autumn rains begin in the cooler months from mid-October through May. In those months, the moisture is usually sufficient to confine a burn easily. Higher moisture conditions and cooler temperatures facilitate controlled burning. The differences in fire effects on Mediterranean-climate vegetation produced by wet-season burns in contrast to summer fires are not well understood.

Annual Frequency of Large Wildfires

Between 1950 and 2007, nineteen large wildfires burned across 11,292 acres, or seventeen percent of Bear Creek watershed (CALFIRE database). Fires burned a second time over 1,430 acres during the 58-year period, mostly in perimeter areas: along the north edge of Mill Creek watershed, on Bear Valley Buttes, along lower Bear Creek, and on Cortina Ridge. Three fires originating west of the watershed stopped at the crests of Walker Ridge or Love Lady Ridge. Fires on ultramafic soils were much less frequent than fires on non-ultramafic soils.

The infrequency of fire belies the presence of fire-prone vegetation. With large loads of flammable fuels and summer weather conditions that set the stage for wildfire, vigilant fire suppression has likely been the key to keeping the number of large wildfires low within the watershed in the past 60 years.

Fire Intensity and Severity

Fire intensity describes the physical features of fire behavior while it is burning. Fire severity, by contrast, describes the outcomes of fire regimes on vegetation, wildlife, and water resources.

Severity of a fire can significantly alter vegetation in the aftermath of the fire. In the past, people have used unnaturally high fire frequency to increase fire severity with a goal to removing mixed-species and chamise chaparral (Haidinger and Keeley 1993) and creating more grassland for livestock forage. This conversion occurs often when invasive non-native (mostly annual) grass species have shifted the species mix in the soil seed bank. Abnormally frequent burning can eventually exhaust the capacity of chaparral shrubs to re-seed or re-sprout. Grassland patches developed for livestock grazing, particularly south of Highway 20 and in parts of Mill Creek watershed are examples of the use of fire severity as a management tool for vegetation.

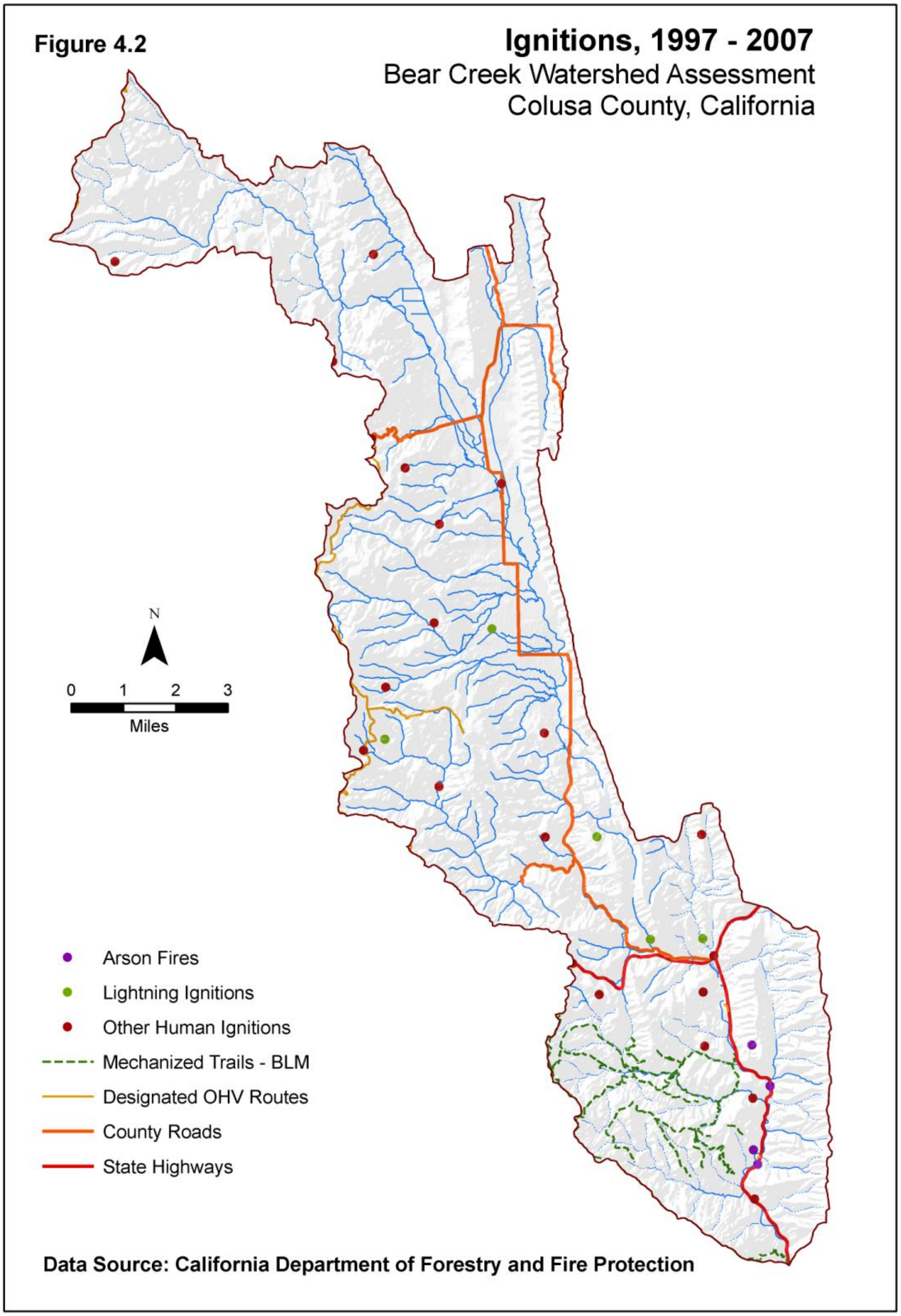


Figure 4.2
Ignitions, 1997 - 2007
Bear Creek Watershed Assessment
Colusa County, California
N
0 1 2 3
Miles
Arson Fires
Lightning Ignitions
Other Human Ignitions
Mechanized Trails - BLM
Designated OHV Routes
County Roads
State Highways
Data Source: California Department of Forestry and Fire Protection

