Big Bear Lake
Technical Support Document for Mercury TMDL

Prepared for:

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and
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1 Introduction

Big Bear Lake is located in the Santa Ana Basin in San Bernardino County in the San Bernardino Mountain Range (Figure 1). The lake was placed on the California 303(d) list for mercury impairment in 2004. Total Maximum Daily Loads (TMDLs) have recently been completed for nutrients and sediment (draft), and the Santa Ana Regional Water Quality Board is developing the mercury TMDL. Tetra Tech was contracted by USEPA Region IX to provide technical support for the mercury TMDL and to assist the Regional Board in data analysis, interpretation, and load allocations.

This report briefly describes the mechanisms of mercury loading likely present in the watershed and describes the techniques used to quantify loads from each source. Local and regional monitoring data will be coupled with model output for the Big Bear Lake watershed to estimate loads from atmospheric deposition (wet and dry) and watershed sources (water column and sediment bound).

In support of the sediment and nutrient TMDLs for this lake, the Regional Board has compiled background information concerning the location, topography, land use, and soil types in the watershed as well as the history and management activities for Big Bear Lake. That information will not be repeated in this technical support document.

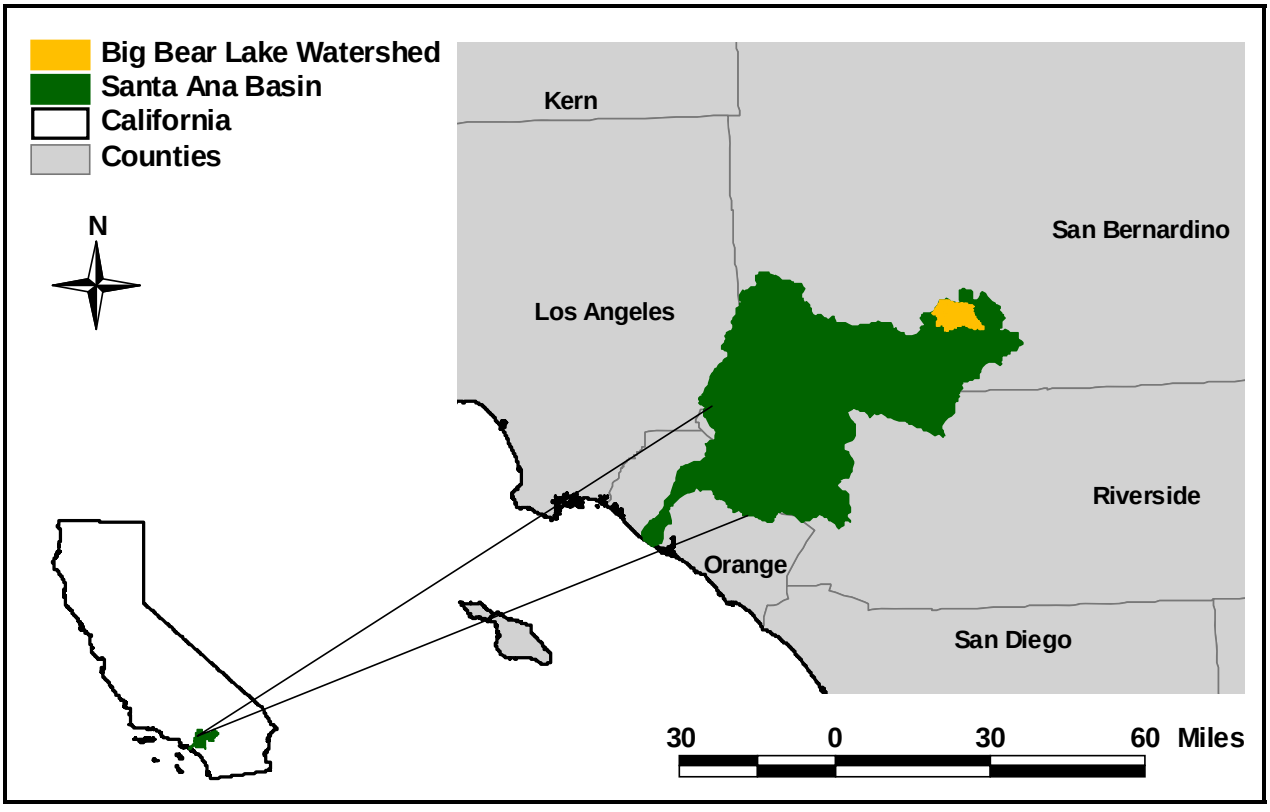

Figure 1. Location of the Big Bear Lake Watershed

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2 Applicable Water Quality Standards

Section 303(d) of the Clean Water Act requires states to identify waters for which technology-based effluent limitations on permitted point sources are not stringent enough to support attainment of all applicable water quality standards. These standards may include numeric water quality standards, narrative standards for the support of beneficial uses, and other associated indicators. A TMDL is developed for such impaired waters to estimate the pollutant loading reductions needed to support the attainment of beneficial uses.

A numeric target identifies the specific goals or endpoints for the TMDL that equate to attainment of the water quality standard. The numeric target may be equivalent to a numeric water quality criterion (where one exists), or it may represent a quantitative interpretation of a narrative standard. This section reviews the applicable water quality standards and identifies an appropriate numeric indicator and associated numeric target level for the calculation of the mercury TMDL for Big Bear Lake.

2.1 Numeric Water Quality Standards

California's beneficial use classifications of Big Bear Lake are water contact recreation (REC1), non-contact water recreation (REC2), warm (WARM) and cold (COLD) freshwater habitat, wildlife habitat (WILD) and municipal and domestic supply (MUN). The California Toxics Rule establishes water quality standards for mercury that apply to these beneficial uses, specifying a criterion of 50 ng/L total mercury in water (USEPA, 2000). The applicable criterion is the most restrictive of values derived for the protection of aquatic life, fish tissue concentrations, and drinking water supplies.

Big Bear Lake was placed on the 303(d) impaired waters list due to exceedences of the water quality criterion of 50 ng/L. The data on which this listing was based, however, were obtained using sampling methods that are subject to contamination and are of suspect accuracy, as discussed further below. To date, mercury concentrations in water in Big Bear Lake obtained using ultra-clean sampling and analysis techniques have not exceeded the applicable water quality standards.

2.2 Fish Tissue Concentrations

Beneficial uses of Big Bear Lake may also be impaired if concentrations of mercury in fish tissue are sufficiently high to pose potential adverse health impacts from the ingestion of sport-caught or local fish. In 2001, USEPA issued a methylmercury criterion of 0.3 ppm in fish tissue (USEPA, 2001b). The applicable numeric targets for the Big Bear Lake TMDL are thus the California ambient water quality criterion of 50 ng/L total mercury in the water column and the USEPA criterion of 0.3 ppm methylmercury concentration in fish tissue. As it is primarily methylmercury that accumulates in fish, the 0.3 ppm criterion may also be applied to total mercury concentration in the edible portion of fish. Total mercury concentrations in edible fish from Big Bear Lake have exceeded the action level. Fish in Big Bear Lake accumulate unacceptable tissue concentrations of mercury even though the ambient water quality standard appears to be met. The most binding regulation is the fish tissue concentration criterion of 0.3 ppm methylmercury (interpreted as 0.3 ppm total mercury), which is selected as the primary numeric target for calculating this TMDL.

Mercury bioaccumulates in the food chain with concentrations increasing in larger fish that consume smaller fish. Within a lake fish community, top predators usually have higher mercury concentrations than forage fish, and tissue concentrations generally increase with age. Top predators (such as bass) are often target species for sport fishermen. Risks to human health from the consumption of mercury-contaminated fish are based on long-term, cumulative effects, rather than concentrations in individual fish. Therefore, the criterion should not be applied to the extreme case of the most-contaminated fish

within a target species; instead, the criterion is most applicable to average concentrations in a top predator species of a size likely to be caught and consumed.

Within Big Bear Lake, the top predator sport fish, and also the fish with the highest reported tissue methylmercury body burden, is largemouth bass (*Micropterus salmoides*). Largemouth bass continue to bioaccumulate mercury with increasing size and age. The California Department of Fish and Game requires that anglers release largemouth bass less than 12 inches (305 mm) in length and that each angler keep no more than five fish per day. The largemouth bass caught for determination of fish tissue mercury concentrations ranged in size from 200 to 450 mm in length, and exceedences of the fish tissue criterion occurred in largemouth bass ranging in length from 350 to 450 mm (Section 3.2).

The selected target for the TMDL analysis in Big Bear Lake is an average tissue concentration of 0.3 ppm or less in largemouth bass greater than 400 mm (the midpoint of the range exceeding the criterion). Predators like bass tend to increase steadily in mercury body burden as they get older and larger; 305 mm bass will typically have a lower concentration than 400 mm bass. Setting the target only on the basis of 305 mm bass (minimum catch size) would be less conservative than using 400 mm. Therefore, setting the target at a length of 400 mm will be more protective across the range of fish typically caught.

3 Mercury Monitoring Data

Mercury is present in many forms and several mediums in the environment. Within Big Bear Lake and its tributaries, mercury may be present in both the water column and the sediments. Throughout the watershed, mercury may be associated with land and water surfaces. From the atmosphere, mercury may be deposited by settling of particles and gases (dry deposition) or become associated with precipitation (wet deposition). Most of these forms and processes have been monitored in or around the Big Bear Lake watershed, with the exception of dry deposition, which is discussed in Section 4.3.4. Figure 2, provided by the Regional Board, shows the location of the in-lake and tributary monitoring locations in the watershed. The Bear Creek location does not show on the map, but is located on the creek just downstream of the dam.

