CHAPTER 5

ENVIRONMENTAL CONTAMINANTS

This chapter summarizes current knowledge about environmental contaminants that are or may be adversely affecting the quality of water, soil, air, and biotic resources in Bear Creek watershed. Contaminants are important to stakeholders when they are obstacles to achieving the watershed assessment goals described in Chapter 1. To assist in developing watershed projects to achieve goals, this chapter identifies contaminants, where they are known to occur in the watershed, and how contaminants relate or respond to natural features and human land uses in the watershed.

5.1 Water Quality Objectives

In California, water quality objectives are complex. The Central Valley Regional Water Quality Control Board (CVRWQCB) has established water quality objectives for Bear Creek watershed in the *Water Quality Control Plan (Basin Plan) for the Sacramento River Basin and the San Joaquin River Basin* (4th edition, as amended 2007). Objectives consist of three elements: designated beneficial uses; numeric and narrative criteria; and antidegradation policies and procedures. Their purpose is to define goals, contaminant limits, and protection requirements for water quality in the watershed.

Information about chemical and biological contaminants from the watershed is critical in support of water quality objectives. Scientific investigations and monitoring in Bear Creek watershed are helping stakeholders to know which contaminants require management, where management should take place, and how much the amounts of contaminants are changing in response to watershed remediation projects designed to improve water quality and meet regulatory requirements.

Existing and Potential Beneficial Uses for Water

Amendments to the Basin Plan (Cooke and Morris 2005) specified beneficial uses for water in the Cache Creek Basin from the Clear Lake Dam (Lake County) to the Yolo Bypass (Yolo County). Bear Creek watershed is part of this section of the Cache Creek Basin. Beneficial uses orient water quality management in Bear Creek watershed. In 2007, the CVRWQCB specifically amended the Basin Plan in Resolution R5-2007-0021 to delete municipal and domestic water supply (MUN) as a beneficial use for lower Sulphur Creek from Schoolhouse Canyon to its confluence with Bear Creek. Table 5.1 lists the existing beneficial uses currently applicable to Bear Creek watershed.

Table 5.1 – Beneficial uses applicable to Bear Creek and its tributaries

Beneficial Uses	Status
Agricultural Supply, Irrigation and Stock Watering (AGR)	Existing
Commercial and Sport Fishing (COMM)	Existing *†‡
Freshwater Habitat, Cold (COLD)	Potential
Freshwater Habitat, Warm (WARM)	Existing
Industrial Process Supply - uses not dependent on water quality (PROC)	Existing
Industrial Service Supply - uses dependent on water quality (IND)	Existing
Municipal and Domestic Supply (MUN)	Existing *‡
Recreation, Contact Water and Canoeing & Kayaking (REC1)	Existing‡
Recreation, Non-Contact Water (REC2)	Existing
Spawning, Reproduction, and/or Early Development (SPWN)	Existing
Wildlife Habitat (WILD)	Existing‡

Sources: Cooke and Morris (2005), Cooke and Stanish (2007)

* COMM and MUN do not apply to Sulphur Creek from Schoolhouse Canyon to the confluence with Bear Creek (Basin Plan as amended 2007)

† A fish advisory from the California Office of Environmental Health Hazard Assessment in 2005 recommends against people consuming any fish or other species found in Bear Creek watershed.

‡ Uses considered impaired due to mercury

The designated beneficial uses for water in Bear Creek and its tributaries apply to the following land uses: ecological services [COLD, WARM, SPWN, WILD], recreation [COMM, REC1, REC2], agriculture [AGR], potable water supply [MUN, in part], and industry [PRO, IND]. MUN, PRO, and IND are economically important largely to stakeholders downstream of the watershed.

Impairment to Beneficial Uses

The California State Water Quality Control Board includes Bear Creek and its tributary Sulphur Creek on the State of California's Clean Water Act 303(d) list of impaired water bodies. Causes given for impairment to beneficial uses are: elevated concentrations of mercury in streams, methylmercury in fish tissue, and an existing advisory against consuming fish caught in Bear Creek watershed.

Numeric Criteria for MUN Water Quality Objectives

Numeric criteria indicate the known toxic concentration of a water contaminant in drinking water or a threshold amount designed to avoid a risk to human health. The numeric criteria apply to: contaminant chemical elements and their compounds; inorganic nitrogen-, sulfur-, and phosphorus-containing ions; ion indicators of salinity and alkalinity; and toxic industrial organic compounds such as solvents and pesticides.

Chemical Criteria for Quality Objectives for Drinking Water

Regulatory numeric objectives for water quality criteria in California come from the following sources:

1. Drinking water objectives established by the California Department of Public Health (CDPH) for the maximum contaminant limit (MCL) to total concentrations of elements and compounds in water
2. California State Notification Levels and Response Levels for Drinking Water from the CDPH for elements and compounds that do not have MCLs
3. Total daily maximum load (TMDL) limits to contaminants not otherwise covered by the existing MCLs
4. California Public Health Goals established by the California Office of Environmental Health Hazard Assessment (OEHHA), which solely considers human health based on best available scientific information and works with the CDPH in determinations of MCLs.

Other sources taken into consideration are:

5. US EPA's California Toxics Rule standards for priority toxic pollutants for which the State has not set water quality objectives
6. The National Toxics Rule
7. US EPA's IRIS database for carcinogens
8. World Health Organizations criteria.

The first numeric three objectives apply to all water supplies having MUN as a beneficial use in California on all land jurisdictions, including federal public lands. Part of Sulphur Creek no longer has MUN as a beneficial use and does not technically need to meet these objectives.

Water quality objectives established by the CDPH (#1 above) have primary and secondary MCLs. Primary MCLs are legally enforceable objectives that apply to public water systems. Secondary MCLs are non-enforceable guidelines for contaminants (for example, iron) or water characteristics (taste, odor, color) in drinking that create unpleasant sensations for people.

In addition, the CDPH requests that operators of water systems with an MUN designation notify the CDPH, county governments, the CVRWQCB, and local citizens whenever the amounts of certain elements and compounds in drinking water exceed a "notification level" of concentration (#2 above). When the particular element or compound exceeds the higher "response level" concentration, CDPH recommends that the water management agency remove the water source exceeding the response level from service until the operator is able to reach concentrations below the response level. Only elements and compounds that do not already have an MCL have notification and response levels.

As part of its Cache Creek Watershed Mercury Program, the CVRWQCB has established a TMDL (#3 above) for methylmercury in all of Bear Creek watershed and a TMDL for total mercury for part of Sulphur Creek.

Appendix G contains specific data on the regulatory and advisory limits of each water contaminant of concern in Bear Creek watershed. Section 5.2 discusses the data and status of each water quality contaminant of concern in the watershed.

Criteria for Fecal Coliform Bacteria Affecting MUN Water Quality

Fecal coliform bacteria in water originate in the excrement of vertebrate animals. Presence of these bacteria in stream water with an MUN beneficial use indicates potential water contamination from other bacteria injurious to human health. The threshold criteria for using fecal coliform bacteria as an indicator of likely adverse impacts to water quality are set forth in the Basin Plan (as amended 2007). Table G.6 in Appendix G provides details of the objectives for these bacteria.

Narrative Criteria for MUN Water Quality Objectives

The CVRWQCB has adopted narrative criteria where specific characteristics of water quality do not have numeric criteria or where numeric criteria need further clarification. These narratives convey the context, conditions, and full intent of water quality protection efforts. Appendix H summarizes the desired objectives for the following components of surface water quality: bacteria, color, dissolved oxygen, fertilizers ("biostimulatory substances"), floating material, methylmercury, oil and grease, pH (an indicator of alkalinity or acidity), pesticides, radioactivity, sediment, settleable material, suspended material, tastes and odors, temperature, toxicity, and turbidity.

Some constituents such as methylmercury, sediment, and toxic amounts of some elements occur naturally in the watershed. However, land uses and management practices may be adding to natural background concentrations of these constituents in the Bear Creek and its tributaries.

Appendix H also details the water quality objectives for ground water applying to Bear Creek watershed. Narratives for ground water pertain principally to human impacts on domestic or municipal supplies (MUN) and consider the following water quality characteristics: bacteria, radioactivity, tastes and odors, and toxicity. Ground water from hot springs in Sulphur Creek subwatershed has naturally high concentrations of some chemical elements and odors from sulfur-containing gases. MUN is not a beneficial use for much of Sulphur Creek because the natural background concentrations in spring waters for mercury and other many constituents are high. No publicly available information on water quality for the Bear Valley Ground Water Basin is available at present.

Recommended Numeric Water Quality Objectives for AGR

The CVRWQCB uses guidelines from Ayers and Westcot (1985) to determine suitable concentrations for chemical elements in agricultural water. Of particular concern to agricultural customers for water from Bear Creek and Cache Creek Basin as whole, is the concentration of boron. Table G.5 in Appendix G gives the recommended objectives for boron in water destined for agricultural uses.

Recommended Numeric Water Quality Objectives for Freshwater Aquatic Life (SPWN, WARM, and WILD)

The California Toxics Rule of 2000, as amended, has established limits for toxic elements to protect human health and aquatic life in freshwater and saltwater environments. Objectives for some chemical elements are constant over all conditions; but most objectives for elements consist of a range of values that correspond to the hardness (alkalinity) of the water. These objectives are criteria to evaluate aquatic life in freshwater ecosystems. Table G.6 in Appendix G gives the criteria concentrations under the California Toxic Rule for key metals for freshwater aquatic ecosystems.

Antidegradation Policies

The antidegradation policies of Section 13000 of the Water Code and CVRWQCB Resolution 68-16 ("Statement of Policy with Respect to Maintaining High Quality Waters California") require that high-quality waters of the State shall be maintained "consistent with maximum benefit to the people of the State."

Implementing policies to prevent or minimize surface and ground water degradation is a high priority for the CVRWQCB. The Board applies these directives when considering issuing a construction permit or a waste discharge permit where the quality of surface and ground water may be impacted. Careful permitting usually prevents pollution and is more cost-effective compared to cleanup costs. At present, pollutant sources in Bear Creek watershed such as abandoned mines, roads, and grazing are not operating under permits (J. Cooke, CVRWQCB, pers. comm.).

5.2 Water Quality Data

This section summarizes data from multiple sources on regulated water contaminants found in Bear Creek watershed. Most pollutants found in Bear Creek watershed originate from chemical elements, ions, compounds, or sediments occurring naturally in the watershed.