Figure 4.3 – Six Decades of Wildfire in Bear Creek Watershed, 1950 - 2008

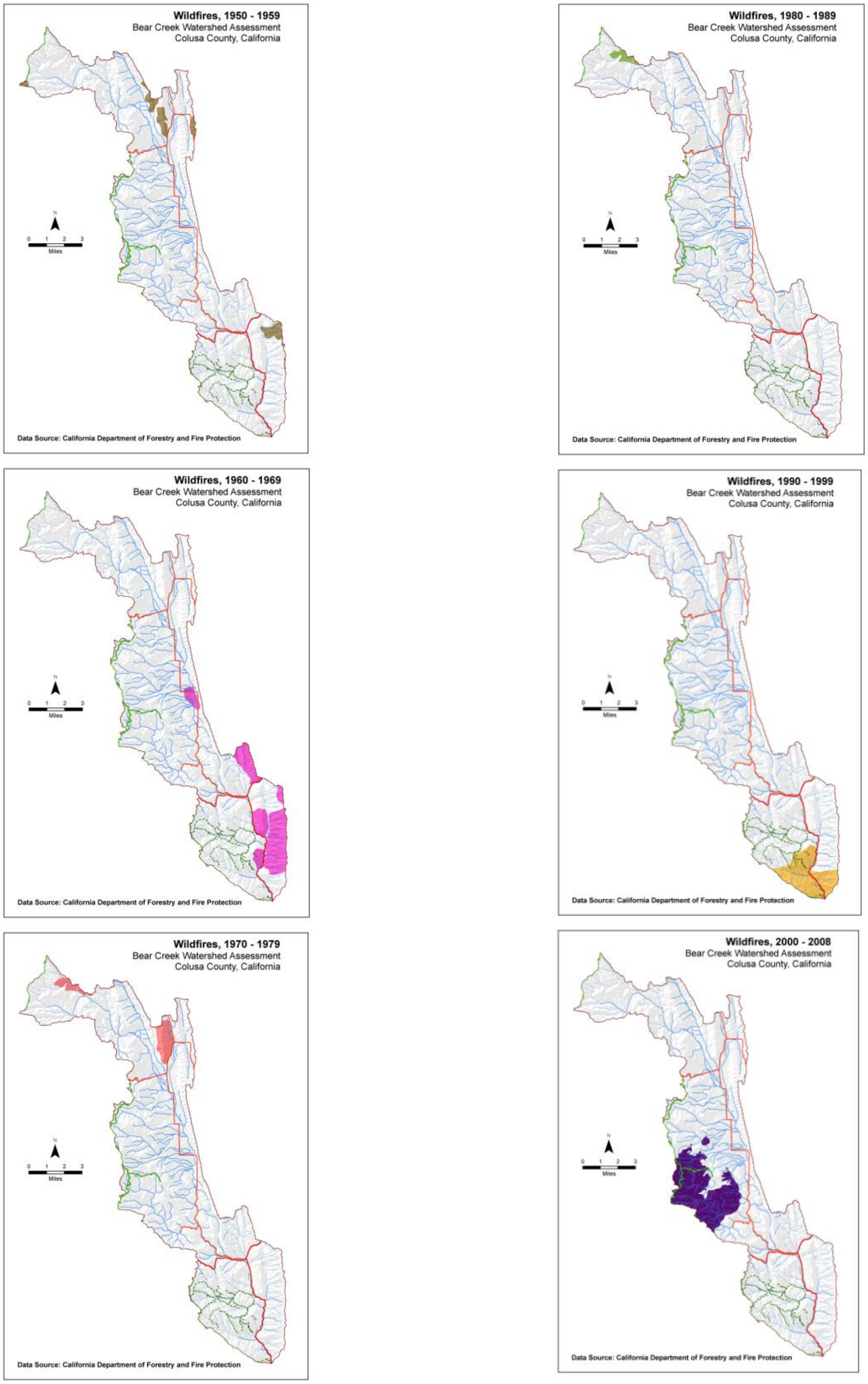


Table 4.2 - Overview of components of fire regimes for major vegetation classes in Bear Creek watershed

Vegetation Type	Season	Fire-Return Interval	Size	Complexity	Intensity	Severity	Fire Type
Foothill Woodland	June - October	Short	Small to Medium	High	Low to Moderate	Low to Moderate	Surface
Valley Grassland	June - October	Short	Medium to Large	Low	Low	Moderate to High	Surface
Knobcone Pine	April - October	Medium - Long	Large	Low	High	High	Crown
Cypress Woodland	April - October	Medium - Long	Large	Low to Moderate	High	Moderate to High	Crown
Chaparral, SS*	?	Short - Medium	?	?	High	Low	Crown
Chaparral, US*	?	Medium - Long	Small	Low	Moderate	Moderate	Crown

Source: Davis and Borchert (2006), Keeley (2008 pers. comm.), Safford and Harrison (2004), Wills (2006)
*SS=chaparral on sedimentary non-ultramafic soils, US=chaparral on ultramafic soils

Fire Fuels

The flammability of fuels depends on the physical properties of the vegetation. The important factors are: the total biomass of vegetation available as the fuel source; size of the individual pieces of fuel; surface area to volume ratio for fuel ignition; moisture content of the fuel; the compactness of fuels ("packing ratio"); and the spatial placement and continuity of fuels in the landscape (Husari et al. 2006, van Wagtendonk 2006).

Fires in grasslands and oak woodlands are usually ground fires with short flame lengths. In woodlands, oaks with fire-resistant bark and boles without dead lower branches create a break in the continuity of fine fuels on the ground and tree canopy fuels consisting of branches, twigs, and foliage. Without a "fuel ladder", ground fires do not spread to tree crowns. By contrast, shrubs and some trees maintain a continuous fuel supply from both dead and live branches between the ground and the tree canopy that frequently gives rise to crown fires which began as ground fires. Chaparral shrubs produce low-canopy fires: the fire burns close to the ground because the canopy is near the ground. Conifer species in Bear Valley watershed, such as knobcone pine and McNab cypress, grow densely, maintain their dead lower branches on the bole, and give rise to stand-replacing high-canopy fires. In other cases, particularly in wetter streamside woodlands, herbs and shrubs in the woodland understory feed flames that then may reach into canopies of overstory trees in a relay system of ladder fuels.