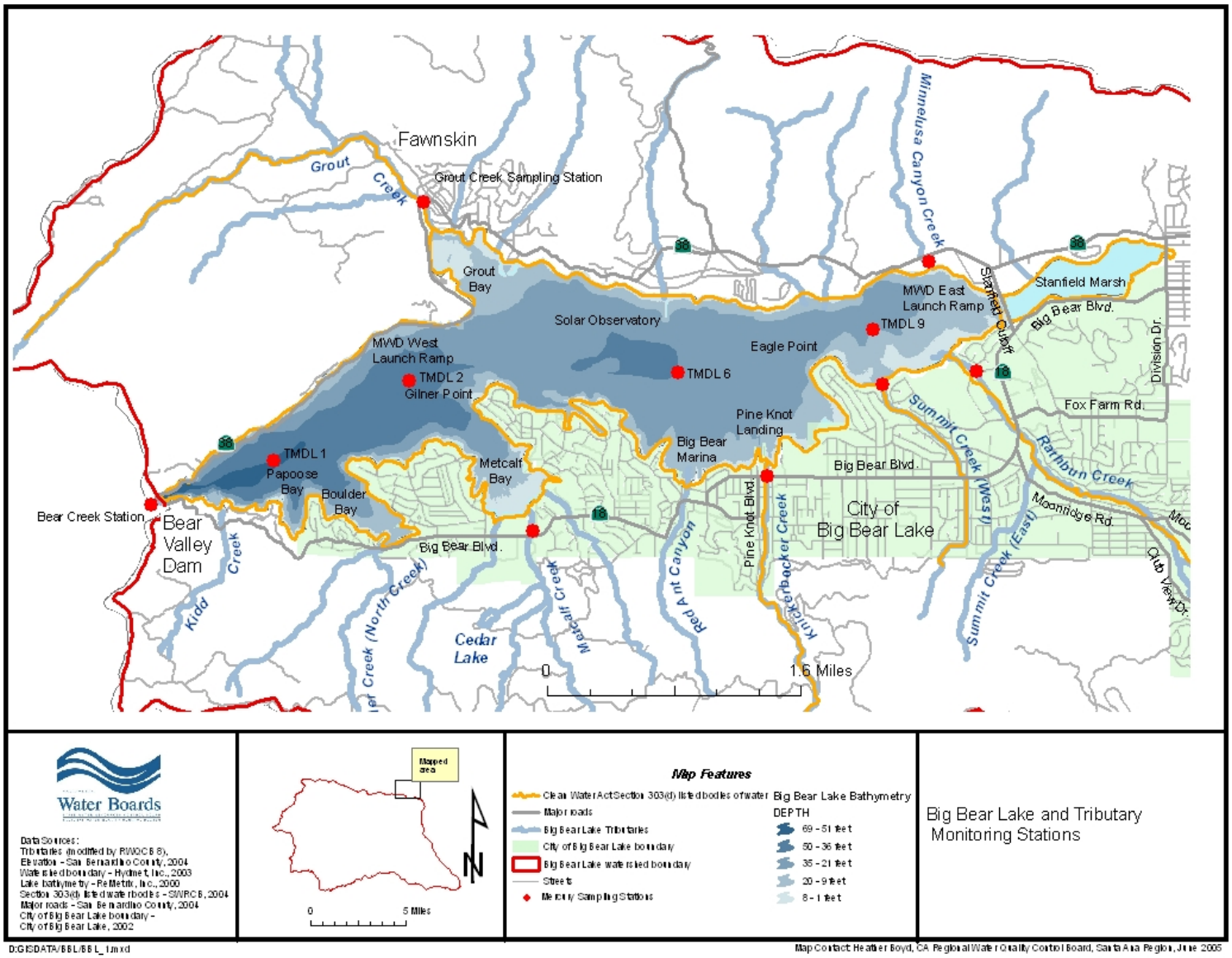

Figure 2. Big Bear Lake Watershed Mercury Sampling Stations

3.1 IN-LAKE WATER QUALITY MONITORING

Big Bear Lake has been sampled for mercury three times in the past several years at four locations.

3.1.1 Water Column Measurements

In June of 2001, water column samples were collected from 10 locations in Big Bear Lake in both the photic zone and near the lake bottom. The detection limit for total mercury in this dataset was 200 ng/L. The analytical method was not specified in the dataset delivered to Tetra Tech. Of the 20 measurements, 13 were below detection; the other seven ranged from 200 to 500 ng/L. Given the high detection limit for this dataset, which is four times higher than the California water quality standard for mercury (50 ng/L), these samples were likely not obtained and/or analyzed using the clean techniques (EPA method 1631) required to avoid sample contamination as described by USEPA (2001a).

Additional lake sampling occurred on May 20, 2008. Table 1 summarizes the dissolved mercury concentrations measured in the water column. This analysis was performed with EPA method 1631Em (USEPA, 2002), which has a detection limit of 0.5 ng/L. During this sampling event, all dissolved mercury concentrations were more than an order of magnitude less than the California standard for mercury.

The particulate fraction of the water column samples collected in May 2008 was also tested for mercury with EPA method 245.7m (detection limit of 10 ng/L) (USEPA, 2005a). All samples tested non-detect for mercury in the particulate fraction. The inlake samples collected in May 2008 were the only water column samples tested for dissolved and particulate mercury fractions. All other water column mercury concentrations were analyzed for total mercury concentration.

Table 1. Water Column Dissolved Mercury Concentrations Observed in Big Bear Lake (May 2008)

Site Number	Count	Minimum (ng/L)	Average (ng/L)	Maximum (ng/L)
MWDL1	3	2.3	2.6	3.2
MWDL 2	2	2.7	3.2	3.6
MWDL 6	2	2.8	3.0	3.2
MWDL 9	1	2.8	2.8	2.8

The Regional Board undertook another sampling event at four stations in the lake on September 10, 2008. Both total and dissolved data were collected (Table 2). This analysis was performed with EPA method 1631Em (USEPA, 2002), which has a detection limit of 0.5 ng/L. During this sampling event, all total and dissolved mercury concentrations were more than an order of magnitude less than the California standard for mercury.

Table 2. Water Column Dissolved Mercury Concentrations Observed in Big Bear Lake (September 2008)

Site Number	Total Mercury (ng/L)	Dissolved Mercury (ng/L)
MWDL1	1.8	0.8
MWDL 2	2.1	1.4
MWDL 6	1.9	1.5
MWDL 9	1.9	1.9

3.1.2 Sediment Samples

Sediment mercury samples were also collected from the lake bottom during the May and September 2008 events. Table 3 summarizes the observed values. Only one sediment sample was collected at each station during each of the two events. The laboratory analysis for these samples (EPA 245.7m (USEPA, 2005a)) has a detection limit of 0.01 µg/g (equivalent to 0.01 mg/kg).

Table 3. Sediment Mercury Concentrations Observed in Big Bear Lake (2008)

Site Number	May Observations (mg/kg)	September Observations (mg/kg)
MWDL1	0.075	0.05
MWDL 2	0.07	0.07
MWDL 6	0.1	0.7
MWDL 9	0.11	0.04

3.2 FISH TISSUE SAMPLING

Fish tissue mercury samples have been collected in Big Bear Lake over the past three decades. Table 4 presents the wet weight mercury concentration data in fillets from fish caught in this lake. Some measurements represent composite samples of three to seven fish; others are measured from individual specimens. The applicable fish tissue criterion for mercury measured as a wet weight concentration is 0.3 ppm.

Figure 3 shows the fish tissue mercury concentration data by species and date collected. Of the nine species collected, only largemouth mass show exceedences of the fish tissue guideline. In the 1980s and 1990s, six measurements of largemouth bass were collected and one exceeded the guideline. In the 2000s, 21 measurements were collected and 13 exceeded the guideline. The frequency of exceedences prior to 2000 is approximately 17 percent and post-2000 is approximately 62 percent. Though it appears that mercury concentrations in largemouth bass in Big Bear Lake are increasing with time, this may actually be an artifact of the length of fish sampled. Prior to 2002 the mean length of fish sampled was 273 mm and the maximum length was 372 mm; after 2002 the mean length sampled was 422 mm and the maximum length was 450 mm. Other species with sufficient data for comparison (carp and rainbow trout) do not show increasing concentrations over the past few decades.

Table 4. Mercury Fish Tissue Concentrations Measured in Big Bear Lake

Date Collected	Station Name	Species	Composite (c) or Individual (i)	Mean Length (mm)	Wet Wt Hg Conc (ppm)
7/13/2005	Big Bear Lake	Black Bullhead	c	274	0.049[3]
7/14/2005	Big Bear Lake	Black Bullhead	c	235	0.041[3]
5/7/1984	Big Bear Lake / Boulder Bay	Carp	c	423.0	0.180[1]
6/23/1988	Big Bear Lake	Carp	c	370.0	0.070[1]
7/10/2000	Big Bear Lake / Dam	Carp	c	396.0	0.211[1]
7/10/2000	Big Bear Lake / Rathbun Creek	Carp	c	1,125.4	0.201[1]
7/10/2001	Big Bear Lake / Rathbun Creek	Carp	c	380.0	0.150[1]
9/21/2004	Big Bear Lake	Carp	c	565	0.138[3]
9/21/2004	Big Bear Lake	Carp	c	582	0.142[3]
9/21/2004	Big Bear Lake	Carp	c	539	0.083[3]
9/21/2004	Big Bear Lake	Carp	c	581	0.169[3]
7/13/2005	Big Bear Lake	Carp	c	348	0.034[3]
7/14/2005	Big Bear Lake	Carp	c	361	0.032[3]
7/13/2005	Big Bear Lake	Channel Catfish	i	509	0.049[3]
7/13/2005	Big Bear Lake	Channel Catfish	i	784	0.142[3]
7/13/2005	Big Bear Lake	Crappie	c	220	0.044[3]
7/13/2005	Big Bear Lake	Crappie	c	190	0.042[3]
7/13/2005	Big Bear Lake	Crappie	c	128	0.037[3]
7/13/2005	Big Bear Lake	Crappie	c	200	0.038[3]
7/13/2005	Big Bear Lake	Crappie	c	146	0.047[3]
5/7/1984	Big Bear Lake / Boulder Bay	Largemouth Bass	c	359.0	0.370[1]
6/23/1988	Big Bear Lake	Largemouth Bass	c	275.0	0.240[1]
6/5/1992	Big Bear Lake	Largemouth Bass	c	239.0	0.130[1]
6/8/1994	Big Bear Lake / Dam	Largemouth Bass	c	226.0	0.030[1]
6/8/1994	Big Bear Lake / Rathbun Creek	Largemouth Bass	c	284.0	0.210[1]
6/20/1995	Big Bear Lake	Largemouth Bass	c	286.0	0.280[1]
7/10/2000	Big Bear Lake / Dam	Largemouth Bass	c	236.0	0.198[1]
7/10/2000	Big Bear Lake	Largemouth Bass	c	273.0	0.593[1]