Contaminant materials imported into the watershed from industrial sources are thought to be insignificant except possibly mercury gas and ions deposited onto the watershed from the atmosphere.

This assessment does not take up industrial organic compounds. Data collected by the California Department of Water Resources in 2001 for a sample of organic compounds showed that the compounds did not exceed State of California water quality objectives in the watershed. No industries in the watershed are manufacturing contaminants such as organic solvents and pesticides that could contaminant watershed streams. However, more data need to be collected to verify the little information currently available.

Most data on concentrations of regulated constituents of water pertain to hot springs in Sulphur Creek watershed and the stream water in Sulphur Creek itself. Few data come from lower Bear Creek, from just above the confluence of Sulphur Creek to the confluence of Bear Creek with the main stem of Cache Creek. Even fewer data are available for Upper Bear Creek and Mill Creek. Goff et al. (2001) and Suchanek et al. (2002) provide the most extensive examinations of the chemical constituents of the thermal springs. Suchanek et al. (2002), Cooke and Morris (2005), and Cooke and Stanish (2007) also provide detailed information along the length of lower Sulphur Creek between Elgin Mine and the mouth of Sulphur Creek and parts of Bear Creek.

Work done on saline cold springs in Bear Valley is scant and dates from the 1970s or earlier; past data do not furnish a reliable basis to assess water quality in these poorly known springs. Ground water data concerning contaminants is lacking.

Stream Data for Mercury and Methylmercury

High concentrations of mercury and methyl mercury are the major concern for watershed management in Bear Creek watershed. Appendix I provides background to understanding the chemical and biological significance of mercury in Bear Creek watershed and impacts mercury on people and wildlife.

The CalFed Bay/Delta Program has worked to improve California water supplies and the ecological function of San Francisco Bay, the Sacramento-San Joaquin Delta, and their watersheds. The Program has sought to clarify the sources, movement, and impacts of mercury to the Bay and Delta from river networks around the Central Valley, including Bear Creek watershed. CalFed research along with additional research by scientists at the US Department of Energy, US Geological Survey, and the University of California at Davis provide the basis for evaluating mercury and methylmercury in Bear Creek watershed.

Foe and Croyle (1998) found that Cache Creek Basin, to which Bear Creek belongs, contributes as much as half the yearly load of mercury to the Sacramento River. Studies of mercury in Bear Creek watershed streams and springs have focused on Sulphur Creek subwatershed, which produces the most total mercury in the watershed.

Concentrations of total mercury and the methylmercury at a stream site do not necessarily correlate well with one another (Slotton et al. 2004). For example, in the north end of Bear Creek watershed, the amount of total mercury is low compared to other monitored areas in the watershed, but the amount of methylmercury is mid-range among reported concentrations from across the watershed.

Table 5.2 displays the most current estimates of mercury and methylmercury production by source in Bear Creek watershed.

Table 5.2 – Estimated annual budgets of mercury and methylmercury production by source in Bear Creek watershed

Sources	**All Bear Creek Watershed**		**Only Sulphur Creek Subwatershed**	
	Total Mercury	**Methylmercury**	**Total Mercury**	**Methylmercury**
Natural Sorces	**kg per year**	**kg per year from all sources**	**kg per year**	**kg per year from all sources**
Soil Erosion	4.9 – 75.9		1.2	
Geothermal Springs	1.4		1.4	
Abandoned Mines	9.9 – 32.7		9.2	
Grazing Erosion	?		?	
Road Erosion	?		?	
Mixed Sources	kg per year	0.021*	kg per year	0.008
Atmospheric Deposition	4.6		0.03	
Volatilization to Atmosphere	1.9 – 43.6		1.9 – 12.3	

Sources: Churchill and Clinkenbeard (2003), Gustin (2003), Cooke and Stanish (2007)

*Bear Creek at Highway 20

Note: Not all mercury that volatilizes into the atmosphere from Bear Creek watershed is exported to other watersheds; some, as yet unknown, percentage of the mercury precipitates back on the ground or vegetation in the watershed.

Unfiltered Total Mercury

The amount of total mercury in (unfiltered) water leaving Bear Creek watershed fluctuates, often greatly, from year to year. Rough estimates of the annual mercury load exported from Bear Creek into Cache Creek are 3.6 kg (2000) and 2.0 kg (2001); and for Sulphur Creek into Bear Creek, 2.7 kg (2000) and 1.6 kg (2001) (Domagalski et al. 2004b). Over the length of Sulphur Creek from Elgin Mine to the confluence with Bear Creek, the total mercury load increases five fold, yielding a load larger than the total mercury loads from either Clear Lake or Indian Valley Reservoir (Domagalski et al. 2004c) elsewhere in Cache Creek Basin.

A midwinter annual spike in the total mercury concentration was apparent in all Bear Creek watershed stream sites monitored in the study. Maximum values recorded for the midwinter spike at the upstream Bear Creek site (north of the Sulphur Creek confluence) were relatively small: 5.4 and 3.8 ng (nanograms) liter^{-1} for 2000 and 2001 respectively. Mid-winter concentrations of mercury in Sulphur Creek were two to three orders of magnitude greater than those upper Bear Creek. Near the confluence of Bear Creek with Cache Creek, concentrations of total mercury in mid-winter ranged from one-half to one-tenth of the concentrations registered at the same time upstream in Sulphur Creek. Nonetheless, Bear Creek had the second highest concentrations of total mercury found in the Cache Creek Basin and the largest amount of total mercury annually directly entering Cache Creek (Domagalski et al. 2004a).

Bosworth and Morris (2009) investigated Bear Creek and ten of its tributaries to provide a first appraisal of where high concentrations of mercury occur in sediment deposits downstream of abandoned mines. Sulphur Creek had the highest concentrations of mercury sediment across all sediment particle sizes, with levels greater than 0.4 ppm, the level designated by the Regional Board as mercury-enriched. The unnamed second tributary on Bear Creek north of the confluence of Sulphur Creek (Bosworth and Morris op. cit.) and the tributaries and cold springs east of the Rathburn-Petray mercury mine complex (Slowey and Rytuba 2008) are the only other tributaries having concentrations significantly above the enriched-mercury threshold. The 32 sediment deposition areas along Bear Creek from the south end of Bear Valley Road to the mouth of Bear Creek are significant as these sites collectively contain an estimated 91 kg of total mercury. Controlling the movement of these deposited sediments further downstream may be a critical management action.

Methylmercury

In the low rainfall years of 2000 and 2001, Domagalski et al. (2004b) found that the second highest concentrations of methylmercury in the entire Cache Creek Basin came from Sulphur Creek subwatershed.

The Basin Plan (2007 as amended) found that 21.1 g yr^{-1} methylmercury come from Bear Creek north of State Highway 20. This amount is 17.3 percent of the methylmercury produced in the entire Cache Creek Basin. Out of that amount, 8.0 g yr^{-1} methylmercury comes from Sulphur Creek alone (6.6 percent of the Cache Creek Basin total).

Peaks in methylmercury concentrations from Bear Creek watershed streams are bimodal (Domagalski et al. 2004a). The highest concentrations occur in summer months (June through August) when water volume is low, with a second, smaller peak in mid-winter when the erosional force of water mobilizes soils and mine sediments with high mercury concentrations.

Other Chemical Elements Potentially Affecting MUN Water Quality

Available data indicate that the following elements regulated under primary or secondary MCLs for drinking water do not occur at concentrations above established MCLs in Bear Creek or Sulphur Creek: beryllium, cadmium, chromium, copper, nickel, selenium, silver, strontium, thallium, vanadium, and zinc. Table 5.3 indicates the chemical elements and their locations in the watershed where their respective concentrations exceed MCLs for drinking water. Data from Mill Creek and upper Bear Creek are lacking. These concentrations would require water treatment for the elements before the water would be available for MUN.

Table 5.3 – Overview of key locations where chemical elements exceed respective MCLs for drinking water

Element	Sulphur Creek Thermal Springs	Water Flow from Abandoned Mine Sites	Mouth of Sulphur Creek	Lower Bear Creek
Aluminum	yes	yes	yes	no
Antimony	yes	yes	yes	no
Arsenic	yes	yes	yes	no
Barium	yes	yes	n.d.	n.d.
Chloride*	yes	yes	yes	yes
Fluoride	yes	yes	n.d.	n.d.
Iron*	yes	yes	yes	yes
Lead	yes	no	no	no
Manganese	yes	yes	yes	no
Mercury	yes	Yes	yes	no
Nitrite	yes	n.d.	n.d.	no
Sulfate	yes	n.d.	n.d.	no

Sources: Goff et al. (2001), Suchanek et al. (2002), Cooke and Morris (2005), California Department of Water Resources (2001 – 2006)

n.d. = no data

*elements specified by secondary MCLs, non-enforceable guidelines for unpleasant but non-toxic water quality

In many cases the concentrations of key chemical elements such as antimony and arsenic become sufficiently diluted by the time water exits from Bear Creek watershed so that the concentration of an element no longer exceeds its respective MCL. A key ecological service of the main stem of Bear Creek may be to dilute water Sulphur Creek and make water from the creek more beneficial downstream than if Sulphur Creek were to drain directly into Cache Creek. Maintaining the dilution capacity of Bear Creek is, therefore, an important to overall watershed management.

Further information on the significance of the elements and ions listed in Table 5.3 for water quality in the watershed appears in Appendix J.

Chemical Elements Affecting Water Quality for AGR

Agricultural objectives for water quality are less strict than those for municipal and domestic water supplies. Based on data from Goff et al. (2001) from 1989 to 1995 and on data from Suchanek et al (2002) from February 2001, the following table relates the data to the objectives for agricultural water, to detect if limitations are present for Bear Creek water used for agricultural water in Bear Creek watershed and downstream in Yolo County. Table 5.4 shows which elements exceed the agricultural water objectives in Sulphur Creek and in lower Bear Creek. Currently, no data exist for upper Bear Creek and Mill Creek.