Chaparral vegetation on non-ultramafic soils has high flammability with its dense, closed canopy. Thus, fires in chaparral shrub ecosystems burn hot and usually remove the standing shrub vegetation. After the fire, chaparral shrubs may sprout from root crowns or germinate prolifically from seeds stored in the soil. Although fires in chaparral are usually hot (intense) because of fuel flammability, the ability of chaparral shrubs to reseed or resprout from root crowns means that the long-term severity of chaparral fires is usually low and shrubs recover rapidly under normal conditions.

In contrast, chaparral vegetation growing on ultramafic soils grows more slowly and less densely. Safford and Harrison (2004) found that annual height growth of chamise found on ultramafic soils had less than half the height growth of chamise growing on sandstone-derived soils. Because ultramafic chaparral vegetation is not as dense, the litter of dead leaves and branches on the ground (fine fuels) is less extensive and forms a shallower layer on the ground compared to chaparral on other soil types. Until 2008, most large fires burning in chaparral did not burn across ultramafic soils on the east slope of Walker Ridge in Bear Creek watershed.

CALFIRE has developed a fuel ranking system to depict the fuel load and its flammability characteristics (Figure 4.4). The fuel rank is useful for prioritizing sites for prescription burning treatments designed to reduce fuel loads and catastrophic fire. Upper Mill Creek subwatershed, Walker Ridge, a band of steep terrain at the west edge of Bear Valley, and the complex terrain between Highway 20 and the south end of Bear Valley are areas that may benefit from fuel load reduction.

Interaction between Wildfire and Erosion

Soil erosion the capacity of soils to store carbon, increases the amount and speed of runoff, and decreases soil moisture. After wildfires, soil erosion rates increase due to exposed ground surfaces. The ecological alteration from wildfire may induce further disturbances by way of landslides and debris flows. CALFIRE has analyzed terrain in Bear Creek and elsewhere in California using the Revised Universal Soil Loss Equation (Figure 4.5). This analysis helps stakeholders quickly identify problem areas from erosion in the aftermath of a wildfire. The following two areas are likely to need emergency stabilization: Cortina Ridge in the southeast corner of the watershed and the steep slopes on the southwest side of Sulphur Creek subwatershed.

Considerations for Fire Management in Bear Creek Watershed

Applying fire treatments to areas with ultramafic soils and chaparral vegetation may need to be different from fire treatments on sedimentary soils with chaparral vegetation. On average, fires burn hotter and faster in sedimentary chaparral. The fire-return interval for chaparral vegetation on ultramafic soils is about four times longer than for chaparral on sedimentary soils (74 years vs. 19 years). Higher productivity on more fertile soils causes faster accumulation of biomass and shorter intervals between fires. In contrast, vegetation on less fertile ultramafic soils accumulates biomass more slowly than non-ultramafic sites (Safford and Harrison 2004).