Date Collected	Station Name	Species	Composite (c) or Individual (i)	Mean Length (mm)	Wet Wt Hg Conc (ppm)
7/10/2000	Big Bear Lake	Largemouth Bass	c	257.0	0.210[1]
7/10/2000	Big Bear Lake / Rathbun Creek	Largemouth Bass	c	266.0	0.256[1]
7/10/2001	Big Bear Lake / Dam	Largemouth Bass	c	372.0	0.600[1]
7/10/2001	Big Bear Lake	Largemouth Bass	c	203.0	0.086[1]
10/15/2002	Big Bear Lake / MWDL2 - Grout Creek	Largemouth Bass	c	427.3	0.363[2]
10/15/2002	Big Bear Lake / MWDC5 - Summit Creek	Largemouth Bass	c	427	0.329[2]
10/15/2002	Big Bear Lake / MWDL6 - North shore/Observatory	Largemouth Bass	c	411.8	0.309[2]
10/15/2002	Big Bear Lake / MWDL1 - Dam	Largemouth Bass	c	427.2	0.378[2]
10/15/2002	Big Bear Lake / MWDC1 - Metcalf Creek	Largemouth Bass	c	432.4	0.438[2]
5/2/2003	Big Bear Lake / Summit Creek	Largemouth Bass	i	450.0	0.31[2]
5/2/2003	Big Bear Lake / North Shore Observatory	Largemouth Bass	i	420.0	0.39[2]
5/2/2003	Big Bear Lake / Summit Creek	Largemouth Bass	i	360.0	0.34[2]
5/2/2003	Big Bear Lake / Summit Creek	Largemouth Bass	i	390.0	0.19[2]
5/2/2003	Big Bear Lake / Summit Creek2	Largemouth Bass	i	450.0	0.55[2]
9/20/2004	Big Bear Lake	Largemouth Bass	c	438	0.28[3]
9/20/2004	Big Bear Lake	Largemouth Bass	c	426	0.244[3]
9/20/2004	Big Bear Lake	Largemouth Bass	c	408	0.219[3]
7/13/2005	Big Bear Lake	Largemouth Bass	c	437	0.313[3]
7/13/2005	Big Bear Lake	Largemouth Bass	c	423	0.321[3]
7/13/2005	Big Bear Lake	Pumpkin Seed	c	175	0.077[3]
11/9/2000	Stanfield Cutoff (SC-RBT-11-08-01)	Rainbow Trout	i	388	<0.04[2]
11/9/2000	Metcalf Bay (MB-RBT-11-08-01)	Rainbow Trout	i	308	<0.04[2]

Date Collected	Station Name	Species	Composite (c) or Individual (i)	Mean Length (mm)	Wet Wt Hg Conc (ppm)
11/9/2000	Dam (DAM-RBT-11-09-01)	Rainbow Trout	i	410	0.04[2]
11/9/2000	Dam (DAM-RBT-11-10-01)	Rainbow Trout	i	332	<0.04[2]
11/9/2000	Stanfield Cutoff (SC-RBT-11-08-01)	Rainbow Trout	i	388	0.04[2]
11/9/2000	Metcalf Bay (MB-RBT-11-08-01)	Rainbow Trout	i	308	<0.04[2]
11/9/2000	Dam (DAM-RBT-11-09-01)	Rainbow Trout	i	410	0.05[2]
11/9/2000	Dam (DAM-RBT-11-10-01)	Rainbow Trout	i	332	<0.04[2]
6/15/2001	Big Bear Lake	Rainbow Trout	i	not listed	0.035[2]
6/15/2001	Big Bear Lake	Rainbow Trout	i	not listed	<0.018[2]
6/15/2001	Big Bear Lake	Rainbow Trout	i	not listed	<0.019[2]
6/15/2001	Big Bear Lake	Rainbow Trout	i	not listed	<0.019[2]
6/15/2001	Big Bear Lake	Rainbow Trout	i	not listed	0.020[2]
6/15/2001	Big Bear Lake	Rainbow Trout	i	not listed	0.027[2]
6/15/2001	Big Bear Lake	Rainbow Trout	i	not listed	0.019[2]
6/15/2001	Big Bear Lake	Rainbow Trout	i	not listed	0.021[2]
10/15/2002	Big Bear Lake near the mouth of Summit Creek (MWDC5 Summit Creek)	Rainbow Trout	i	not listed	<0.05[2]
10/15/2002	Big Bear Lake near the mouth of Summit Creek (MWDC5 Summit Creek)	Rainbow Trout	i	not listed	<0.05[2]
10/15/2002	Big Bear Lake near the mouth of Summit Creek (MWDC5 Summit Creek)	Rainbow Trout	i	not listed	<0.05[2]
10/15/2002	Big Bear Lake near the mouth of Summit Creek (MWDC5 Summit Creek)	Rainbow Trout	i	not listed	<0.05[2]
10/15/2002	Big Bear Lake near the mouth of Summit Creek (MWDC5 Summit Creek)	Rainbow Trout	i	not listed	<0.05[2]

Date Collected	Station Name	Species	Composite (c) or Individual (i)	Mean Length (mm)	Wet Wt Hg Conc (ppm)
10/15/2002	Big Bear Lake near the mouth of Summit Creek (MWDC5 Summit Creek)	Rainbow Trout	i	not listed	<0.05[2]
10/15/2002	Big Bear Lake near the mouth of Summit Creek (MWDC5 Summit Creek)	Rainbow Trout	i	not listed	<0.05[2]
10/15/2002	Big Bear Lake near the mouth of Summit Creek (MWDC5 Summit Creek)	Rainbow Trout	i	not listed	<0.05[2]
9/20/2004	Big Bear Lake	Rainbow Trout	c	306	0.017[3]
9/21/2004	Big Bear Lake	Rainbow Trout	c	333	0.014[3]
9/21/2004	Big Bear Lake	Rainbow Trout	c	467	0.013[3]
9/21/2004	Big Bear Lake	Rainbow Trout	c	430	0.016[3]
9/21/2004	Big Bear Lake	Rainbow Trout	c	412	0.021[3]
7/14/2005	Big Bear Lake	Sculpin	c	86	0.109[3]
6/14/1989	Big Bear Lake	Smallmouth Bass	c	339.0	0.280[1]

[1] Fish tissues collected for the Toxic Substances Monitoring Program.

[2] Fish tissues collected by Chadwick Ecological Consultants and Jim Weber of the Big Bear Municipal Water District.

[3] Fish tissues collected and analyzed by Moss Landing Marine Laboratories.