Table 5.4 - Status of chemical elements and ions exceeding agricultural water quality objectives

Chemical Element or Ion	Sulphur Creek	Mouth of Bear Creek
Aluminum	?	no
Arsenic	no	no
Boron	yes	yes
Cadmium	no	no
Chloride	yes	yes
Chromium (VI)	no	no
Cobalt	no	no
Copper	no	no
Fluoride	yes	n.d.
Iron	?	no
Lead	no	no
Manganese	yes	no
Molybdemum	no	n.d.
Nickel	no	no
Selenium	?	no
Sodium	yes	yes
Vanadium	no	n.d.
Zinc	no	no
pH	yes	yes

Source: DWR readings 2001-2006 near the mouth of Bear Creek
n.d. = no data
? = uncertain

Boron

Naturally occurring boron in drinking water usually does not pose a health risk to people. The greater concern is for agriculture. Boron is an essential plant micronutrient that quickly becomes toxic to plants at concentrations slightly above nutritional requirements. High concentrations of boron in irrigation water and farm soil adversely affect soil fertility and crop yields.

Most boron found in the Cache Creek Basin originates in Bear Creek watershed, and, more specifically, in Sulphur Creek subwatershed. Boron concentrations in Sulphur Creek thermal springs are fairly even throughout the year and exceed 225 mg $liter^{-1}$. Thompson et al. (1978) also recorded high boron levels in a saline cold spring in Bear Valley. Boron concentrations in Sulphur Creek seasonally exceed 100 mg $liter^{-1}$ (Goff et al. 2001). These concentrations are higher than the recommended threshold concentration of 10 mg $liter^{-1}$ (response level) to close a drinking water supply and the 0.7 mg $liter^{-1}$ maximum for agricultural uses.

The Yolo County Flood Control and Water Conservation District has monitored boron concentrations since the late 1930's in the lower Bear Creek watershed. Dissolved boron collected there averaged 13.9 mg $liter^{-1}$ in 250 samples collected between 1988 and 2006 (Stevenson 2007). Data collected by the US Geological Survey from 1968 to 1978 found concentrations in lower Bear Creek between 2.1 to 21.0 mg $liter^{-1}$ with no apparent seasonal trend.

The District uses Bear Creek water during its irrigation season, which usually extends from April through October. This period coincides with the time of annual lowest flows from Bear Creek when Bear Creek supplies on average 2.8 percent of the total Cache Creek flow diverted by the District for irrigation (J. Weigand and M. Stevenson, pers. comm.). The much larger water contributions from Clear Lake and Indian Valley Reservoir to the main stem of Cache Creek effectively dilute the high summer concentration of boron in the small water volume coming from the Bear Creek. Water treatment to dilute or remove boron may not be cost effective or necessary, as long as the water flow in Cache Creek upstream of the confluence of Cache Creek and Bear Creek continues to dilute boron from Bear Creek before water is diverted for irrigation in Yolo County (M. Stevenson, pers. comm.).

Other Constituents

Naturally occurring chloride and sodium ions remain at concentrations that could be detrimental to agricultural uses when Bear Creek enters Cache Creek. Given the small amount of water from Bear Creek used for irrigation and the corresponding dilution effect with water from the main stem of Cache Creek, the impact to agriculture is likely not significant.

pH (Concentration of Hydrogen Ions in Water) for AGR

The concentration of hydrogen ions in water is expressed as pH. Water quality objectives for agriculture recommend that pH in water must range between 6.5 and 8.4. pH values at sites in Sulphur Creek approach or exceed the upper range limit, indicating alkaline water.

Data for pH from USGS data station 11451720 collected between 1969 and 1978 near the mouth of Bear Creek had values greater than 8.4 on 18 out of 112 days of record on dates at all times of year. By comparison, data for pH from the nearby USGS data station 1141715 on

Bear Creek showed that all ten days of record for 2000 (the only year for which data are available) exceeded pH 8.4.

Table 5.5 – Physical properties of Sulphur Creek water samples from 2001 02 23 and three samples from lower Bear Creek in the same period

Water Sources	Temp °C	Field pH	Electro-conductivity (µS at field temp)	Specific Conductance (µS at 25°C)	Redox Potential (volts)
In-Stream Water from Sulphur Creek					
Sulphur Creek INDEX STATION • SUL-540	7.0	8.14	1.41	2.15	111.6
Sulphur Creek below Wilbur Springs Resort • SCM-600	7.2	8.09	1.38	2.09	-37.4
Sulphur Creek above Wilbur Springs Resort • SCM-601	9.5	7.98	0.93	1.32	-34.8
Side Stream to Sulfur Creek • SCM-602	8.2	8.72	0.30	0.44	-183.8
Sulphur Creek above "Jones Fountain" geyser • SCM-604	9.8	8.40	0.86	1.21	-185.1
Sulphur Creek above 605/606 input • SCM-607	9.0	8.39	0.80	1.12	-143.5
Sulphur Creek above all mines except Elgin • SCM-608	8.7	8.38	0.68	0.97	-86.4
Creeks Flowing into Sulphur Creek					
Creek from Wide Awake Mine • SCM-605	16.0	7.97	7.18	8.67	-306.6
Sulfurous creek by Cherry Hill • SCM-606	10.0	8.46	1.39	1.94	-160.1
In-Stream Water from Lower Bear Creek					
USGS Station 1141715 2001 02 20	--	8.50	--	--	--
USGS Station 1141715 2001 02 27	--	8.80	--	--	--
DWR Station A1825000 2001 03 01	7.5	8.30	--	--	--

Sources: Suchanek et al. (2002), USGS Station Data, and CA Department of Water Resource Water Data Library

Chemical Elements Affecting Water Quality for Aquatic Life (SPWN, WARM, WILD)

Data collected at the California Department of Water Resources gage station in lower Bear Creek showed that none of the critical chemical elements included in the California Toxic Rule for aquatic life exceeded the Rule limits. The high alkalinity of Bear Creek stream water raises the not-to-exceed critical threshold amounts for many chemical elements well above concentrations found in Bear Creek at monitoring station site A1825000.

Bacteria Affecting Water Quality for MUN and REC1

No sampling of ground water in Bear Creek watershed has been undertaken to determine whether coliform bacteria are less than 2.2 per 100 milliters, the count acceptable for any seven-day sampling period (Basin Plan 2007).

No data are available to determine whether fecal colifornm bacteria counts in Bear Creek and its tributaries are within the State of California water quality objectives for contact recreation given in Appendix H. Fecal coliform bacteria are likely to be high in Bear Creek on account of livestock grazing (J. Alderson, pers. comm.).

Oxygen Dissolved in Water (SPWN, WARM)

Schwarzbach et al. (2001) found that the dissolved oxygen concentration in Sulphur Creek in October 1998 was 7.63 mg $liter^{-1}$ or 72 percent of the concentration found nearby in Bear Creek. The percent value from Sulphur Creek was the lowest of recorded values in the Cache Creek Basin at the same time. Near the mouth of Bear Creek, readings of dissolved oxygen ranged from 7.9 mg $liter^{-1}$ (June 2005) up to 13.7 mg $liter^{-1}$ (March 2005) at the Department of Water Resources monitoring station. The values recorded to date exceed the minimum amounts set by the CVRWQCB for both SPWN (7.0 mg $liter^{-1}$) and WARM (5.0 mg $liter^{-1}$).

Sediment

The concentration of total mercury in suspended sediments in Sulphur Creek (Wilbur Springs) was about ten times greater (25 micrograms per gram dry weight of sediment) compared to concentrations near the mouth of Bear Creek (Domagalski et al. 2004b). The Wilbur Springs site and the USGS gage on Sulphur Creek had the highest instantaneous mercury loads (averaging > 1000 nanograms per liter) recorded at stream sites in Cache Creek Basin (Cooke and Morris 2005, Domagalski et al. 2004b). Bosworth and Morris (2009) found, however, that individual sediment deposition areas along the lower Bear Creek contained up to 19 kg of total mercury.

5.3 Aquatic Biological Data

This section describes existing biological data for Bear Creek watershed in regard to aquatic species exposed to water contaminants, especially methylmercury. These species are indicators, or “bio-sentinels”, to alert people to the condition of the stream environment, and in particular water quality. This assessment examines three categories of aquatic species: benthic macroinvertebrates, fishes, and foothill yellow-legged frog.

Existing data are few but indicate the spatial and temporal distribution of methylmercury in watershed creeks and among species at different trophic levels in the aquatic food web. Total mercury (including methylmercury) concentrates (“bioaccumulates”) as the trophic level of predation increases. Therefore, the predators in the highest trophic levels (fishes, birds, mammals) have the highest mercury concentrations (Domagalski et al. 2004c). Recently, Hothem et al. (2008) have proposed tracking the pathway of aquatic methylmercury with terrestrial indicator species as well, based on their studies of cliff swallow (*Petrochelidon pyrrhonota*) populations in Bear Creek watershed and elsewhere in the Cache Creek Basin.

Benthic Macroinvertebrates

Aquatic biologists and geochemists sample many kinds of aquatic insect and worm species (benthic macroinvertebrates) that live on the bottom of a stream (the benthos). These animals are indicators to track the presence and dispersion pattern of water contaminants. Three studies for regional sampling of benthic macroinvertebrates in the Cache Creek Basin have included data from Bear Creek (Schwarzbach et al. 2001; Slotten et al. 1997, 2004).

Benthic macroinvertebrates indicate relative levels of methylmercury in streams because invertebrates accumulate methylmercury directly from sediment and from predation on other invertebrates. Methylmercury originates in the stream benthos where an anaerobic (oxygen-less) environment creates a favorable habitat for bacteria to transform mercury into methylmercury. The levels of methylmercury detected in these organisms are not direct predictors of mercury toxicity to people or wildlife, however.

Macroinvertebrate surveys showed that the highest concentrations of total mercury in macroinvertebrates came from Sulphur Creek. There, concentrations ranged from 5.0 to 8.7 ppm dry weight. Concentrations of total mercury in damselfly larvae were 25 times higher at Sulphur Creek than in Bear Creek above its confluence with Sulphur Creek (Schwarzbach et al. 2001).