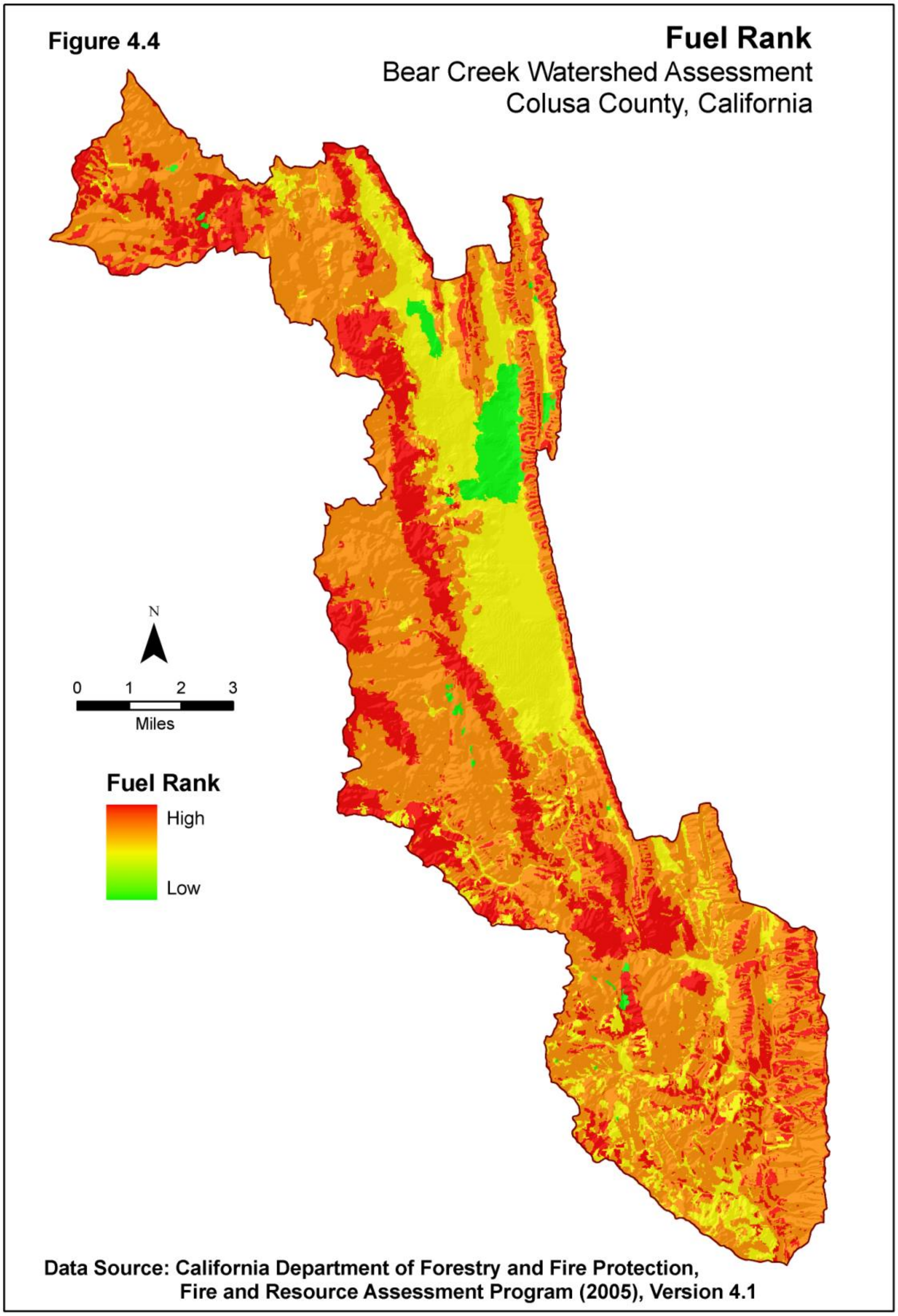


Figure 4.4
Fuel Rank
Bear Creek Watershed Assessment
Colusa County, California
N
0 1 2 3
Miles
Fuel Rank
High
Low
Data Source: California Department of Forestry and Fire Protection,
Fire and Resource Assessment Program (2005), Version 4.1

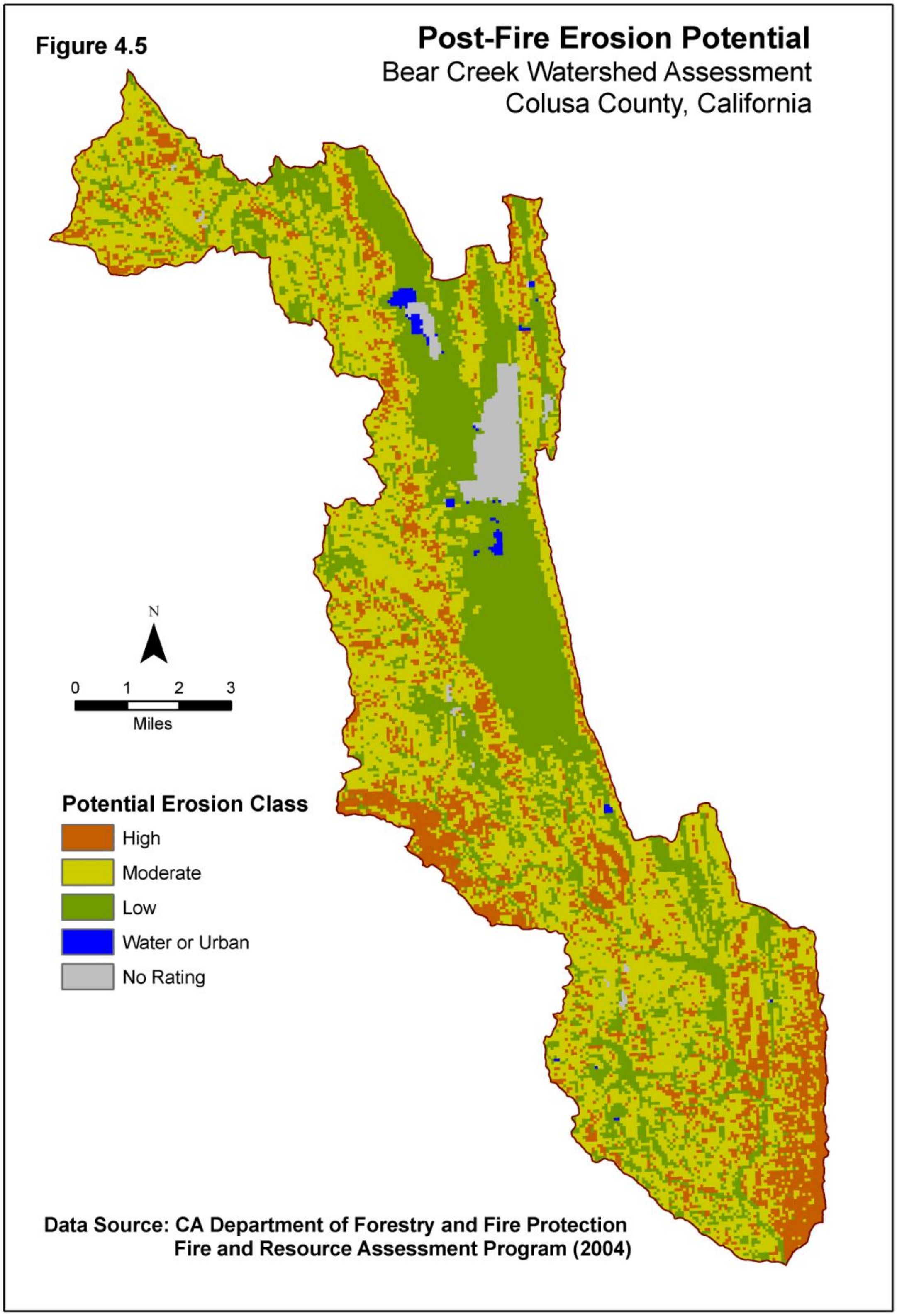


Figure 4.5
Post-Fire Erosion Potential
Bear Creek Watershed Assessment
Colusa County, California
N
0
1
2
3
Miles
Potential Erosion Class
High
Moderate
Low
Water or Urban
No Rating
Data Source: CA Department of Forestry and Fire Protection
Fire and Resource Assessment Program (2004)

Fires in chaparral ecosystems increase plant species diversity, largely through an increase in herbaceous species. One adverse effect is that fire in chaparral ecosystems exposes the burned sites to greater risk of invasion of non-native plant species. Safford and Harrison (2004) found that the number of non-native plant species tripled after chaparral fires on both sedimentary and ultramafic soils.

Mercury Emissions from Wildfires

During fires, mercury is released from the soil as a gas into the atmosphere. The Mediterranean Basin, for example, emits an estimated annual average of 4.3 metric tons of mercury (Cinnirella et al. 2008) from wildfires. An initial estimate of the annual range in the United States is between 19 to 64 metric tons of mercury (Wiedinmeyer and Friedli 2007).

The relation between mercury and wildfires is an emerging topic of research. Mercury emissions from wildfires in other parts of the world with environmental conditions similar to those of the inner North Coast Range in California (frequent wildfires and high background levels of naturally occurring mercury) are now under scrutiny for potential long-term ecological and human health impacts (Cinnirella and Pirrone 2006).