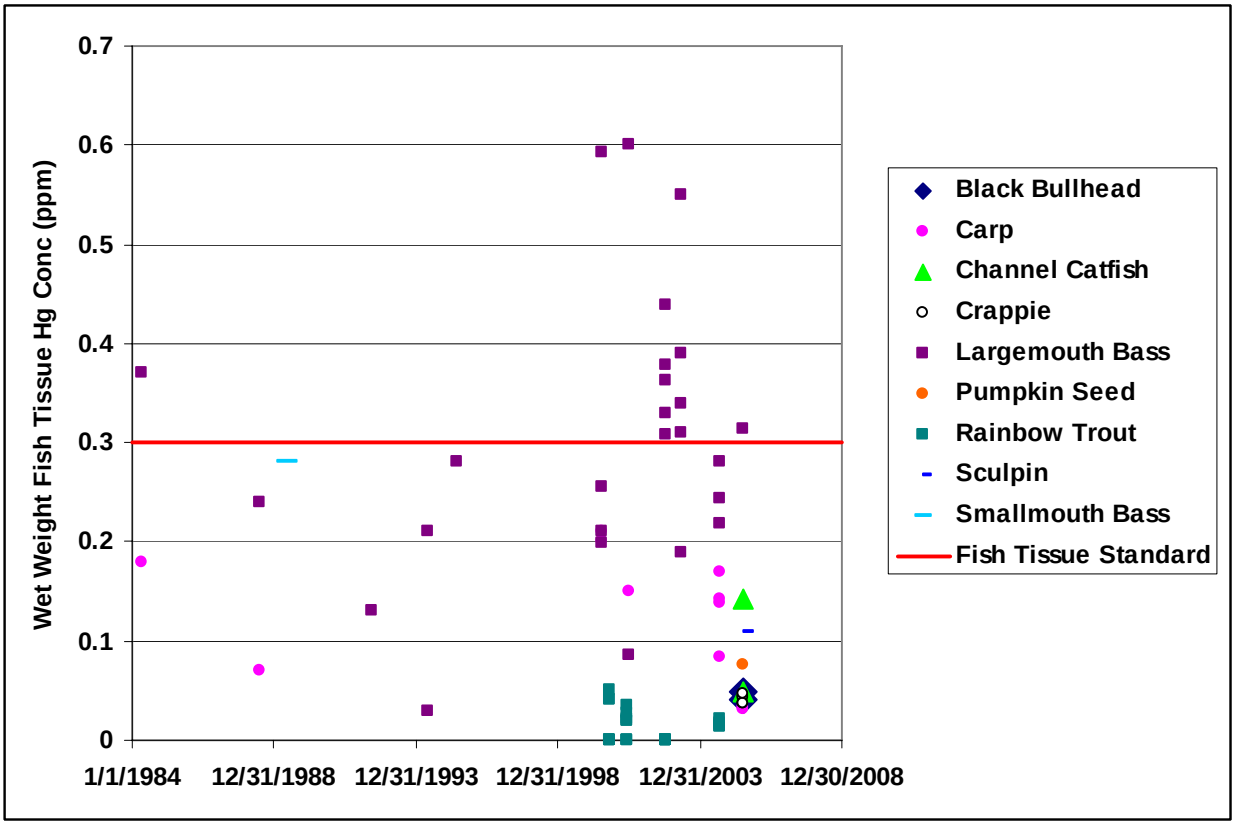

Figure 3. Fish Tissue Mercury Concentration Data Collected in Big Bear Lake

Piscivorous fish tend to have increased mercury tissue concentrations with age. Figure 4 shows the mercury concentrations in largemouth bass plotted against length, which is an approximate surrogate for age. For composite fish samples, concentration is plotted against mean length.

As expected, fish tissue mercury concentrations increase with length. Of the 10 measurements with mean length less than 300 mm, only one (10 percent) exceeds the State standard for mercury. Of the 17 samples with mean length greater than 300 mm, 13 measurements (approximately 76 percent) exceed the State standard.

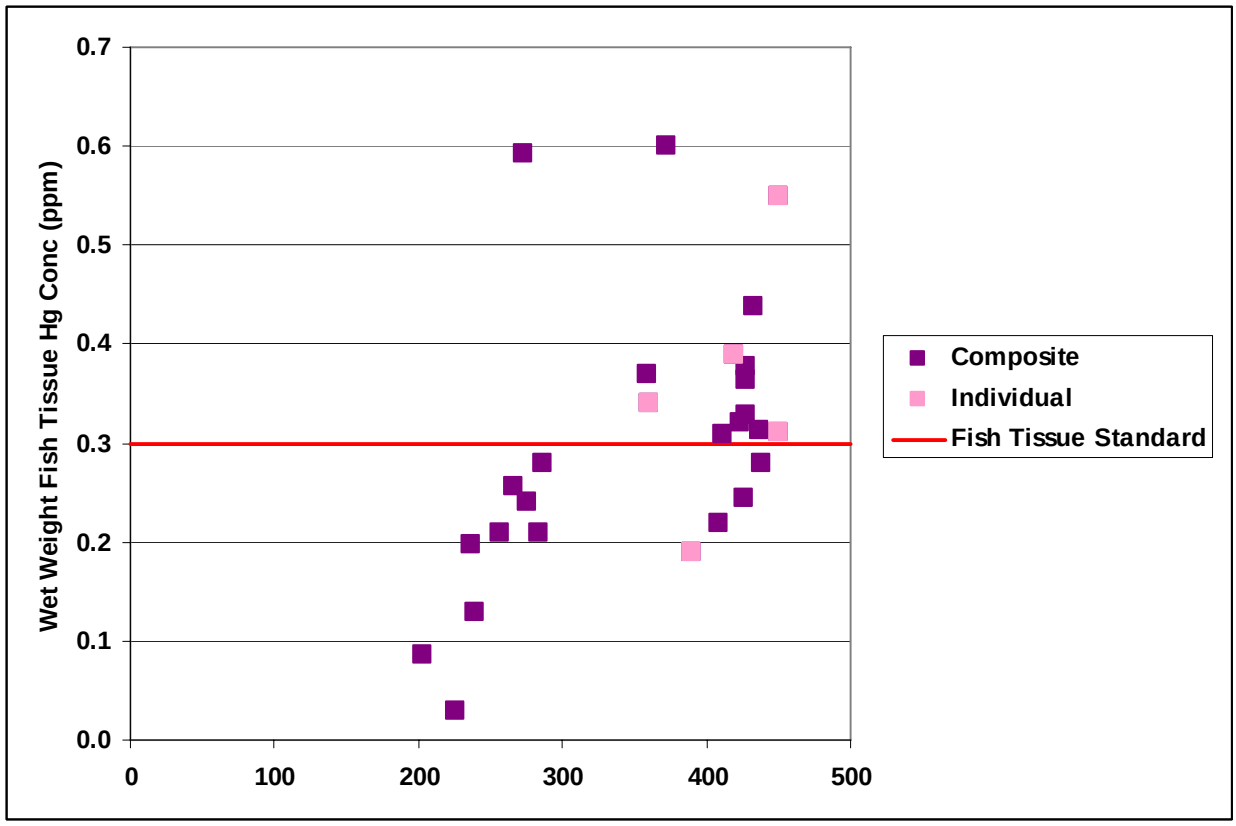

Figure 4. Mercury Concentrations in Largemouth Bass Versus Mean Length

3.3 TRIBUTARY MONITORING

The tributaries in the Big Bear Lake watershed have been sampled for water-column mercury concentrations during six events. Tributary sediment concentrations were sampled twice in June 2008.

3.3.1 Water Column Measurements

The Regional Board provided Tetra Tech with data from 1993 and 2002 in the form of copies of tables from two reports. The 1993 data table is referenced as a Clean Lakes Study – Phase I Report titled *Investigation of Toxics and Nutrients in Big Bear Lake*. Both Rathbun and Grout creeks had reported mercury concentrations of 0.0025 mg/L (2,500 ng/L). Neither the analytical methodology nor the detection limit was included in the photocopied pages provided to Tetra Tech, although the Clean Lakes Study stated an analytical method of 245.1 which has a minimum detection limit of 200 ng/L (personal communication, Michael Perez, Santa Ana Regional Water Quality Board to Alix Matos, Tetra Tech, October 14, 2008). Because the 1993 data were collected several years prior to the release of EPA's guidelines for the collection and handling of clean mercury samples (USEPA, 2001a), these samples may not be reflective of mercury concentrations present in the tributaries to Big Bear Lake.

Measurements on Knickerbocker Creek were taken on October 10, 2002. This data indicates a field measurement of 0.94 ng/L and a field duplicate of 0.60 ng/L. The source of this data was not identified although the laboratory analysis methodology listed was EPA 1631c (USEPA, 2001a) (information on the detection limit was not included).

On December 7, 2007, mercury samples were collected from four tributaries in the watershed. Table 5 summarizes the observed concentrations from each tributary. These data were analyzed with EPA method 1631Em (USEPA, 2002) with a detection limit of 0.5 ng/L.

Table 5. Water Column Mercury Concentrations (Total) Observed in Tributaries to Big Bear Lake (December 2007)

Creek	Count	Minimum (ng/L)	Average (ng/L)	Maximum (ng/L)
Grout	1	20.0	20.0	20.0
Knickerbocker	3	10.1	11.8	14.9
Rathbun	2	16.8	17.1	17.4
Summit	2	12.4	15.1	17.8

On May 29, 2008 six tributaries were sampled for total mercury concentrations (Table 6). All samples were analyzed with EPA method 1631Em (USEPA, 2002), which has a detection limit of 0.5 ng/L. These values are an order of magnitude less than those measured in December 2007, and relatively close in magnitude to those measured in October 2002. This may be indicative of seasonal variations in mercury concentrations delivered to Big Bear Lake.

Table 6. Water Column Mercury Concentrations (Total) Observed in Tributaries to Big Bear Lake (May 2008)

Creek	Observations (ng/L)
Bear	0.8
Grout	1.4
Knickerbocker	1.0
Metcalf	1.2
Rathbun	1.4
Summit	1.8

On June 11, 2008 another round of tributary water column sampling occurred. Samples collected on Bear, Rathbun, Metcalf, Grout, Knickerbocker, and Summit creeks were all less than the detection limit of 0.5 ng/L. Additional samples were collected on June 25, 2008 on Bear, Metcalf, Grout, Knickerbocker, and Minnelusa Canyon creeks, and samples were again all less than detection (0.5 ng/L). Both rounds of sampling that occurred in June 2008 were analyzed with EPA method 1631Em (USEPA, 2002).

3.3.2 Sediment Samples

Measurements of sediment-mercury concentrations were analyzed in June 2008 for six tributaries. Two different mercury analyses were performed by the laboratory. The EPA 1631Em method (USEPA, 2002), which has a detection limit of 0.0005 mg/kg, was used to analyze one sample from each of three tributaries: Grout, Metcalf, and Rathbun. Measurements for these observations range from 0.00093 mg/kg to 0.00248 mg/kg. Samples from these three creeks were also analyzed using EPA method 245.7m

(USEPA, 2005a), which has a detection limit of 0.01 mg/kg. Using this analysis, the samples collected had mercury concentrations less than detection.

Samples from the other three creeks were only analyzed with EPA method 245.7m (USEPA, 2005a). Observations range from 0.02 to 0.03 mg/kg on Knickerbocker and Summit creeks and from 0.09 to 0.11 mg/kg on Minnelusa Canyon Creek. The sediment samples collected from Minnelusa Canyon Creek are similar to those observed in Big Bear Lake which had mercury concentrations ranging from 0.07 to 0.11 mg/kg and were also analyzed with EPA method 245.7m. Observations from the June tributary sampling events are shown in Table 7.