Table 5.6 – Concentrations of total mercury (THg) and methylmercury (MeHg) benthic insect larvae from Bear Creek watershed

Sites from north to south	Anisoptera Dragonflies		Megaloptera dobsonflies		Trichoptera caddisflies	
	THg	MeHg	THg	MeHg	THg	MeHg
	parts per million, dry weight					
Mill Ck @ Brim Rd	0.035	0.032	--	--	0.036	0.033
Sulphur Ck @ Wilbur Spr Rd	1.349	0.180	--	--	0.348	0.035
Bear Ck below Sulphur Ck	0.077	0.058	0.495	--	0.103	0.062
Bear Ck @ Hamilton Cyn	0.036	0.030	--	--	0.026	0.017
Bear Ck @ Highway 20	0.433	0.259	0.245	0.168	0.429	0.176
Bear Ck @ 15-37	0.235	0.159	0.204	0.151	0.534	0.255

Source: Schwarzbach et al. 2001

Table 5.7 – Concentrations of total mercury (THg) and methylmercury (MeHg) in benthic insect larvae

Sites from north to south	**Anisoptera dragonflies**		**Hemiptera true bugs**		**Odonata dragonflies and damselflies**		**Trichoptera caddisflies**	
	THg	**MeHg**	**THg**	**MeHg**	**THg**	**MeHg**	**THg**	**MeHg**
	micrograms per gram wet body weight							
Bear Creek in Bear Valley	0.031	0.030	0.041	0.033	n.d.	n.d.	0.034	0.033
Sulphur Creek	n.d.	n.d.	0.416	0.139	1.987	0.290	n.d.	n.d.
Bear Creek below Sulphur Ck confluence	0.343	0.286	0.465	0.306	0.168	0.138	0.425	0.359
Bear Creek near Cache Ck confluence	n.d.	n.d.	n.d.	n.d.	n.d.	n.d.	*0.250*	*0.074*

Source: Slotton et al. 2004, collection dates: May 8-9, 2000 for all insect larvae except February 15, 2001 for larvae in Bear Creek near its confluence with Cache Creek

The total mercury concentration in some insect larvae groups from Sulphur Creek subwatershed is at least an order of magnitude higher than at the north end of Bear Valley (Mill Creek at Brim Road) (Schwarzbach et al. 2001). But, the benthic environment most conducive for mercury methylation is in Bear Creek below the confluence with Sulphur Creek (Slotton et al. 2004). The stream environment in Bear Creek near the bridge at Highway 20 may furnish, at least seasonally, better conditions for bacterial mercury methylation and subsequent methylmercury uptake by invertebrates as evidenced by the high ratio of methylmercury to total mercury found in invertebrates there.

Methylmercury concentrations in invertebrates at the lower Bear Creek site peaked in mid-summer (June to August), with a smaller February peak. In July 2001, methylmercury values reached nearly 1.0 microgram per gram wet body weight in Bear Creek invertebrates (Slotten et al. 2004). Slotten et al. (2004) also examined a site in Bear Valley above the confluence with Sulphur Creek where methylmercury concentrations in invertebrates ranged just up to 0.160 micrograms per gram wet body weight during the mid-summer peak. They propose that the winter methylmercury peak in invertebrates results from high storm flows that mobilize methylmercury-enriched bed material. Summer peaks in invertebrate methylmercury, on the other hand, point to sites of high methymercury uptake, linked to locally high rates of bacterial mercury methylation during low flows where stream sediment is less mobile and warm creek water is oxygen-deficient.

Away from the lower main stem of Bear Creek, larvae from tributaries in Lynch Canyon, Thomson Canyon, and the unnamed canyon closest to the mouth of Bear Creek had concentrations of methymercury about ten percent of concentrations found in Bear Creek itself.

Both Schwarbach et al. (2001) and Slotten et al. (2004) found a high methylmercury to total mercury ratio in Mill and Bear creeks in Bear Valley, indicating a high methylation rate for a comparatively low concentration of total mercury in these streams. One explanation for the high methylation rate at these locations is the extensive presence of algal mats that create anaerobic sites for methylating bacteria.

Fish in Bear Creek

Fish are critical to water quality management in Bear Creek because the watershed TMDL established for methylmercury requires monitoring it in fish tissues to ascertain whether the watershed is attaining goals set by the CVRWQCB to reduce methylmercury. Several factors determine the amounts of total mercury and methylmercury that fishes accumulate: the species of fish (and its trophic level), mercury concentrations in stream sediment, and the rate of bacterial methylation, which in turn depends on the availability of sulfate, iron, bacterial nutrients, and organic matter. Different stretches of Bear Creek have fish with differing concentrations of mercury. Bear Creek has fish with higher concentrations of total mercury and methymercury below the confluence with Sulphur Creek (mid-Bear Creek) than in Bear Valley above the confluence.

For comparable size classes, different fish species have differing mercury levels as a function of their diets. Carnivorous fishes such as the Sacramento pikeminnow (*Ptycholeilus grandis*) prey on other fish and generally have higher levels of mercury than detritivore (eating organic debris) fishes such as the Sacramento sucker (*Catostomus occidentalis*). Therefore, different TMDL amounts of methylmercury apply to different fishes depending on their diets and their position as predators (trophic level) in the food chain.

Fish Consumption Advisory

OEHHA issued a health advisory and consumption guidelines for fish and shellfish from Bear Creek and its tributaries (Gassel et al. 2005) on January 20, 2005. The advisory states that no one should eat any fish or shellfish from Bear Creek watershed because of the risk of damage to people's central nervous systems from methylmercury toxicity. Risks are highest for young children, particularly nursing children, and unborn children whose mothers eat mercury-laden fish. The health advisory responds to findings that average methylmercury concentrations found in Sacramento pikeminnow and Sacramento sucker in Bear Creek, exceeded OEHHA's standards for health safety.

Total Mercury and Methylmercury in Fish

Both Schwarzbach et al. (2001) and Slotten et al. (2004) found that fish sampled from Bear Creek had markedly higher concentrations of total mercury and methylmercury than elsewhere in the Cache Creek Basin. For example, total mercury concentrations in fish sampled at a mid-Bear Creek monitoring site were greater than concentrations found in fish from the main stem Cache Creek below Bear Creek: about seven times greater in Sacramento pikeminnow and nine times greater for Sacramento sucker. All fish at the mid-Bear Creek site had mercury levels sixteen and eighteen times greater respectively than at the Clear Lake outflow and in the North Fork Cache Creek. Muscle tissue in California roach (*Hesperoleucus symmetricus*) weighing less than 0.6 kg from a Bear Creek site 6.25 miles downstream of the Sulfur Creek confluence had methylmercury concentrations up to 0.95 micrograms per gram fish wet weight. This amount is more than three times greater than the US EPA Recommended Fish Tissue Criterion for methylmercury in fish at 0.30 micrograms of methylmercury per gram fish wet weight (Slotten et al. 2004).

Within Bear Creek itself, total mercury concentrations in fish in upper Bear Creek (Bear Valley) averaged about a third or less of the total mercury concentrations in fish from mid-Bear Creek below Sulphur Creek (Tables 5.8 and 5.9).

Both carnivore Sacramento pikeminnows and detritivore Sacramento suckers had higher than expected methylmercury levels at an upper Bear Creek site, by comparison. This finding corresponded to high ratio of methylmercury to total mercury concentrations in upper Bear Creek invertebrates.

Table 5.8 – Average total mercury concentrations in ppm wet weight in three fish species from Bear Creek, 1997

Location	Sacramento Pikeminnow	Sacramento Sucker	California Roach
Bear Ck above Sulphur Ck	0.577 (n=10)	0.125 (n=11)	0.363 (n=10)
Bear Ck below Sulphur Ck	0.337 (n=3)	0.351 (n=8)	0.418 (n=9)
Bear Ck at Highway 20	1.655 (n=1)	1.047 (n=6)	0.872 (n=10)

Schwarzbach et al. (2001), Appendix C

Table 5.9 – Data on total mercury concentrations in ppm wet weight in two fish species from Bear Creek, 2000

Species	Average THg (ppm)*	Mean Fork Length (mm)	Maximum Mercury (ppm)		Sample Size
			Upper Bear Creek	Middle Bear Creek	
Sacramento Pikeminnow	2.20 (1.23 – 3.17)	273	1.15	6.43	15
Sacramento Sucker	0.62 (0.33 – 0.90)	220	0.43	1.65	17

Source: Gassel et al. (2005)
*numbers in parentheses comprise the range of values for 95 percent of all data for that species

Amphibians

Until recently, researchers have not monitored amphibians, and in particular frogs, for mercury. Hothem et al. (in press) sampled total mercury concentrations in three frog species in Bear Creek: foothill yellow-legged frogs (*Rana boylii*), bullfrogs (*Lithobates catesbeianus*), and Pacific treefrog (*Pseudacris regilla*).

Other chemical constituents of Bear Creek water may affect frog populations. High concentrations of boron and chloride in Bear Creek may contribute the absence of California red-legged frogs (*Rana draytonii*) in watershed, for example (letter from Dr. K. Shawn Smallwood to Cecilia Brown, US Fish and Wildlife Service, Sacramento, dated July 18, 2000).

Invasive Aquatic and Riparian Species

Invasive aquatic and riparian species are threatening native vegetation, aquatic species biodiversity, and hydrologic function in Bear Creek and its tributaries. In the *Report of Independent Science Advisors for the Yolo County Natural Community Conservation Plan*, Spencer et al. (2006, p. 43) state that "conservation of Bear Creek watershed and restoration of riparian vegetation there should be a high priority". Enhancing and restoring riparian habitat is critical for many rare riparian species of concern and for creating habitat for large game animals, protecting riparian forests, and stabilizing stream buffers in Bear Creek watershed.

One benefit of riparian tree and shrub cover is the effect of shade on moderating stream temperatures. Maintaining cooler water temperatures in Bear Creek, particularly during May and June when exotic fish generally reproduce, may also reduce non-native fish invasions. Many exotic species, particularly bass (*Micropterus* spp.), have difficulty reproducing in cold water conditions. Restoration and maintenance of riparian vegetation along Bear Creek would help to reduce local stream temperatures in Bear Creek during warm months and favor better reproduction of native fish species.

The California Aquatic Invasive Species Management Plan (Invasive Species Program 2008) has identified 48 critically important non-native invasive aquatic species. Control of these species in the watershed would contribute to reestablishing native aquatic and riparian species. Eight of these species are definitely known to occur in the watershed and four others are likely to occur.