Although scientists have not collected data from Bear Creek watershed, recent research gives an idea of the quantities of mercury being released during wildfires. Biswas et al. (2008) have estimated that one wildfire in Washington State in 2001 released 6.7 grams per hectare (equivalent to 9.5 pounds per square mile) of mercury from the soil. Changes occur to amounts of mercury in soils as well. In Wyoming, Biswas et al. (2007) found that post-fire soil samples from a burned watershed had only 25 percent of the amount of soil mercury found in samples from an adjacent unburned watershed with same soil type (38 parts of mercury per billion vs. 158 parts per billion).

Past Prescribed Fire Treatments in Bear Creek Watershed

A historical record of prescribed fire treatments in Bear Creek watershed is not available in a GIS layer for display here. In past decades, landowners burned extensive areas of chaparral or cut and burned oak woodland habitats at the north end of the watershed and on the BLM Bear Creek Ranch at the south end to accomplish “type conversion” of vegetation to grasslands intended for increased forage for livestock. Recently, the BLM has prescribed burns for meadows in the Ranch. CALTRANS and CALFIRE have burned portions of the Bear Creek Botanical Management Area along Highway 20 to suppress invasive non-native plants and to promote native plants, especially herbaceous prairie species. Occasionally, prescribed fire treatments burn out of control and become wildfires. Such an incident, the Bear Fire, occurred on private land on the east slope of Walker Ridge in May, 2002.

Hazard to Communities at the Urban-Wildland Interface

CALFIRE has modeled the hazard to communities throughout California. The greatest hazard to communities is at the south end of the watershed, the area closest to the Capay Valley. The single rural community of concern for fires spreading from Bear Creek watershed is the town of Rumsey, 5.8 miles southwest of the mouth of Bear Creek along the main stem of Cache Creek in Yolo County. The BLM manages the public lands where the fire hazard is greatest. As part of fire planning, the BLM has made the following composite hazard rating and component hazard evaluations for the community of Rumsey:

Composite Rating	Fuels Hazard	Ignition Risk	Resource & Economic Values	Fire Protection Capability	Catastrophic Fire Potential	Wildland Fire History
Moderate	High	Moderate	High	Moderate	Moderate	High

Source: Bureau of Land Management (2008 draft)

Sources of ignition risk include: presence of power lines, multiple kinds of popular recreation, a nearby urban population, outdoor burning, woodcutting, fireworks, and arson. Fire features of concern are high (> eight feet) flame lengths, high potential for crown fires, and steep and elevated terrain in the area. Resources at high risk on the public lands for the community of Rumsey are Native American cultural resources, wildlife and fisheries, domestic water supply, riparian habitat and flood protection, visual quality, and soils. Air quality and standing timber are secondarily important.

Fire Agency Authority and Collaboration

Fire management authorities for governmental agencies fall into two categories: management for fire suppression and management for prescribed burning to benefit land uses.

Fire Suppression

BLM and the CALFIRE have a Memorandum of Understanding where CALFIRE leads fire suppression and property protection efforts for the BLM public lands in northern California, including lands in Bear Creek watershed. CALFIRE has lead responsibility for suppressing fires on private lands and on public lands managed by California state agencies as well. The US Forest Service has lead authority for fire suppression for the portion of the Mendocino National Forest in the watershed.

CALFIRE has two stations in the watershed: the Leesville station at the north end of the watershed (currently closed) and the Wilbur Springs station at the intersection of Highways 16 and 20.

Prescribed Agricultural and Wildland Burning

The Colusa County Air Pollution Control District (APCD) regulates all planned agricultural and wildland vegetation burning in Bear Creek watershed. Regulations established by the Colusa County APCD support the goals of the regional Sacramento Valley Air Basin Plan. The Control District requires burn plans at least seven days in advance of a prescribed ignition. No more than 640 acres (one square mile) total of wildlands in Colusa County may burn by prescription during a single day.

The California State Air Resources Board has established the Bear Valley-Indian Valley Fire Protection District office in Stonyford, north of Bear Creek to cover Bear Creek watershed. An Air Pollution Control Officer there issues permits for agricultural, forestry, and wildland burning.

Bear Creek watershed differs from the Sacramento Valley portion of Colusa County, where agricultural debris is common. In the watershed, most prescribed burning is done to achieve goals for ecosystem services such as invasive plant suppression, forage improvement for livestock, wildlife habitat improvement, and reduction of fire hazard.

Interagency Collaboration for Fire Suppression and Prescribed Burning

Common interests among different agencies charged with fire management have promoted long-term collaboration among agencies, especially in situations where the need for fire suppression is urgent and requires more resources than one agency alone can provide. Locally, the BLM Cache Creek Natural Area Manager and the CALFIRE Wilbur Springs fire station staff have collaborated on prescribed burning. Public lands offer a training ground for CALFIRE staff, and CALFIRE helps the BLM accomplishes management goals specified for the Cache Creek Natural Area (Bureau of Land Management 2004).

Fire Modeling

Modeling fire hazards, risks, and future fire behavior uses the suite of modeling tools known as LANDFIRE, created jointly between the wildland fire management programs of the US Forest Service and the US Department of the Interior land management agencies, including the BLM. Federal fire managers have not yet used LANDFIRE (www.landfire.gov) in Bear Creek watershed. Critical data for vegetation and fuels are not updated for modeling purposes. Once data are available for the watershed, the data for analyses of fire behavior will consist of GIS layers of vegetation composition and structure, surface and canopy fuel characteristics, and historical fire regimes. The model is capable of producing raster data on a 30-meter grid.

The goal of LANDFIRE analysis is to identify priorities to reduce hazardous fuels watershed-wide and to restore ecosystem conditions in the watershed that enhance multiple resources such as biological diversity, landscape visual resources, soil conservation, water quality, and recreation. Fire program managers at CALFIRE, the BLM, and the US Forest Service can jointly use information from modeling to support decision making about scheduling and funding fire management programs. Collaborative planning across boundaries of management jurisdiction is intended to reduce high costs for fire suppression in the region and to integrate fire resources seamlessly.