Table 7. Sediment-Mercury Concentrations Sampled from Tributaries to Big Bear Lake

Creek	Sampling Data	Observations (mg/kg)	Detection Limit
Grout	June 11, 2008	0.00093 ND	0.0005 0.01
Metcalf	June 11, 2008	0.00248 ND	0.0005 0.01
Rathbun	June 11, 2008	0.00243 ND	0.0005 0.01
Knickerbocker	June 11, 2008	0.02	0.01
Summit	June 4, 2008	0.03 0.02	0.01 0.01
Minnelusa Canyon	June 25, 2008	0.11 0.09	0.01 0.01

4 Source Estimation

Sources of mercury to Big Bear Lake include loads from the watershed and atmosphere. Though the majority of the watershed load likely originates from atmospheric deposition, delivery is dependent on runoff and sediment transport to the lake. These processes are simulated based on results of previous HSPF modeling for the watershed (Boyd, 2005), as described in Section 5.

4.1 Near Field Sources of Atmospheric Mercury

Major atmospheric point sources of mercury can cause locally elevated areas of near-field atmospheric deposition downwind. Mercury emitted from man-made sources usually contains both gaseous elemental mercury (Hg(0)) and divalent mercury (Hg(II)). Hg(II) species, because of their solubility and their tendency to attach to particles, are redeposited relatively close to their source (probably within a few hundred miles), whereas Hg(0) remains in the atmosphere much longer, contributing to long-range transport. Reactive gaseous mercury and particulate mercury are also associated with man-made sources and typically deposit within approximately 100 miles of the source.

Significant potential near-field emission sources of airborne mercury include coal-fired power plants, steel recycling facilities, waste incinerators, cement and lime kilns, smelters and gold mine roasters, pulp and paper mills, and chlor-alkali factories. Emissions from such sources are summarized in EPA's Toxic Release Inventory (TRI). Facilities that reported emissions of mercury in southern California in 2006 to the USEPA (2008) are shown in Figure 5. Table 8 summarizes the loads reported from each facility in the TRI within 200 miles of the Big Bear Lake watershed. Forty-three out of 78 facilities listed in the database reported zero pounds of mercury released in 2006; 23 reported emissions less than 10 pounds per year. Four of the top five sources of mercury emissions were due to cement manufacturing facilities; one of the top five is an oil refinery. Total reported mercury emissions in 2006 in Southern California were 1,551 pounds, and nearly 40 percent of emissions were produced at the Lehigh Southwest Cement Co. located approximately 100 miles from the watershed.

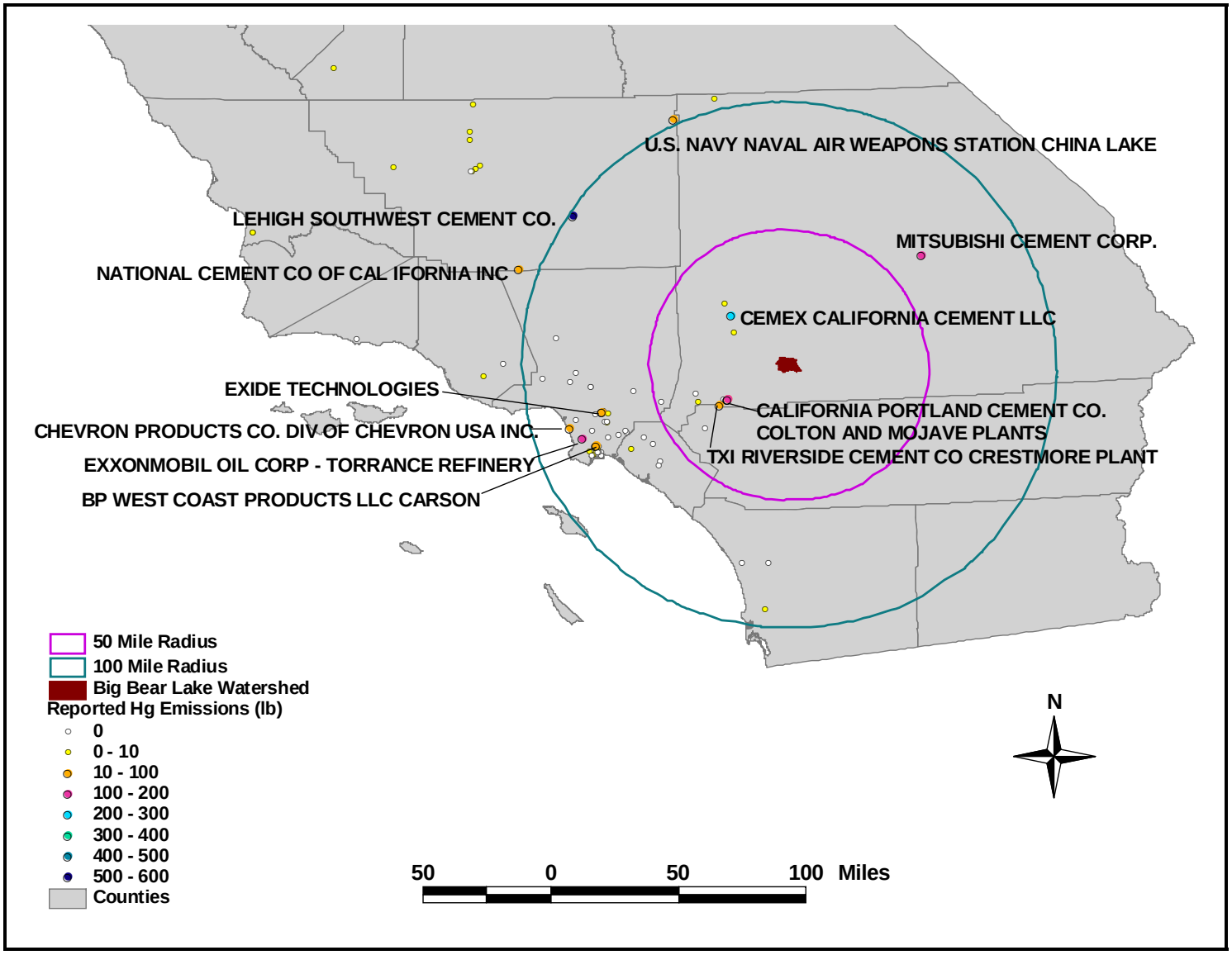

Figure 5. Location of Facilities Reporting Mercury Emissions in Southern California

Table 8. Mercury Emissions Reported in the 2006 USEPA Toxic Release Inventory

Facility Name	Total Air Emissions (lbs)
Lehigh Southwest Cement Co.	586.3
Cemex California Cement LLC	271.0
Exxon Mobil Oil Corp - Torrance Refinery	162.7
Mitsubishi Cement Corp.	161.0
California Portland Cement Co. Colton Plant	137.5
National Cement Co. of California Inc.	59.00
Exide Technologies	58.60
U.S. Navy Naval Air Weapons Station China Lake	20.90
BP West Coast Products LLC Carson	17.50
Chevron Products Co. Div of Chevron USA Inc.	16.10
California Portland Cement Co. Mojave Plant	13.10
TXI Riverside Cement Co. Crestmore Plant	11.82
Ultramar Inc. Wilmington Refinery	5.21
Commerce Refuse-To-Energy Facility	4.03
Conoco Phillips Co. LA Refinery Wilmington Plant	3.90
Conoco Phillips Santa Maria Facility Carbon Plant	3.62
Tesoro Los Angeles Refinery	3.00
Ace Cogeneration Facility	2.40
Conoco Phillips Co. Los Angeles Refinery Carson Plant	2.40
GHN Neon Inc.	1.79
Big West of California Refinery	1.60
Mt. Poso Cogeneration	1.48
Rio Bravo Poso	0.95
Chemical Waste Management Inc.	0.90
Rio Bravo Jasmin	0.84
Clean Harbors Buttonwillow LLC	0.81
Lunday-Thagard Co	0.64
TIN, Inc. Dba Temple Inland	0.50
Alltech Associates Inc.	0.50
San Joaquin Refining Co. Inc.	0.33
Teledyne Imaging Sensors	0.20

Facility Name	Total Air Emissions (lbs)
TXI Riverside Cement Oro Grande Plant	0.20
Hanson Aggregates Pacific Southwest	0.10
Tricor Refining LLC	0.03
Conoco Phillips Santa Maria Facility - Refinery	0.03
Facilities Reporting Zero Pounds of Mercury Emissions in 2006	
Ultramar Inc. Marine Terminal	Raytheon Vision Systems
ATSC East Hynes Terminal	National Ready Mix Concrete Co.
ATSC Marine Terminal 3	National Ready Mix Concrete Co.
Clean Harbors Los Angeles LLC	Tesoro Ref & Mktg Co. Long Beach Terminal
Ribost Terminal LLC	BP West Coast Products LLC Carson
Blue Heron Paper Co. of California LLC	BP West Coast Products LLC Carson
Mercotac, Inc.	Equilon Bakersfield Terminal
Kinsbursky Brothers Supply Inc.	BP Wilmington Calciner
Tesoro Corp Wilmington Sales Terminal	Rho-Chem Corp
Chemoil Terminals Corp	American Polymers Corp
National Ready Mix Concrete Co.	Conocophillips Los Angeles Refinery Marine Terminal
National Ready Mix Concrete Co.	Amvac Chemical Corp
Marchem Pacific Inc.	Polyone Corp
Huntsman Advanced Materials Americas Inc. - La Site	Pacific Polymers International Inc.
National Ready Mix Concrete Co.	National Ready Mix Concrete Co.
Spectrum Laboratory Products Inc.	National Ready Mix Concrete Co.
National Ready Mix Concrete Co.	Innovative Polymer Systems Inc.
Arco Vinvale Terminal	Hanson Aggregates Pacific Southwest
National Ready Mix Concrete Co.	Arco Colton Terminal
International Coatings Co. Inc.	Hydroseal Polymers Inc.
Long Beach Marine Terminal	B.J.B. Enterprises Inc.
National Ready Mix Concrete Co.	