Table 5.10 – Principal aquatic invasive species known or likely to occur in Bear Creek watershed

Species **Scientific Name** **Family Name**	**Locations in or near Bear Creek Watershed**	**Eradication Treatments to Date**
Vascular Plants		
Perennial pepperweed *Lepidium latifolium* Brassicaceae	Leesville Road, Bear Creek Ranch along Bear Creek	Grazing with goats

Species **Scientific Name** **Family Name**	**Locations in or near Bear Creek Watershed**	**Eradication Treatments to Date**
Parrot feather milfoil *Myriophyllum aquaticum* Haloragaceae	Likely to encounter but no known detections	None
Eurasian milfoil *Myriophyllum spicatum* Haloragaceae	Likely to encounter but no known detections	None
Small-flowered tamarisk *Tamarix parviflora* Tamariceae	Sulphur Creek, Bear Creek Ranch, Bear Valley Road	Herbicide treatment; the tamarisk defoliator *Diorhabda elongata* may move into Bear Creek
Waterthyme (Hydrilla) *Hydrilla verticillata* Hydrocharitaceae	Possible but no known detections	None
Giant reed (Arundo) *Arundo donax* Poaceae	Sulphur Creek, along Highway 20 east of Highway 16	Eradication has been initiated
Curly pondweed *Potamogeton crispus* Potamogetonaceae	Leesville Road, Bear Creek Ranch	None
Invertebrate Animals		
New Zealand mudsnail *Potamopyrgus antipodarum* Hydrobiidae	Not yet recorded but found nearby in the Putah Creek and Russian River watersheds	None
Vertebrate Animals		
Green sunfish *Lepomis cyanellus* Centrachidae	occurs in lower Bear Creek	None
Bluegill *Lepomis macrochirus* Centrachidae	occurs in lower Bear Creek	None
Smallmouth bass *Micropterus dolomieui* Centrachidae	occurs in lower Bear Creek	None
Bullfrog *Lithobates catesbeianus* Ranidae	occurs in lower Bear Creek	None

Sources: Consortium of California Herbaria, Marchetti et al. (2004), Montana State University New Zealand Mudsnail Project on-line, G. Mangan, pers. comm. (2006)

Stream Survey Data

Stream surveys of channel types, bedloads, substrates, stream bank stability, slump potential, large woody debris, and riparian vegetation have not occurred uniformly across the watershed. In 1999, the BLM Ukiah Field Office conducted an aerial survey of the streams on remote public lands at the north end of the watershed using the BLM Proper Functioning Condition protocols for riparian areas (Prichard 1998, 1999). All streams in Mill Creek subwatershed and in the subwatersheds draining east from Walker Ridge were found to be in proper functioning condition based on hydrology, vegetation, and sediment indicators. Streams south of Highway 20 were not surveyed at the time because the lands were in private ownership at the time.

5.4 Sources of Water Contaminants

High concentrations of contaminants in Bear Creek watershed stem almost entirely from naturally occurring materials in the watershed. However, land uses have increased the conversion of contaminants to more toxic chemicals and have spread contaminants in the watershed and further downstream.

Contaminants in the watershed are considered “non-point” sources rather than “point” sources because they accumulate in stream water from multiple, diffuse sources across the watershed rather than from a single identifiable source point in the landscape. Non-point source pollution usually involves rainfall striking the ground, running overland, infiltrating through the soil, or eroding stream banks. Contaminants may then become part of aquatic environments, precipitate to solids become part of soils or streambeds, or reach ground water.

This chapter section takes up the natural sources of water contaminants and, then, the sources of contamination from current and past land uses in Bear Creek watershed.

Hydrothermal Springs

White et al. (1973) first identified the role of hydrothermal springs in conveying mercury from deep in the earth up to surface water in Sulphur Creek subwatershed. Peters et al (1993) and Sherlock (2005) have characterized properties of hydrothermal spring waters in the Sulphur Creek area as follows:

- hot (> 50°C) water originating from deeply-buried ancient seawater similar to the subsurface water found in the Arbuckle oil and gas field in the Sacramento Valley
- high concentrations of mercury, antimony, and arsenic
- highly alkaline (pH > 7.0)
- concentrations of chloride (Cl^-) lower than in sea water but abnormally high for hydrothermal springs
- concentrations of chloride greater than the concentrations of sulfate (SO_4^{2-}) but both present in high concentrations to promote mercury methylation
- high concentrations of hydrogen sulfide (H_2S), ammonia (NH_3), and boron originating in deeply buried marine sediments.

Table 5.11 lists the major springs near Sulphur Creek and summarizes their chemical elements and ions that may impact water quality downstream. More detailed data on the variability in readings from the uniform data collection efforts by Goff et al. (2001) and Suchanek et al. (2002) are available in Appendix K.

Table 5.11 – Springs and associated elements and ions possibly affecting water quality

Spring Sources	**Elements and Ions with concentrations that may affect water quality down stream in Bear Creek**
Wilbur Spring Don White's	mercury, barium, boron, chloride, fluoride, nitrite, sulfate
Wilbur Spring, Main	mercury, arsenic, barium, boron, chloride, fluoride, manganese
Jones Fountain of Life	mercury, arsenic, barium, boron, chloride, fluoride, iron, lead, manganese
Blanck Spring	mercury, arsenic, barium boron, chloride, fluoride, nitrate, sulfate
Elbow Spring	mercury, barium, boron, chloride, fluoride, manganese, nitrate, sulfate
Elgin Spring Main	mercury, barium, boron, chloride, fluoride, iron
Elgin Spring Orange Tub	barium, boron, chloride, fluoride, sulfate
Unnamed Hot Spring	mercury, barium, boron, chloride, fluoride

Source: Goff et al. (2001), Suchanek et al. (2002)

Table 5.12 – Hydrothermal spring flows and their mercury loads

Hydrothermal Springs	**Flow cfs**	**Average Mercury Load (mg liter^{-1})**	**Annual Geothermal Mercury Load (lbs)**
Wilbur Spring Main	0.047	5.556	0.51
Jones Fountain of Life	0.012	26.642	0.63
Blanck Spring	0.008	6.900	0.11
Elbow Spring	0.0003	61.000	0.04
Elgin Spring Main	0.015	11.000	0.32
Total			**1.61**

Source: Goff et al. (2001)

Of the major springs in Sulphur Creek subwatershed, Jones Fountain of Life and the main Wilbur Spring are the principal known suppliers of mercury to Sulphur Creek. Other spring sources may be significant but no data are available. The CVRWQCB does not intend to manage natural sources of mercury coming from hydrothermal springs as these sources are natural (or background) features of the watershed.

Cold Mineral Springs

The contribution of cold mineral springs in Bear Creek watershed to mercury loads is less well understood. This category of springs occurs outside Sulphur Creek subwatershed, and studies of these springs thus far have short-term and infrequent.

Slowey and Rytuba (2008) report on cold springs associated with an alluvial fan at the southwest corner of the Bear Valley floor. These springs along the newly discovered Bear Fault have naturally high concentrations of mercury in water dissolved by means of reactions with sulfate ions or with organic acids to form methylmercury. Water from these spring sources shares features of the hydrothermal springs in Sulphur Creek subwatershed: high amounts of chloride (salinity), boron, alkalinity (high pH), and total mercury. However, water temperatures are about 25°C cooler during the early summer compared to hydrothermal springs and drop to 10°C during winter months. The springs often go dry by the end of the summer if water from rainfall stored in the ground water is insufficient (J. Rytuba and J. Weigand, field obs., October 2007). Dry-season total mercury concentrations from spring water samples along the Bear Fault ranged from 0.0076 to 0.690 mg $liter^{-1}$. Fluctuations in concentrations of total mercury and methylmercury depend on the availability of cinnabar (the source of mercury), carbonate, dissolved organic acids, and the amount of rainwater mixing with the connate spring water to dilute total mercury and methylmercury.

No estimate is available yet of an annual background amount of total mercury and methylmercury flowing naturally from saline cold springs on or just above the floor of Bear Valley. Boron, chloride and sulfate ions are the only other potential water contaminants known from these cold spring sites.

Stream Bank Erosion

Flowing water erodes stream banks and streambeds, especially during powerful winter storms. The erosion impact of these high-velocity flows depends as well on the stability of the bank material. For instance, sand will erode more easily than gravel or silt. Stream bank erosion is a significant natural non-point source of mercury and other chemical elements.

Land uses have added to stream bank erosion as well. Local engineering of Bear, Sulphur, and Mill creeks has led to straightening streams and loss of natural meander, with the outcome that stream water gains velocity and power to erode banks. Bear Valley Road and Wilbur Springs Road have encroached on Bear Creek and Sulphur Creek at several sites. Efforts to stabilize banks alongside roads in Sulphur Creek and in lower Bear Creek with riprap and boulders is displacing the erosion force of water to the opposite bank or further downstream and does not appear to provide a solution to curtailing erosion. Channel incision is the most prevalent recent manifestation of stream bank erosion. Hoorn et al. (2008) estimated that 20,080 yd^3 of sediments migrated from six incised sites along Sulphur Creek between 1968 and 2005.

Background Soil and Sediment Erosion Rate Related to Mercury

No baseline studies provide actual field data on background soil erosion in Bear Creek watershed. Churchill and Clinkenbeard (2003), however, have estimated the annual background erosion rate of total mercury at 10.1 to 208.1 lbs for the entire Bear Creek watershed. The wide range in values reflects impacts of widely differing rainfall amounts from year to year. Mercury-rich sediment may erode but not necessarily reach a stream during a given storm; therefore, the amount of mercury reaching Bear Creek and its tributaries may be less than the total mercury erosion projected.

Atmospheric Deposition of Mercury onto Bear Creek Watershed

The rate of mercury deposition from the atmosphere onto the ground surface is likely much less than the volatilization of mercury to the atmosphere from the watershed. Churchill and Clinkenbeard (2003) projected atmospheric mercury deposited onto Bear Creek watershed from the atmosphere at an annual rate of 11.2 lbs. No other data exist at this time.

Abandoned Mercury Mines and Mine Waste

The California Department of Conservation developed the PAMP (Principle Areas of Mine Pollution) database in 1972 to identify known or potential mine sources compromising water quality. Five PAMP areas lies within Bear Creek watershed, four of them within Sulphur Creek subwatershed, the other originating with the Rathburn Petray mine complex and possibly associated with the alluvial fan into the main stem of Bear Creek in southwest Bear Valley (Figure 3.5).