There is concern that climate change is changing fire behavior in California. A range of fires scenarios of climate change indicate that a warmer, drier climate will create losses from fire in the cover of oak woodlands resulting in the expansion of grasslands (Lenihan et al. 2008). Modeling of future fire behavior specifically for Bear Creek watershed is not yet available.

4.2 Geological Hazards

A geological hazard may cause environmental changes, damages to resources, or pose risks to human health and safety. Most geological hazards are small in scope but can at times attain catastrophic proportions and significantly transform landscapes. Knowledge of geological hazards comes from interdisciplinary research into past geology, plate tectonics, soil science, and geomorphology of a region. While knowledge of the past can give a sense of likely future geological hazards, this information can rarely forecast the timing and size of a future geological hazard. This section covers specifically earthquakes and landslides as the principal hazards known to have occurred over the last two centuries in Bear Creek watershed.

Earthquakes

Seismic Activity

A historical record of earthquakes in the inner North Coast Range extends back 150 years. The two largest earthquakes originating locally occurred in April 1892; they had local earthquake magnitudes greater than 6.2 and 6.5 respectively. Other strong earthquakes in the area occurred in 1885 (Rogers 1891), 1898, 1906 (the San Francisco earthquake), and 1980-1985 (URS Corporation 2006).

The watershed lies in a less active seismic zone in contrast to the 68-mile long Barlett Springs Fault Zone just west of the watershed. As a result, few earthquakes have their epicenters in the watershed itself (URS Corporation 2006). The fault likeliest to generate an earthquake in the watershed is the Resort Fault, which passes through Sulphur Creek subwatershed.

Seismic Hazard

Peak ground acceleration (PGA) is the standard measure of the seismic hazard from ground shaking during an earthquake. PGA estimates the intensity of shaking expected at a set chance (10% likelihood) of occurring within a specified time (50 years). The California Geological Survey has mapped the distribution of PGA in Bear Creek watershed. Areas with higher PGAs for the fifty-year period are at greater risk of damage to structures from earthquakes. Ground shaking from earthquakes in the watershed is likely to be highest on the west side of the watershed: at the headwaters of Mill Creek, along Walker Ridge, in Sulphur Creek subwatershed, and west of Highway 16. Overall, the risk for Bear Creek watershed is moderate in contrast to high-earthquake activity areas in California along the San Andreas Fault, in the Los Angeles Basin, and in the Humboldt Bay region.

Earthquakes also can trigger landslides. At present, no information about correlations between landslides and earthquakes exists. However, the density of landslides appears to largely overlap the likely zones of highest ground shaking – the steeper parts of the west side of the watershed.

Concerns

With its current small population, the watershed has a low probability of loss of life and property from earthquakes. Should the population of the watershed increase or should new land uses develop such as commercial energy production, optimal siting for buildings and infrastructure will be critical to reducing earthquake hazards.

Landslides

Manson (1989) mapped landslides for the main stem of Cache Creek, and that effort included a small part of the southern end of Bear Creek watershed where landslides are infrequent. Until recently, the extent of landslides in the watershed was poorly understood. Hoorn et al. (2008) analyzed landslide sites in Bear Creek watershed north of Highway 20 based on aerial photographs. Of the 118 landslides occurring between 1937 and 2005, all but six stabilized after the initial slope failure and did not slide further downslope later. Debris slides were the most frequent (96 percent) and most massive (98 percent of volume) form of landslide. Debris flows, occurring after water has saturated steep slopes, were rare events, and only a single complex debris landslide was recorded. The eight largest landslides mapped (all >20,000 cubic yards) comprised 44 percent of the volume from all landslides. None of the largest landslides originated from specific land uses or human ground disturbances.

Relation to Landform

Steep inner gorge slopes (≥ 30°) and streamside slopes (< 30°) were the sources of 43 percent and 48 percent of all landslides respectively. A much smaller share of landslides occurred at locations where slopes change abruptly ("headwalls"). On average, rock and soil debris delivered to streams was nearly twice as high from individual slides coming off the steeper inner gorge slopes than off streamside slopes (7,200 cubic yards vs 4,380 cubic yards).

Relation to Vegetation and Soils
Fifty-one percent of all landslides occurred at sites dominated by chaparral shrubs on higher-elevation slopes with ultramafic soils in the western half of Bear Creek watershed. Six of the eight largest landslides occurred at sites with ultramafic Henneke soils on steep slopes (>30°) slopes (Hoorn et al. 2008, J. Weigand GIS analysis).

Oak woodlands, found for the most part on sedimentary soils, had about 30 percent of detected landslides. However, this percentage corresponds to the relative proportion of oak woodlands across the entire watershed and does not indicate a correlation between landslide frequency and vegetation type. Most oak woodland slides were at lower elevations and at streamside sites with gentler slopes and deeper soils.

Relation to Land Uses
Hoorn et al. (2008) found that 69 percent of all landslides and 89 percent of the total sediment volume delivered to watershed creeks and streams north of Highway 20 originated from landslides unrelated to a land use. Roads and trails were the most common cause of landslides associated with a human land use and accounted for six percent of total sediment delivery. The largest single slide caused by roads is along Highway 20 west of Bear Creek Bridge, with an estimated debris volume of 16,400 cubic yards. Grazing, mining, and reservoirs together contributed another five percent of all landslide debris.

Concerns
Three of the largest natural landslides have occurred in Sulphur Creek subwatershed. The subwatershed is also prone to erosion after fires (refer to Section 4.1 above). A landslide triggered near mercury mines has the potential to destabilize extensive mercury-rich waste piles and increase the passage of mine waste into Sulphur Creek.

4.3 Flooding and High Flows

Flooding affects water quality, sediment deposition patterns, fish and wildlife habitats, and options for habitat restoration. When inundated, floodplains can temporarily expand habitats at key life stages for fishes, amphibians, and aquatic invertebrates. Floods scour sediments from stream banks and terraces, redistribute streambed substrates, erode soil, uproot vegetation, and rearrange patterns of sediment deposition areas along waterways. Floods may directly impact landowners economically in Bear Valley if losses to livestock result.