4.2 GEOLOGICAL SOURCES

The geology underlying a watershed has the potential to both directly and indirectly contribute to mercury loadings. Geological formations that contain mercury species can directly contribute to mercury loadings through weathering and erosion. Geological formations containing low-grade deposits of precious metals (e.g., gold, silver, and copper) have also often been mined using mercury as an amalgam to leach these metals from the ore. As a byproduct of mining activities, mercury loadings can indirectly be influenced by certain geological formations.

4.2.1 Direct Geological Sources of Mercury

There are no known geological formations within the Big Bear Lake watershed that definitively contain significant mercury concentrations. In general, however, mercury has a higher probability of occurrence in mineralized areas along fault lines, intrusive dikes in igneous formations, or resulting from natural springs. Volcanic activity has the potential to release mercury into the air, so areas with large ash deposits may contain higher concentrations of mercury. Mercury is also more likely to occur in shale and slate deposits as they are derived from clays, which have high affinities for adsorbing metals such as mercury (this affinity explains why coal burning power plants emit mercury).

The Big Bear Lake watershed is located in the Transverse Range on the east side of the San Andreas Fault. The California Geological Survey has posted a map online of the earthquake hazard across the state (http://www.consrv.ca.gov/cgs/rghm/psha/Pages/index.aspx). This map indicates that fault line activity in the Big Bear Lake watershed is moderate. The sediment TMDL for this watershed includes a discussion of its geology which indicates that the three primary rock groups include carboniferous and pre-carboniferous sedimentary rocks, volcanic and metamorphic rocks, and Cenozoic sedimentary deposits (Boyd, 2005).

Though the geological characteristics of the watershed indicate some potential for naturally elevated mercury levels, this has not yet been confirmed. Sediment mercury concentrations sampled from the mouths of tributaries and the lake bottom typically range from non-detect to 0.11 mg/kg. The highest tributary concentrations have been collected from Minnelusa Canyon Creek on the north side of the lake. Inlake sediment concentrations near this creek are somewhat higher than those measured further downlake, and could indicate some local geological contributions from this area.

4.2.2 Indirect Geological Sources of Mercury

Geological formations containing deposits of precious metals (e.g., gold, silver, and copper) have been targets of historic and current mining activities. In cases where the desired metals are contained in ore as opposed to veins, extraction of the desired metal commonly occurs through the process of amalgamation, in which mercury is used as the amalgam. Amalgamation is an easy and inexpensive process of removing fine metal particles from ore, but when poorly implemented, it can lead to spillage of mercury, contaminated mine tailings, and localized atmospheric deposition. Thus, in relation to mining potential, the geological formations in a watershed can indirectly influence mercury loadings, and are reviewed in this section.

No precious metal mines are known to have operated within the Big Bear Lake watershed (personal communication, Michael Perez, Santa Ana Regional Water Quality Control Board). A statewide map of historic gold mines produced by the California Geological Survey shows a large number of mines in the southwest quadrant of San Bernardino County (http://www.conservation.ca.gov). Anecdotal information infers that while prospecting activities occurred briefly in the watershed, the larger mines were located to the north and east of Bear Valley.

4.3 Atmospheric Deposition

Deposition of mercury from the atmosphere may occur in either wet or dry form. Though wet deposition of mercury has been monitored near Big Bear Lake, the period of record is relatively short. A regression analysis based on elevation and National Atmospheric Deposition Program (NADP) monitoring data may be used to predict wet deposition rates for years without monitoring data. Dry deposition is rarely monitored; national scale mercury deposition models are used to estimate loads from dry deposition.

4.3.1 Simulated Mercury Deposition Rates

USEPA has undertaken several national-scale modeling efforts to characterize mercury deposition. For the 1997 Report to Congress, EPA developed the Regional Lagrangian Model of Air Pollution (RELMAP) modeling (USEPA, 1997, Section 5.1.3) to produce gridded estimates of deposition rates. The report included comparisons between wet deposition of mercury from local anthropogenic sources and a global-scale background concentration. While the RELMAP modeling is now believed to be outdated and does not fully reflect the current state of understanding of atmospheric chemistry leading to deposition of mercury (personal communication, O. Russell Bullock, USEPA, to J. B. Butcher, Tetra Tech, 7/25/2001), these results suggested that the deposition of mercury in the southwest has a strong global or long-range component.

The RELMAP modeling had considerable uncertainty, particularly for the Southwest, where monitoring data were scarce and dry deposition of mercury may play a larger role. The broad-scale RELMAP modeling also could not take into account the effects of local topography on deposition, nor does it account for the interaction of chloride ions in power plant emissions with elemental mercury to form species such as mercuric chloride that are subject to more rapid deposition. EPA subsequently developed a more sophisticated regional mercury transport model (Community Multiscale Air Quality (CMAQ-Hg)) based on the Models-3/CMAQ system (Byun and Ching, 1999), which incorporated a more sophisticated representation of mercury chemistry. In support of the Clean Air Mercury Rule, the CMAQ-Hg model was used to predict mercury deposition for the 2001 base case on a 36x36 km model grid (USEPA, 2005b). The baseline scenario was used to estimate wet and dry mercury deposition rates.

The CMAQ 2001 analysis was also conducted with US power plant emissions set to zero. Wet and dry rates of deposition were not distinguished in the output supplied to Tetra Tech. In most of the southwest region of the US, turning off US power plants did not significantly impact the rate of total mercury deposition. Simulated mercury deposition rates for the CMAQ grid cell that contains the Big Bear Lake watershed are summarized in Table 9.

Table 9. CMAQ 2001 Output for Grid Cell Underlying the Big Bear Lake Watershed

Component	Mercury Deposition Rate g/km^2/yr
Baseline Scenario	
Wet	2.3235
Dry	21.1343
Total	23.4578
Zero Out Scenario	
Total	23.4302

An additional run of the CMAQ model was undertaken for 2002 meteorological conditions, with alterations to the functional description of processes leading to the dry deposition of mercury. The 2002 CMAQ results are summarized in Table 10. The two simulations predict similar rates of wet deposition, but dry deposition is nearly twice as high in the 2002 simulation. Results of the CMAQ 2002 model run are generally more accurate than the 2001 simulation for watersheds where ambient mercury concentration data have been used to calculate local rates of dry deposition (Tetra Tech, 2008a).

Table 10. CMAQ 2002 Output for Grid Cell Underlying the Big Bear Lake Watershed

Component	Mercury Deposition Rate g/km^2/yr
Wet	2.0790
Dry	39.5869
Total	41.6659

4.3.2 Wet Deposition Monitoring

Mercury deposition from the atmosphere to the earth's surface may occur in several forms: gaseous elemental mercury (Hg(0)), divalent ionic mercury (Hg(II)), reactive gaseous mercury (RGM), and aerosol particulate mercury (Hg-P). Atmospheric deposition can be divided into short-range or near-field deposition, which includes deposition from sources located near the watershed, and long-range or far-field deposition, which includes mercury deposition from regional and global sources. Mercury emitted from man-made sources usually contains both gaseous elemental mercury (Hg(0)) and divalent ionic mercury (Hg(II)). Hg(II) species, because of their solubility and their tendency to attach to particles, are redeposited relatively close to their source (probably within a few hundred miles), whereas Hg(0) remains in the atmosphere much longer, contributing to long-range transport.

Deposition may either occur in wet form (associated with precipitation) or dry form (associated with particulate or gaseous settling). Wet deposition is monitored at select locations across the country by the Mercury Deposition Network (MDN). In May 2006, a MDN station was installed at Converse Flats, CA approximately four miles south of Big Bear Lake. Quality-assured data are available from the MDN website through July 2007; provisional data were provided to Tetra Tech through April 2008.

Figure 6 through Figure 8 show the measurements of precipitation, mercury concentration, and mercury deposition at Converse Flats. Points connected by lines indicate successive weeks with measured precipitation and mercury wet deposition measurements. Single points indicate that no precipitation fell the week prior or the week after. Weekly precipitation measurements range from 0 to 130 mm (0 to 5.1 inches). The average observed mercury concentration during precipitation events is 14.0 ng/L, and the volume-weighted average concentration is 9.0 ng/L. Weekly deposition rates measured at Converse Flats range from 0 to 1,442 ng/m^2, resulting in an average annual deposition rate of 3.45 g/km^2/yr.