Hoorn et al. (2008) estimated total sediment delivery from mine waste to streams in Bear Creek watershed north of Highway 20 to be at least 18,400 tons (13,600 cubic yards). Sediment from mine waste moves primarily by way of gullies rather than by debris landslides into streams. The gullies are of human origin rather than part of natural processes in the watershed. Although only two percent of the volume of sediment derives from mines and mine waste, the mercury content in the sediment is cause for concern.

Cooke and Morris (2005) and Cook and Stanish (2007) have underscored the significance of sediment stemming from abandoned mercury mines as sources of mercury contamination. Sediment erosion and accompanying cinnabar and metacinnabar transport from abandoned mines in Sulphur Creek and Upper Bear Creek subwatersheds have been unmanaged until recently. Table 5.13 gives estimates of annual mercury erosion from individual mines

Table 5.13 – Estimated range of annual sediment and mercury erosion at abandoned mine sites

Mine	Sediment tons per year	Total Mercury pounds per year	Type of Material
Central	0.85 – 1.76	0.01 – 0.07	tailings, retort
Cherry Hill	0.02	0.00 – 2.20	waste
Clyde	17.7 – 36.0	0.09 – 0.15	waste rock, tailings
Elgin	27.9 – 52.8	8.60 – 20.50	waste rock, retort
Empire	0.41 – 0.61	0.09 – 0.13	waste rock
Manzanita	0.98 – 11.0	0.66 - 14.33	waste
Rathburn - Petray	2.9 – 26.0	2.65 – 53.57	waste rock
West End	0.02 – 5.9	0.004 – 2.43	waste rock
Wide Awake	2.7 – 17.0	0.002 – 1.1	waste rock, retort
Total	53.5 – 151.1	12.1 – 94.4	

Source: Churchill and Clinkenbeard (2003)

Agriculture and Livestock Grazing

Agricultural and grazing contamination covers five topics: (1) herbicides and pesticides; (2) fertilizers; (3) fecal bacteria; (4) dissolved organic matter; and (5) stream bank loss from livestock trampling.

Herbicides and Pesticides

Herbicides and pesticides have been applied for agricultural uses at times in the watershed to protect crops, particularly in Upper Bear Creek and Leesville subwatersheds. But, the impact is likely to be minor because crop agriculture in the watershed is on a small scale. BLM law enforcement officers have found contraband herbicides and pesticides (rodenticides in particular) in illegal marijuana gardens on public lands in the watershed. Other applications of herbicides have related to invasive plant control projects in riparian zones along lower Bear Creek (C. Thomsen, pers. comm.).

Fertilizers

Illegal marijuana farming operations use high quantities of nitrogen fertilizers to promote crop growth on infertile ultramafic soils. Data collected from Sulphur Creek subwatershed, Bear Valley, and from lower Bear Creek do not show abnormally high nitrogen concentrations in water sampling thus far. However, the existing sampling data may pre-date the start of actual illegal marijuana cultivation in the watershed.

Fecal Bacteria

Both domesticated livestock and wild animals contribute fecal matter and fecal coliform bacteria to Bear Creek and its tributaries. If fecal coliform bacteria counts are high, the counts serve as indicators that Bear Creek water is not suitable for MUN and REC1 beneficial uses. No public data are available at present for counts of coliform bacteria in the watershed.

Dissolved Organic Matter

Slowey and Rytuba (2008) have hypothesized that plant matter in livestock excrement in Bear Valley is providing a large amount of dissolved organic matter to Bear Creek and its tributaries. Dissolved organic matter is an essential component for forming methylmercury in streams and wetlands. Geochemists are presently preparing scientific articles (E. Suess, pers. comm.) about the correlation between high dissolved organic matter and rates of mercury methylation in Putah Creek watershed to the south of Bear Creek watershed.

Erosion of Stream Banks from Livestock Trampling

Stream bank collapse and resulting bank erosion also may stem from excessive soil trampling along stream banks where large animals, including livestock and game animals, concentrate. North of Highway 20, livestock grazing in Bear Creek watershed does not appear to have been a major direct source of new landslide erosion into Bear Creek and its tributaries in the last seventy years. Hoorn et al. (2008) found only one stream channel erosion event related to livestock grazing since 1937 that generated sediment delivery greater than 1,000 cubic yards. Three pre-1937 erosion sites, however, were more severe (sites 62, 63, 64), with a combined sediment delivery of more than 7,000 cubic yards.

The legacies of livestock grazing on erosion in the watershed south of Highway 20 may have a different pattern. More intensive grazing in steeper terrain where blue oaks (*Quercus douglasii*) and chaparral shrubs were removed to provide more non-native grassland forage may have led to the numerous landslides on haploxeralf soils (Reed 2006) on Bear Creek Ranch and to abnormally high sediment transport from upland ultramafic soils to Bear Creek.

No information is available on livestock impacts to sediment and dissolved organic matter from Mill Creek subwatershed.

Tree Cutting

Cutting oaks in Sulphur Creek subwatershed may increase the impact of rainfall on soils, increase soil erosion overland, and mobilize mercury-rich sediments from soils and abandoned mine waste (Cooke and Morris 2005). Data on erosion from tree cutting in the watershed do not exist.

Wildlife

Big game species such as tule elk, deer, and non-native wild pig, can disturb soils, destabilize stream banks, and add organic matter to streams in ways similar to livestock. No studies at present document the impact of these species on water quality in Bear Creek or other inner North Coast Range watersheds.

Transportation

Estimates of sediment production stemming from the motorized transportation infrastructure in Bear Creek watershed come from two sources: CALTRANS modeled estimates for the state highways in the watershed and Hoorn et al. (2008) for road-related erosion in the watershed north of Highway 20.

Of all human management and land use impacts, roads and trails are the largest source of sediment in Bear Creek watershed north of Highway 20 (Hoorn et al. 2008). Travel and maintenance engineering on county roads, off-highway motor vehicle trails, and new and enlarged access roads for eventual energy projects in uplands could add to the sediment loads reaching Bear Creek.

Impermeable road surfaces consist of State Highways 16 and 20 and county-maintained roads in the northeast part of the watershed. These surfaces can present challenges to dispersing the loads and force of water. The Office of Water Programs at the California State University at Sacramento has estimated annual stormwater sediment loads for planning purposes from the stretches of Highways 16 and 20 that pass through Bear Creek watershed. Table 5.14 gives the estimated amounts of total solids and selected elements and nutrients. Estimates of total mercury and methylmercury transported on state highways are not available. No estimates or data on erosion and chemical elements in sediment from county roads are available.

Table 5.14 – Combined estimates of sediment loads in Bear Creek Watershed from State Highways 16 and 20 by key constituents

Constituents	**Tons per Year**	**Chemical Elements**	**Lbs per Year**
Total dissolved solids	12.27	Arsenic	0.99
Total suspended solids	12.07	Cadmium	0.15
Dissolved organic carbon	2.68	Copper	2.34
Suspended organic carbon	0.21	Lead	9.72
Nutrients	**Lbs per Year**	Nickel	6.33
Nitrate	308.65	Zinc	70.77

Source: California State University at Sacramento, Office of Water Programs at: http://stormwater.water-programs.com/wqpt/HSA.asp?HSA=551320&ID=3019

Management of stormwater runoff from paved surfaces that have cut through ultramafic rock and soil may be important to reducing mercury-rich sediment that enters into the sediment and bed load of Bear Creek. CALTRANS scraped a 10.6-acre block of ultramafic rock and soil along the east side of Highway 20 between the Colusa-Lake county line and the bridge over Bear Creek, to remove a landslide hazard to the highway. Erosion from the unvegetated block onto the highway may be contributing ultramafic sediment and contaminant chemical elements. The site has been the subject of revegetation studies to reduce sediment flow and stabilize slopes (O'Dell and Claassen 2006 a,b). The cost for successful vegetation restoration in the remaining soils and on the parent rock has been very high (V. Claassen, UC-Davis soil scientist, pers. comm.).

Off-Highway Routes and Trails

BLM and National Forest Service field staffs have mapped existing off-highway trails on federal lands in Bear Creek watershed. The Mendocino National Forest has completed designation of authorized OHV trails on National Forest lands. The BLM Ukiah Field Office designated some OHV trails in its Resource Management Plan (Bureau of Land Management 2006) and will be considering additions to the designated OHV route network for the Walker Ridge area. At present, 24 miles of trails are designated as open to off-highway vehicles on federal lands in the watershed. Some of the nearly 110 miles of undesignated routes will require restoration to natural conditions to prevent erosion and link currently fragmented vegetation and wildlife habitat.

Sulphur Creek subwatershed has the highest density of currently unauthorized off-highway routes and trails. The region around the Rathburn-Petray mine complex in Upper Bear Creek subwatershed is another area of concentration. The presence of off-highway routes at abandoned mercury mine sites raises concerns about water quality and for ride safety in the unstable terrain.

Stream Fords
At several points a BLM-designated off-highway trail traverses stream beds and a rare ultramafic wetland. These disturbances may impair hydrologic function and increase sediment transport downstream.

Fire Management
CALFIRE created a 21-mile dozer fire line across watershed terrain in 2008 to halt the progress of the Walker Fire into Bear Valley. The fire line creates management issues: increased soil erosion, invasive plants, little natural revegetation, and unauthorized vehicle travel.

Recreation
Non-motorized recreation in Bear Creek watershed is mostly low-impact as recreation activities are dispersed. At sites such as Cowboy Camp, facilities are engineered to accommodate large numbers of visitors and small numbers of campers in ways that minimize the human imprint on the public land. In the Cache Creek Natural Area, the BLM has established 35.9 miles of trails for mechanical and non-mechanical recreation (mountain bike riding, equestrian use, hiking). The BLM manages this non-motorized trail system to avoid sediment erosion and channel incision in seasonal and permanent streams that flow from side canyons into lower Bear Creek.

Septic Systems
Documentation on septic systems in the watershed does not presently exist. Homes and lodging facilities are few in number and not likely to limit the capacity of soils to decompose or disperse loads of nutrients (nitrogen, phosphorus) and bacteria.

5.5 Permits Affecting Water Quality

National Pollutant Discharge Elimination System (NPDES) permits regulate pollutant discharges at specific locations from pipes, outfalls, and conveyance channels (point sources). The CVRWQCB issues NPDES permits covering Bear Creek watershed. Permits relate to roadwork affecting surface water discharges and to controls on storm water runoff from mine sites. In addition, the CVRWQCB sets objectives for permits, determines compliance with permits, and enforces compliance when necessary.