The Colusa County Soil Survey (Reed 2006) predicts frequent winter flooding along three stretches of Sulphur Creek, the lower reach of Mill Creek, and at one site in the lower Bear Valley. Periodic flooding is likely to occur elsewhere on the east side of Bear Valley and in the Cowboy Camp area south of Highway 20. Elsewhere, flooding is rare or non-existent. Figure 4.6 displays a generalized winter flood frequency map from the Colusa County Soil Survey.

Data on past flood frequencies in Bear Creek watershed are not directly available but may be inferred from flood data from the closest National Weather Service station downstream in Middle Cache Creek at Rumsey. These data provide an indication of the frequency and timing of flooding in Bear Creek watershed. Flood crests of Cache Creek at Rumsey Bridge have occurred on ten dates between 1960 and 2007 (National Weather Service data 2008).

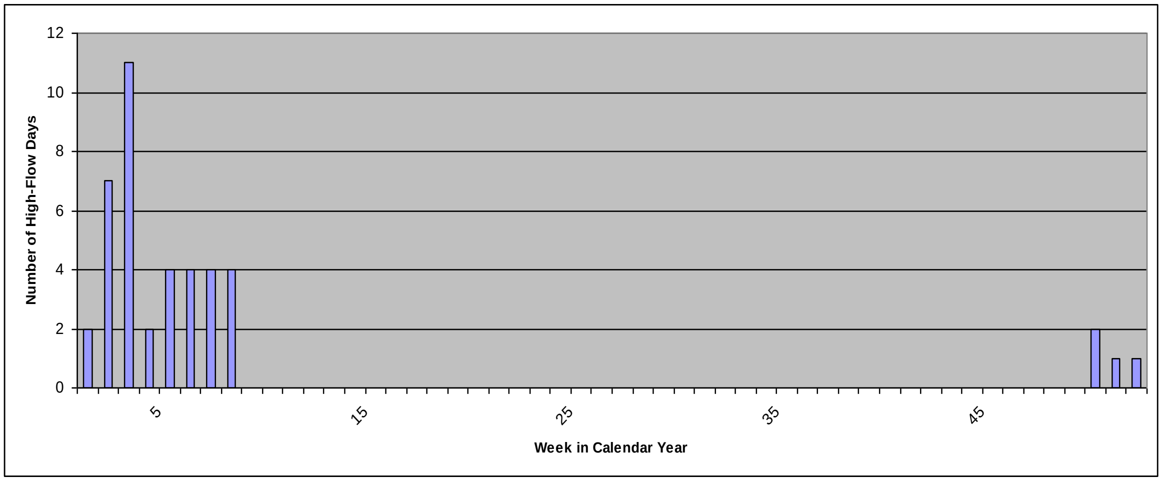
Intense rainfall can generate a high-flow response in Bear Creek within just a few hours of the start of a heavy rainstorm, especially if soils in steep topography are already saturated with water. Bear Creek and its tributaries then produce a quick-response, short-term ("flashy") water flow pattern typical of steep landscapes with a Mediterranean climate (Gasith and Resh 1999).

Of concern downstream on Cache Creek is the potential contribution of Bear Creek watershed to floods in the Western Yolo floodplain. The towns of Madison and Esparto are vulnerable to flooding, and the City of Woodland has protections in place for only a 10-year flood. A 100-year flood in Cache Creek would inundate approximately 35 percent of the City of Woodland according to the Federal Emergency Management Agency (2009).

Yates (1989) has estimated the 100-year one-day maximum flow for Bear Creek at 5,120 cubic feet per second (145 $m^3\ s^{-1}$). For the periods of record for water gages in lower Bear Creek (water years 1959 – 1980 and 1999 – 2007), 42 days exceeded an average daily water flow of 1,765 cubic feet per second (50 $m^3\ s^{-1}$) and five days exceeded an average daily flow of 3,530 cubic feet per second (100 $m^3\ s^{-1}$). The highest flow recorded on Bear Creek during the periods of record was 4,377 cubic feet per second (124.0 $m^3\ s^{-1}$) on February 5, 1965.

High flows in Bear Creek appear over an eleven-week interval from mid-December through the end of February, with a peak in mid-January.

Table 4.3 – Distribution of the 42 days with Bear Creek flows >50 cubic meters per second by week of the year in which they occurred



Source: USGS data from Bear Creek water gages, water years 1959 – 1980 and 1999 – 2007

High flows usually last less than 24 hours in Bear Creek. Of the 42 days of high flows on Bear Creek (greater than 1,765 cubic feet per second), periods of multiple days of sustained high flows occurred on only six occasions for the periods of record as follows:

1973 February 11/12
1978 January 14/15/16/17
1980 February 12/13
1980 February 17/18/19
1999 February 2/3 and
1999 February 6/7.

All multi-day high flows occurred in El Niño winters.

4.4 Drought

Droughts affect the resilience of Bear Creek watershed differently depending on their duration and severity. Studies of past droughts on the environment of Bear Creek watershed have not been undertaken. However, studies in other parts of California and the Southwest provide past evidence of drought disturbance and shed light on the outcomes of different kinds of droughts.