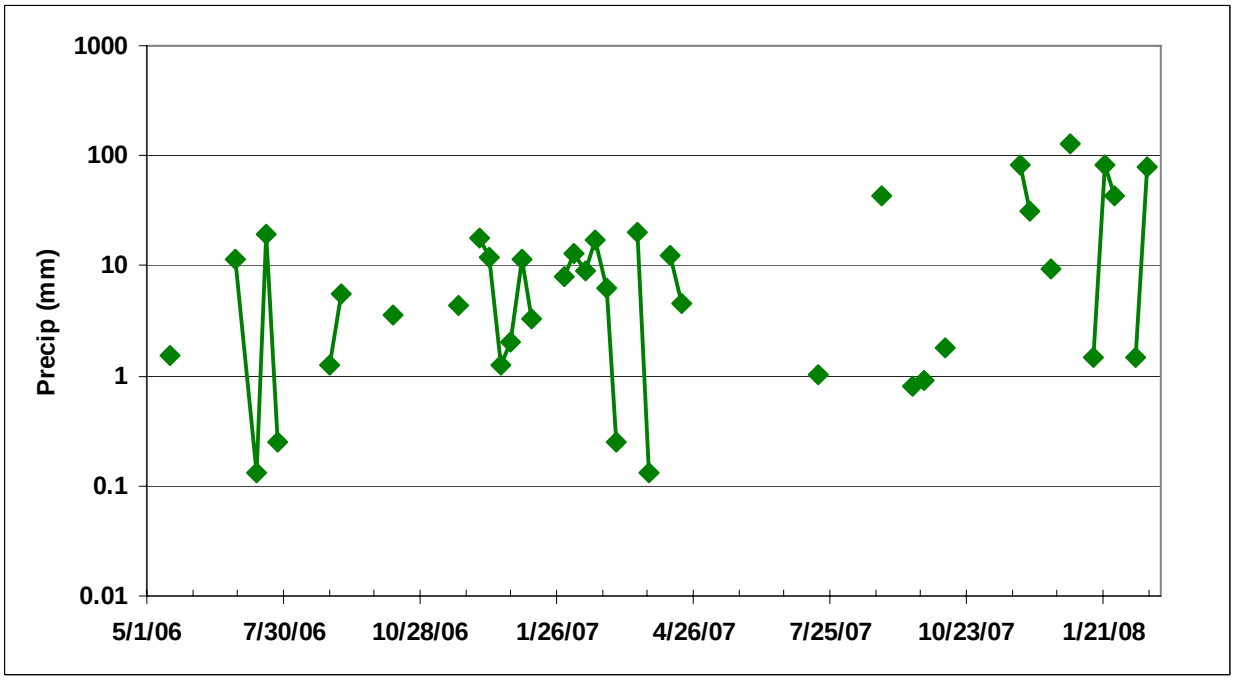

Figure 6. Weekly Precipitation Measurements at CA94

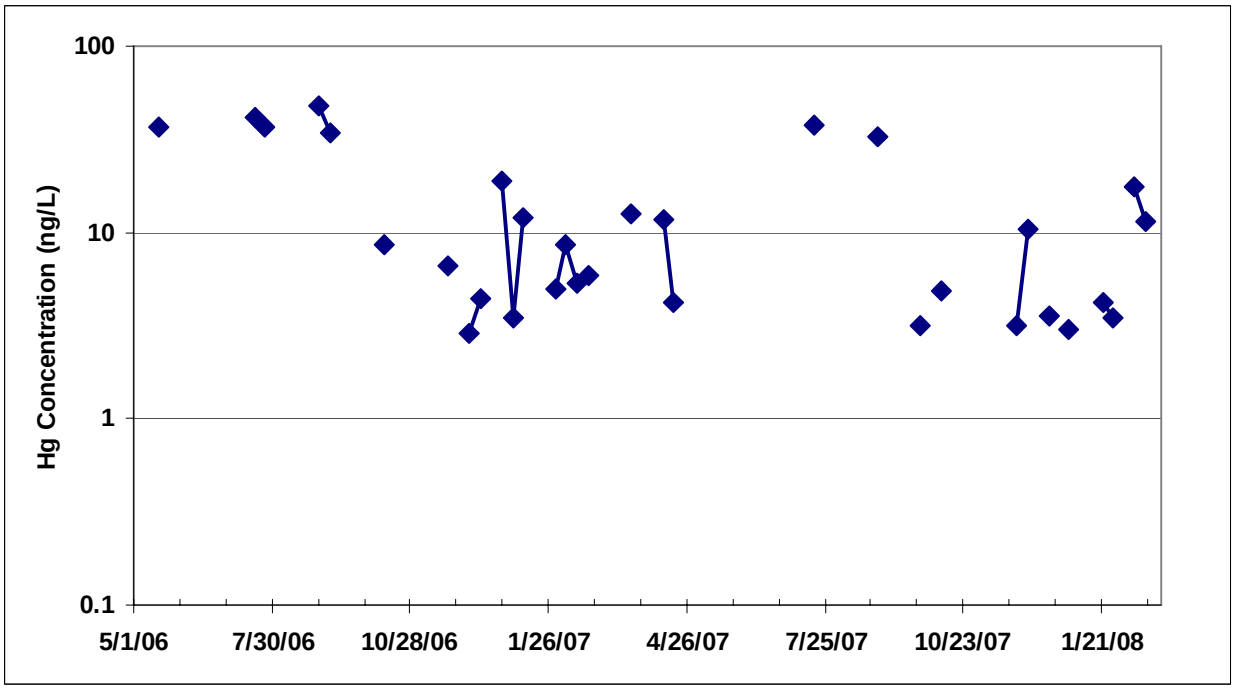

Figure 7. Weekly Mercury Concentrations at CA94

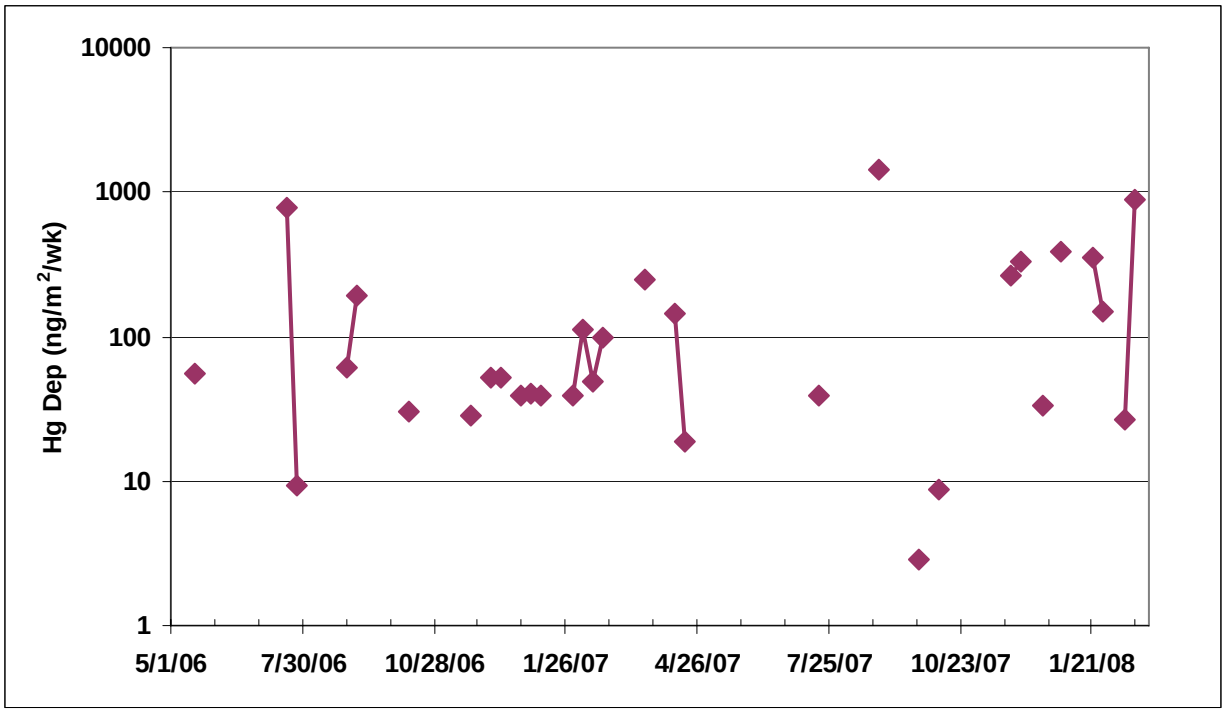

Figure 8. Weekly Mercury Wet Deposition Rates at CA94

4.3.3 Wet Deposition Estimation

MDN station CA94 (Converse Flats) was installed in May 2006 to support development of the Big Bear Lake mercury TMDL. During the period of record, the average annual wet deposition rate is 3.45 g/km^2/yr. In addition to mercury concentrations, this site also monitored nitrate and sulfate wet deposition concentrations through the National Atmospheric Deposition Program (NADP). Deposition of particulate and reactive gaseous mercury derived from combustion sources is often correlated with nitrate and sulfate deposition. A multiple regression on nitrate and sulfate deposition concentrations measured at CA94 yields an estimate of mercury concentration with an R^2 of 0.64. Figure 9 shows a comparison of the measured and estimated mercury concentrations resulting from the following equation:

$$LOG_{10}\,(Hg, ng/L) = 1.1644 + 0.0918\ LOG_{10}\,(NO_3, mg/L) + 0.4949\ LOG_{10}\,(SO_4, mg/L),\ R^2 = 63.6\%.$$