Permits for confined animal facilities and wastewater treatment do not apply to conditions in Bear Creek watershed where no confined animal facilities are present.

Phase II Stormwater Permits

Phase II stormwater permits are required for construction sites between one and five acres in extent. These sites need not be for industrial purposes. Phase I stormwater permits do not apply to Bear Creek watershed because of the small human population and the lack of industry requiring a storm sewer system.

Construction projects in the watershed since 1990 needing stormwater permits to manage altered stormwater flow coming from constructed sites have been few in number. The two permittees in the watershed are CALTRANS for work on Highways 16 and 20, and the BLM for development of recreation and visitor services facilities at Cowboy Camp and at High Bridge Camp. No storm water permitting has occurred in the last eighteen years on private property.

Place ID	Place Name	Type	Status
218591	Cowboy Camp Facilities Development	BLM Facility	Terminated March 22, 2004
633082	High Bridge Annex Group Horse Camp	BLM Facility	Terminated May 12, 2006
633083	High Bridge Trailhead and Parking Area	BLM Facility	
262307	CA DOT District 3	DOT Facility	Teminated

Source: California State Water Quality Control Board database

No violations for wastewater treatment or storm water management occurred from January 1, 1990 through June 30, 2008.

Permits Required for Bear Creek Bridge Reconstruction and Highway 20 Realignment

In 2008, CALTRANS initiated reconstruction of Bear Creek Bridge on Highway 20 and related highway realignment. Bear Creek Bridge and the stretch of State Route 20 between milepost 2.8 and milepost 3.8 have flooded during ten-year flood events. The existing culverts had not been large enough to convey floodwaters. Consequently, during heavy rainstorms the culverts were not functioning adequately, and Bear Creek overflowed the bridge and highway. The following permits have been required for compliance during new construction:

- a United States Army Corps of Engineers Section 404 Permit for filling or dredging waters of the United States
- a CDFG 1602 Agreement for Streambed Alteration
- a CVRWQCB Section 401 Water Quality Certification

5.6 Beneficial Uses of Water at Risk

The following beneficial uses assigned to Bear Creek watershed are at risk of degradation:

AGR – Agricultual Supply, Irrigation, and Stock Watering

Mercury-rich water intended for crop irrigation may be building mercury concentrations from Bear Creek environmentally across a much broader area of arable land than might naturally occur, i.e., by way of Cache Creek stream diversions, the Cache Creek Settling Basin, and the Yolo Bypass before reaching the Bay-Delta marshes and wetlands. Boron concentrations might become a problem and require ongoing monitoring.

COMM – Commercial and Sport Fishing

High concentrations of mercury in tissues of wild fishes have led to advisories against consuming fish caught for sport or subsistance use in Bear Creek and its tributaries. The CVRWQCB has deleted COMM as a beneficial use for Sulphur Creek because no fish live in Sulphur Creek on account of the naturally high concentrations of dissolved salts.

MUN – Municipal and Domestic Supply

Concentrations of total mercury in Sulphur Creek led to the CVRWQCB to remove MUN as a beneficial use. Monitoring mercury loads downstream from the confluence with Bear Creek is critical to ensure that MUN is not put at risk elsewhere.

REC1 – Recreation, Contact Water and Canoeing and Kayaking

Children playing occasionally in the streambed of Sulphur Creek or lower Bear Creek are unlikely to have exposure to methylmercury in toxic quantities. A greater concern for contact recreation is a health risk from bacteria in streams excreted by livestock and wildlife.

REC2 – Recreation, Non-Contact Water

None

SPWN – Spawning, Reproduction, and/or Early Development

Native fishes in Bear Creek watershed may be unfit for spawning, and young fish may develop circulatory or nervous system maladaptations. There is no local data on adverse effects in fish (J. Cooke, CVRWQCB, pers. comm.).

WARM – Freshwater Habitat, Warm

Summertime low flows on Bear Creek create warm quiet shallows and pools that become incubators for bacteria to transform mercury into methylmercury (Schwarzbach et al. 2001). Methylation also increases where organic matter builds up in the stream during low flows. Successive predators at higher trophic levels amass higher bodily concentrations of methylmercury. These concentrations may impair the reproduction of some vertebrate species.

WILD – Wildlife Habitat

The resident populations of fish-eating bald eagles, ospreys, and river otters build up potentially harmful concentrations of methylmercury in their bodies over time as they fish along lower Bear Creek. The riparian zone and stream water in lower Bear Creek, in particular, may become degraded habitat for foothill yellow-legged frogs and western pond turtles, both US Forest Service and BLM sensitive species.

5.7 Future Conditions and Target Loads for Water Contaminants

Abandoned Mines

The CVRWQCB has established target total daily maximum load (TMDL) concentrations for mercury from inactive mines, load allocations for methylmercury in water (total mass but not instantaneous concentration), and water quality objectives for methylmercury in fish. The TMDLs also contain an aqueous methylmercury concentration goal (0.06 nanograms per liter) that is linked to the fish tissue objectives, but the goal is not enforceable. Additional TMDL requirements for total mercury in stream water apply to Sulphur Creek subwatershed. Table G.5 in Appendix G summarizes the load allocations.

The CVRWQCB has planned to complete mercury mine cleanup and control mercury discharges into Bear Creek watershed streams by the end of 2011, but this date may need revision. Legally determined responsible parties and current owners of abandoned mines shall develop and submit to the CVRWQCB Executive Officer a cleanup and abatement plan and schedule to reduce anthropogenic mercury loading in Sulphur Creek. The goal is to reduce loads of mercury from mining or other anthropogenic activities by 95 percent consistent with State Water Resources Control Board Resolution 92-49 (Basin Plan as amended 2007). The responsible parties shall be in compliance with this requirement when cleanup actions and maintenance activities follow the approved plans resulting from the cleanup and abatement orders.

Separating natural and anthropogenic sources of mercury is not always straightforward. For example, mercury and methylmercury produced by interaction of the natural Elgin thermal springs with mine wastes from the Elgin Mine are considered entirely part of anthropogenic loading.

The Basin Plan also requires landowners and public land managers to have special permitting for activities that result in discharges of mercury within the ten-year floodplains of Bear Creek, Sulphur Creek, and their tributaries.

Methylmercury

The goals for methylmercury are: a 50 percent reduction in Bear Creek at the southernmost bridge crossing on Bear Creek Road, a 90 percent reduction for Sulphur Creek subwatershed in methylmercury load, and an 85 percent reduction for Bear Creek at Highway 20 (Basin Plan 2007). The past contribution of Bear Creek watershed north of Highway 20 has average 17 percent (or 21.1 grams per year) of the Upper Cache Creek Basin methylmercury load, and the CVRWCB goal is to reduce that amount to 3.0 grams per year. No data on total annual loads of methylmercury are available for the entire Bear Creek watershed, and there are no established targets for reducing methylmercury loads for Bear Creek below Highway 20.

Goals for Other Contaminants

OEHHA has established California Public Health Goals for elements and compounds with maximum contaminant loads for MUN. These Health Goals are listed in Table G.1 in Appendix G.

5.8 Soil Contamination

Some soils in Bear Creek watershed have high natural concentrations of metals. Concentrations of these metals may pose health risks to some people. Ford (2004) has developed threshold criteria used by the BLM to determine instances when concentrations in soils of eleven elements commonly associated with commercial mining may merit risk assessment. Table 5.15 presents these criteria concentrations for four types of environments for people.

The threshold concentrations for risk from metals in Table 5.15 are lower for local residents because their exposure is longer term (chronic exposure) than, say, the high thresholds for an ATV driver who may stir up and inhale dust on a riding trail but undergo a relatively short exposure time (acute exposure).

Geochemists have not yet studied the chemistry of soils extensively in Bear Creek watershed. Analyses have come from Sulphur Creek subwatershed and lower Bear Creek. Churchill and Clinkenbeard (2003) sampled several background (uncontaminated and potentially contaminated) sites in Bear Creek watershed for mercury.

The only full-spectrum analysis of soil chemistry comes from work by Morrison et al. (2008, Table 6) for six sites in the Sulphur Creek basin: one ultramafic upland soil (site S0), two sites at alluvial fans entering from side drainages to Sulphur Creek (sites S1 and S2), a narrow riparian zone (S3), a point bar (S4), and flood plain (S5). An additional sample came from lower Bear Creek (B1).

Table 5.15 – Soil concentrations in parts per million for elements with potential risk to human health based on exposure

Element	Local Resident	Camper	ATV Driver	Worker
	milligrams per kilogram			
Antimony	3	50	750	100
Arsenic	1	20	300	12
Cadmium	3	70	950	100
Copper	250	5,000	70,000	7,400
Lead	400	1,000	1,000	2,000
Manganese	960	19,000	250,000	28,000
Mercury	2	40	550	60
Nickel	135	2,700	38,000	4,000
Selenium	35	700	9,600	1,000
Silver	35	700	9,600	1,000
Zinc	2,000	40,000	550,000	60,000

Source: Ford (2004)

Table 5.16 summarizes data from Morrison et al. (2008) about the order of magnitude in concentrations of five elements found in watershed soils compared to the BLM threshold objectives for local residents (Table 5.15). As with water contaminants, cadmium, copper, lead, selenium, silver, and zinc did not reach potential threshold risk levels in soils. The following five elements attained concentrations exceeding risk threshold criteria for residents (Ford 2004): antimony, arsenic, manganese, mercury, and nickel.

Sampled soils had mercury concentrations as high as 605 mg/kg. For perspective, the North American average for mercury in soils is 0.06 mg/kg). High mercury, nickel, arsenic, and antimony concentrations come from the natural hydrothermal alteration of minerals deep in the ground and possibly supplemented by mining waste (J. Holloway, USGS geochemist, pers. comm.). Apart from mercury, researchers have not distinguished what share of heavy metal loads in soils originate from naturally occurring (background) concentrations of elements and which loads come from abandoned mine sites (anthropogenic).

The few data from watershed soils show the high variability of concentrations of chemical elements within a relatively small area. The data also do not indicate conclusively the extent or pattern of high concentrations of elements potentially toxic to people. Studies are needed to clarify whether there is significant contamination from chemical elements other than mercury.