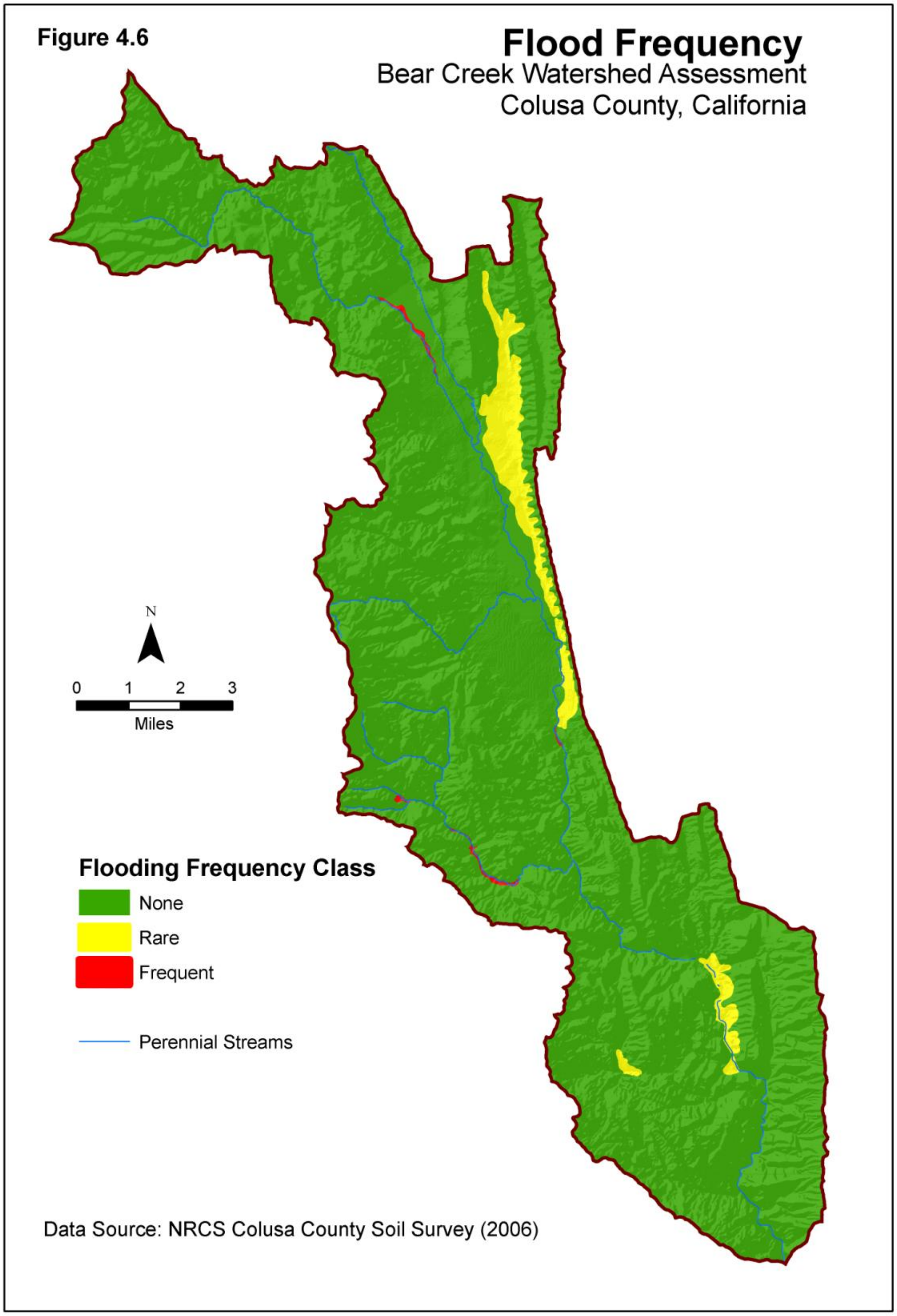


Figure 4.6
Flood Frequency
Bear Creek Watershed Assessment
Colusa County, California
N
0
1
2
3
Miles
Flooding Frequency Class
None
Rare
Frequent
Perennial Streams
Data Source: NRCS Colusa County Soil Survey (2006)

Multi-year droughts have occurred three times since 1960 in Bear Creek watershed. Although lower Bear Creek ceased flowing aboveground in the summer during the 1976/1977 drought, fish populations and aquatic processes rebounded in subsequent years. However, centuries-long droughts that indicate climate change in the past have led to more drastic changes. Enduring drought such as occurred 10,900 to 10,600 years ago across North America contributed to altered habitats and extinction of large mammal species such as mastodons and mammoths (Haynes 2002).

Drought may also predispose a watershed to other disturbances. For example, insect infestations and fungal pathogens can more easily kill drought-stressed trees and shrubs. The resulting standing dead wood in woodlands and chaparral then increase fire hazard and alter fire frequency (Brunelle and Anderson 2003).

Long-term drought may contribute to cumulative large-scale geographic impacts when drought extends across several adjacent bioregions at the same time. The medieval climate anomaly (9^{th} through the 14^{th} centuries) caused by long-term cooling in the Pacific Ocean off California created a series of droughts across the entire state lasting 30 to 60 years. These droughts altered or extinguished once vital human communities in the Southwest when people were powerless to prevent water shortages (deMenocal 2001). A future long-term drought across the Sacramento River system, including Bear Creek, would fail to provide water for Californians and create economic and societal instability (MacDonald et al. 2008). To alleviate impacts from future droughts, whatever their durations and severities, landowners and resource managers need to coordinate water conservation measures in the watershed.

4.5 Information Gaps

Resource management can be challenging when managers must deal with unscheduled natural disturbances in combination with disturbances resulting from human land uses. Addressing gaps in information about the following topics can help assist stakeholders understand, prepare for, and manage disturbances in the watershed. Major information needs are:

- Best practices for fire management on sites with ultramafic soils, for (1) enhancing populations of associated rare plant species; (2) reducing the likelihood of landslide hazards in the aftermath of fires; (3) preventing invasion of ultramafic-adapted non-native invasive plant species after fire; and (4) reducing damage to ultramafic landscapes during fire suppression actions

- Long-term effects of wet-season prescribed fires on vegetation and fuel characteristics in comparison with effects from natural dry-season fires

- Methods and strategies to regenerate stands of conifer tree species (e.g., cypress species) as a hedge against their extirpation as the result of a catastrophic wildfire and loss of viable seed banks

- Potential mercury emissions and human health impacts from wildfires in the watershed

- Updated vegetation information on non-Forest Service lands in the watershed to make the entire watershed compatible for modeling fire behavior with LANDFIRE

- Responses by vegetation, wildlife, and soils to prescribed burning over time to ascertain which practices are most effective for achieving management goals for these resources

- Maps and analyses of landslides south of Highway 20

- Best management practices designed to retain water in Bear Creek watershed longer (e.g., grazing practices, floodplain and wetland restoration, road and drainage design)

- Water flows and flood frequencies in Bear Valley, Sulphur Creek and Mill Creek subwatersheds, and the Cowboy Camp area

- A watershed hydrologic model.