The upland ultramafic Henneke soil (S0) comes from an ultramafic area on the east side of Sulphur Creek subwatershed. It differs from the hydric alluvial Arand soil (S5) along Sulphur Creek in the following ways: higher iron content, a high ratio of magnesium to calcium (10:1), a high ratio of alkali earth metals (magnesium and calcium) to alkali metals (sodium and potassium), and low total carbon. The low total carbon signals the comparatively low biomass of vegetation aboveground on ultramafic soils; the remaining features indicate soil originating from ultramafic parent rock.

The floodplain soil from Sulphur Creek (S5) originates from sediment deposited from steep hillsides during high flows (Morrison et al. 2008). These alluvial fans from the Sulphur Creek catchment are mapped as Arand Soils (Reed 2006) derived from Skyhigh and Millsholm soils upslope. Metal concentrations (e.g., nickel, lithium, and titanium) in the point bar soil from Sulphur Creek (S4) reflect adjacent stream sediment chemistry. The A-horizon of the Sulphur Creek riparian soil (S3) resembles Sulphur Creek stream sediment, but the proportion of nickel is lower, thus more typical of Skyhigh and Millsholm soils (J. Holloway, USGS geochemist, pers. comm.).

Table 5.16 – Contaminant levels for elements higher (•) and 10x higher (• [red]) than the BLM risk management criteria for residents from soil sampling sites in Bear Creek watershed*

Element	**Lower Bear Ck**	**Sulphur Creek**					
	B1	**S0**	**S1**	**S2**	**S3**	**S4**	**S5**
	Corval	**Henneke**	**Arand**				
Antimony						• [red]	
Arsenic	•	•	• [red]	•	• [red]	•	•
Manganese		•		•	•		•
Mercury	•	•	•	•	• [red]	•	•
Nickel	•	• [red]		•	•	•	•

*Soil series for each site are listed below the sample site number
Sources: Ford (2004), Morrison et al. (2008)

In contrast, the Bear Creek (B1) floodplain soil (Corval Series) has a more complex origin owing to its proximity to the mouth of Bear Creek, which results in the accumulation of diverse sediments from across the entire watershed upstream. The higher ratio of magnesium to calcium points to prevalence of ultramafic sediments.

Data on the chemical compositions of more extensive principal soil series in Bear Creek watershed other than the Henneke soil series are not yet available.

In conjunction with the Bear Creek Bridge reconstruction project on Highway 20, the California Department of Transportation sampled mercury concentrations in the project area (California Department of Transportation 2006). Soil samples taken from cut slopes and a roadside ditch in November 2005 showed concentrations ranging from "not detectable" to 1.5 mg/kg. A sample from sediment taken directly from Bear Creek registered 7.7 mg/kg mercury to sediment by weight, which is below the threshold for health risk to people having contact with water during recreation (Ford 2004).

Samples taken of the three endemic ultramafic soil series found on the Bear Valley floor (Bear Valley, Leesville, and Venado) had concentrations of nickel ranging from 1235 to 1658 mg/kg and chromium from 368 to 892 mg/kg (J. Alderson, pers. comm.). No adverse impacts to the environment or people have been demonstrated from these natural concentrations.

5.9 Hazardous Waste

Comprehensive Environmental Response, Compensation, and Liability Act (CERCLA) Site

Only one site in Bear Creek watershed falls under the category of a site targeted for hazardous waste removal under the BLM's CERCLA authority: the Rathburn-Petray mine complex. The BLM is the project lead for completing the removal required by the CVRWQCB. This extensive site is being cleaned up because of the high volume of mercury-rich sediments. Recent estimates for the BLM find that waste piles at Rathburn and Rathburn-Petray Mines together contain approximately 101,500 cubic yards of mercury-bearing waste material. The material appears in cuts, slopes, open pits, mine waste piles, and stormwater retention ponds. Also, the ash deposited around the brick retort at the Rathburn Mine has high levels of mercury.

The major concern for water quality is surface water runoff during storm events. Especially powerful rains could erode waste and tailings piles, overflow the retention ponds, and transport mercury-laden sediment into the broad alluvial fan and into tributaries of Bear Creek on the southwest side of Bear Valley. Presently, other partners involved in the Rathburn-Petray CERCLA remediation include the CVRWQCB and the US Geological Survey-

Geologic Division.

Action to achieve needed management and remediation piles at the Rathburn and Rathburn-Petray mines in Upper Bear Creek subwatershed began in December 2005, when the CVRWQCB issued a Cleanup and Abatement Order to the BLM Ukiah Field Office. The BLM has provided a work plan with background levels of mercury in the soil and surface water, and the vertical and lateral extent of mine waste piles, soil, and sediment contaminated with mercury. The BLM has also finalized an engineering evaluation and cost analysis (EE/CA) for the Rathburn-Petray mine complex for CERCLA response actions (Ecology and Environment, 2008). Remediation work is scheduled on the ground in 2010.

Mercury remediation has begun at the Clyde and Elgin mines as well. The latter mine is mostly on private property with a small part on the BLM lands. Otherwise, responsible parties have not begun work to remediate mercury mines on private lands. In 2009, the CVRWQCB initiated the process for cleaning up all mercury mines on private lands in Sulphur Creek subwatershed.

Brownfields

"Brownfields" are potentially suitable for redevelopment or reuse, but the properties remain unused due to actual or perceived contamination on site. Generally, these sites are in urban settings or rural industrial settings such as lumber mills. No brownfields sites are designated in Bear Creek watershed.

Underground Storage Tanks

Two contamination cleanups involving gasoline have taken place in Bear Creek Watershed. Gasoline contamination of soils and an aquifer potentially used for drinking water around the CALFIRE Wilbur Springs Forest Fire Station (case T0601100051) on State Highway 16 was discovered in 1998. The cleanup at the station was completed and the case closed as of September 4, 2002. Gasoline contamination of soils around the CALFIRE Leesville Forest Fire Station (case T0601100052) on Bear Valley Road was discovered in 1998. Ground water testing in 2004 and 2005 did not detect any residual petroleum. The cleanup at the Leesville station was completed and the case closed as of July 24, 2008.

Hazardous Waste Sites and Substances (Cortese List)

The California Department of Toxic Substances Control does not list any hazardous waste and substances sites in Bear Creek watershed.

5.10 Air Quality Contaminants

Two sources of atmospheric contamination with potential impacts to human health are asbestos and mercury.

Asbestos

Chrysotile and tremolite forms of serpentinite asbestos are frequently found in association with ultramafic soils and rocks occurring in Bear Creek watershed (Churchill and Hill 2000). Goff and Guthrie (1999) noted that the dominant mineral in ultramafic rock on Walker Ridge, was harzburgite, a non-asbestos form of serpentinite. O'Dell and Claassen (2006a), however, found that the asbestos content of serpenitinite minerals at a restoration sites along Highway 20 is one to five percent asbestos by mass. Data on the occurrence and density of airborne asbestos fibers are not available.

Mercury

Little information is available on mercury volatilization into the atmosphere from naturally mercury-enriched soils and from mercury mine sites. Bear Creek watershed generates more volatilizing mercury than it receives from deposition from the atmosphere (refer to Table 5.2). Mercury vapor coming from springs is not well documented, but the largest percent of molar gas composition was 4.6×10^{-6} percent from Elbow Springs (Goff et al. 2001). No data are presently available concerning mercury emissions from soils in the watershed. A study of mercury volatilization in the Knoxville Mining District southwest of Bear Creek watershed showed that the highest mercury emissions occurred along the Stony Creek Fault, a major fault which also bisects Bear Creek watershed. Gustin (2002, 2003) scaled her mercury readings to estimate emissions of 37.6 kg^{-2} km^{-2} yr^{-1} for the Knoxville region (Gustin 2002, Gustin 2003), equal to 29.9 pounds per square mile per year. Roughly one-half of that quantity is from natural sites; the other half comes from specific mercury mines.

5.11 Identification of Critical Areas for Remediation

Management of total mercury, methylmercury, and total sediment are interrelated as subjects for remediation in Bear Creek watershed. Seven principal projects are needed for targeted remediation:

1. Control and sequestering of abandoned mine sites and their mine wastes in Sulphur Creek subwatershed to reduce total mercury reaching Bear Creek and exiting downstream into Cache Creek
2. Confinement of sediments in Rathburn-Petray mine complex to prevent potential erosion into Bear Creek
3. Reduction of ultramafic sediment erosion into the lower Bear Creek riparian corridor from ultramafic soils in subwatersheds south of the confluence of Sulphur Creek with Bear Creek
4. Reduction of dissolved organic matter in Bear Valley and in lower Bear Creek south of Highway 20 to slow the rate of mercury methylation
5. Management of benthic environments in Bear Valley and lower Bear Creek to create

conditions less conducive to methymercury production, particularly in summer months
6. Restoration of hydrologic flow and native vegetation to closed off-highway motor vehicle trails on public lands in Sulphur Creek subwatershed to reduce sediment in Sulphur Creek from ultramafic rocks and soils.
7. Removal of mercury sediment deposits along lower Bear Creek.

In addition, watershed planning and coordination within the ten-year flood zone is a necessary "best mercury management practice". This step would avoid soil disturbances that might increase the amount of total mercury reaching creeks and tributaries or increase the production of methylmercury in stream bottoms (Cooke and Morris 2005). Care is warranted, for example, when removing invasive plants to avoid disturbing stream sediments and stream bank soils and unintentionally mobilizing mercury and methylmercury.

5.12 Information Gaps

The following items are information needs critical to make improvements to the ecosystem function of Bear Creek watershed:

- water quality monitoring to detect the presence of industrial organic compounds and fecal coliform bacteria
- water quality monitoring for ground water
- a study of the impacts on mercury methylation from dissolved organic matter stemming from wild animals and livestock concentrating along sections of Bear Creek, Sulphur Creek, and Mill Creek
- a map of mercury volatilization rates into the atmosphere from soils and geologic features in Bear Creek watershed
- multi-year field data collection to determine the sources, seasonality, and amounts of sediment flows from the Rathburn-Petray mine complex into Bear Valley
- data on total mercury loads from cold mineral springs in Bear Valley and elsewhere
- more intensive soil sampling of potentially toxic chemical elements in alluvial soils along Bear, Sulphur, Trout, and Mill creeks
- annual monitoring at key sites in the watershed to track methylmercury amounts in fish tissues as an indicator of the effectiveness of management actions intended to reduce total mercury and methylmercury.