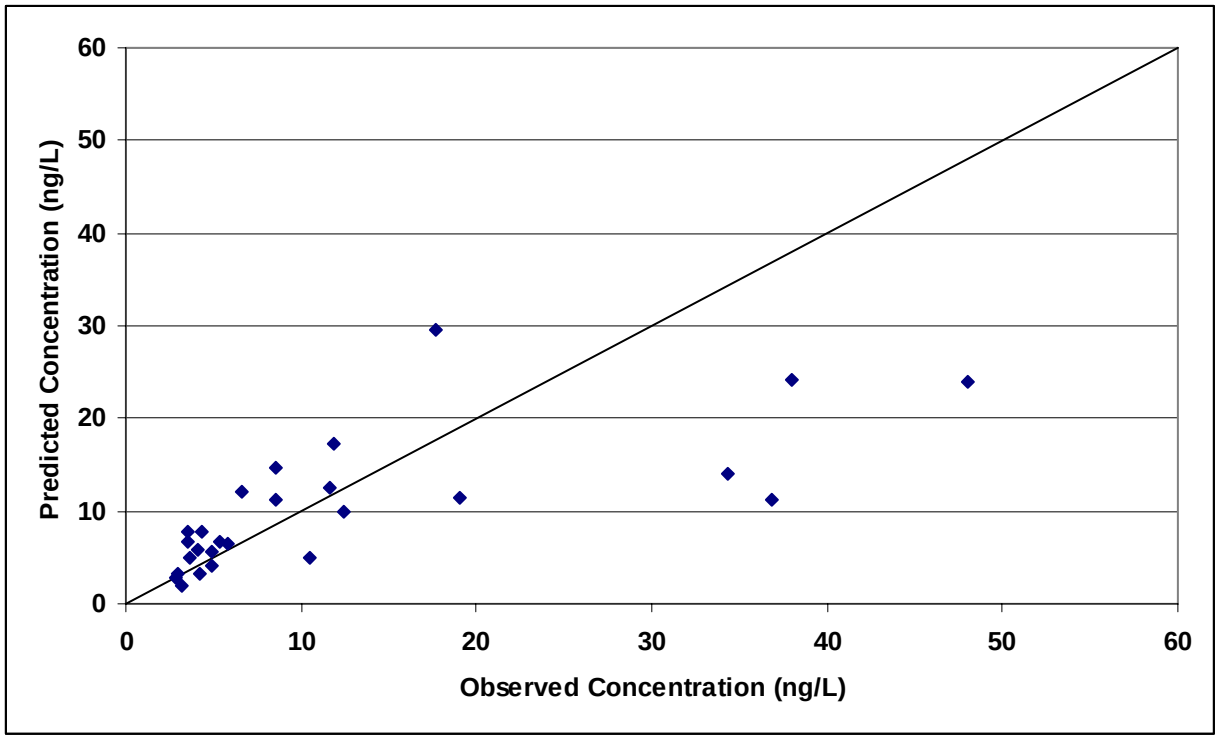

Figure 9. Comparison of Measured and Predicted Mercury Wet Deposition Concentrations at Converse Flats

The NADP has four stations in southern California where nitrate and sulfate concentrations have been measured weekly over a longer period of time (Figure 10). Data from these stations were combined to develop a regression equation that could be used to predict annual precipitation-weighted nitrate and sulfate concentrations at Big Bear Lake to extend the estimated mercury deposition time series. Data from the Converse Flats location were excluded because complete years were not available. Table 11 lists the NADP monitoring stations and their periods of record used for this analysis.

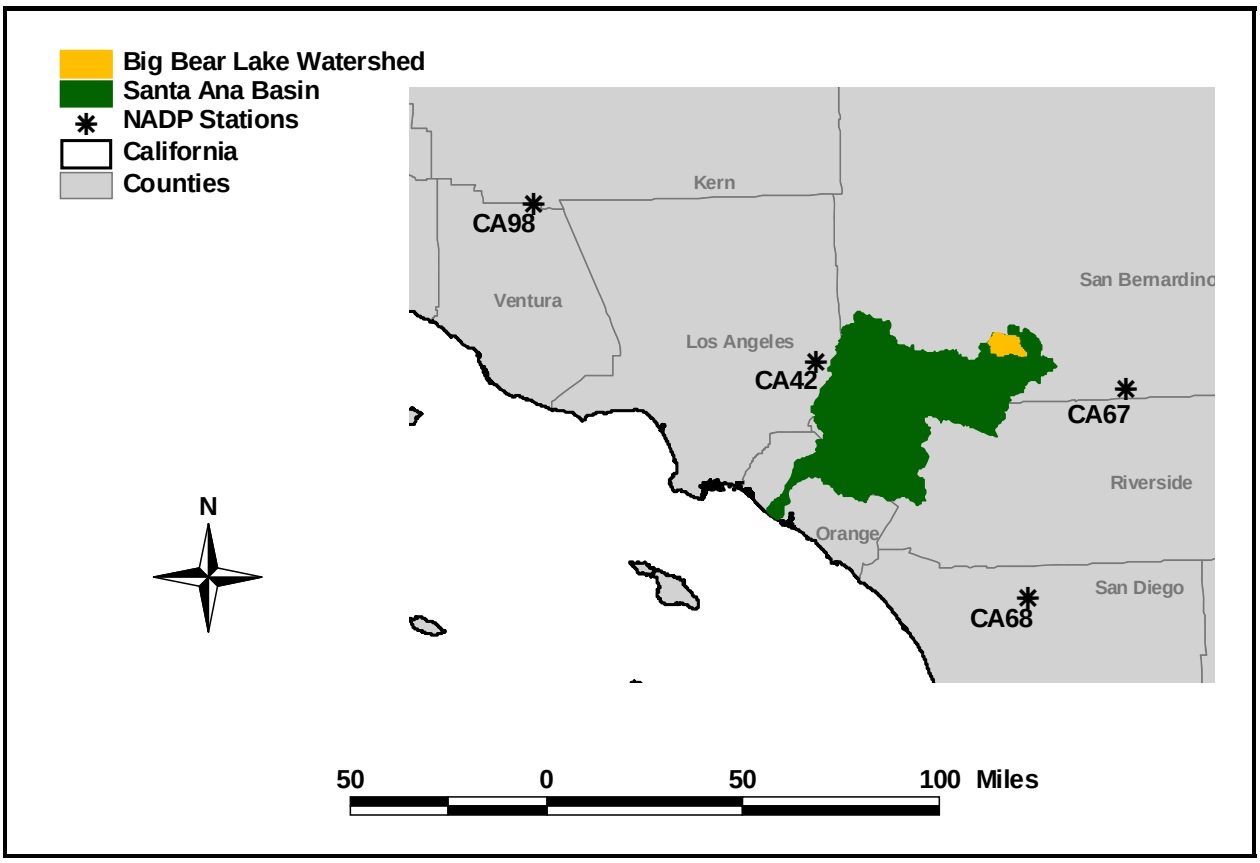

Figure 10. Location of NADP Monitoring Stations

Table 11. NADP Stations Used to Develop Nitrate and Sulfate Regressions Based on Elevation and Year

ID	Name	Period of Record	Elevation (m)
CA42	Tanbark Flat	January 1982 to February 2008	853
CA67	Joshua Tree	September 2000 to February 2008	1,239
CA68	Palomar Mountain	March 1983 to January 1988	1,695
CA98	Chuchupate Ranger Station	March 1983 to January 1996	1,614

Figure 11 and Figure 12 show the annual precipitation-weighted nitrate and sulfate concentrations, respectively, at each of the four sites used for the regression analysis. At each of the four stations, concentrations of both species show a decreasing trend with time.

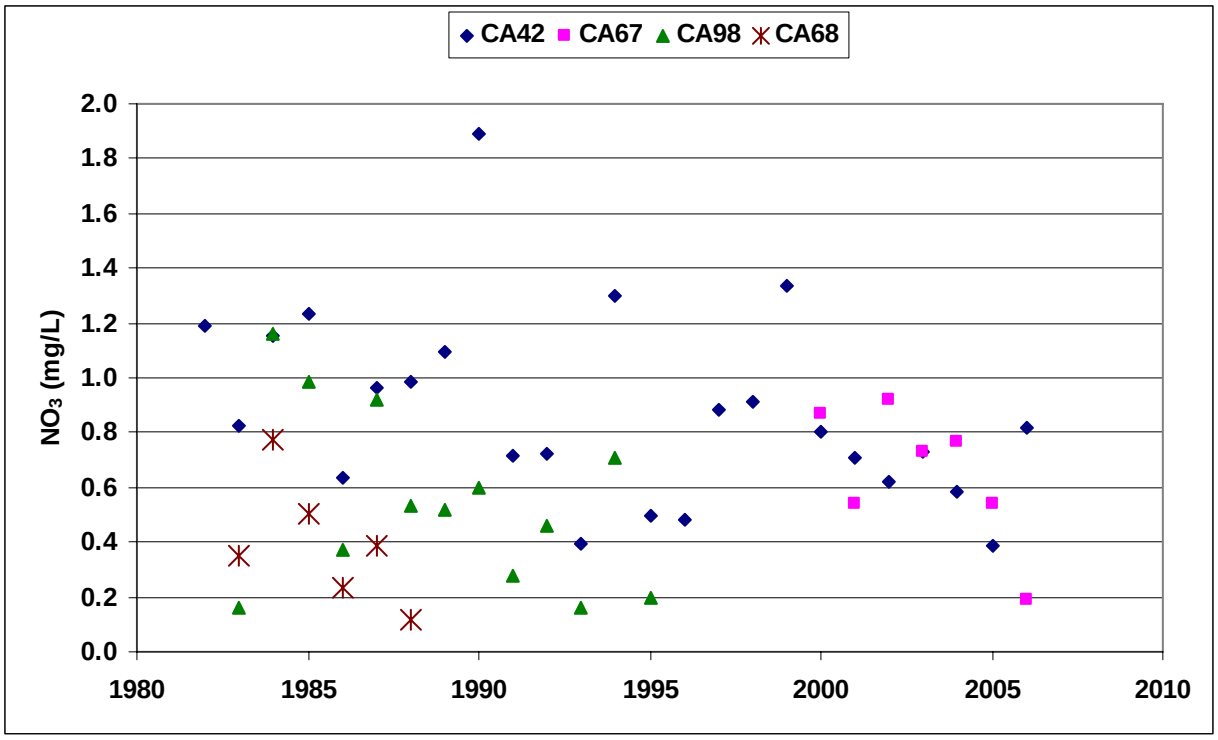

Figure 11. Annual Precipitation-Weighted Nitrate Concentrations at Four Locations in Southern California

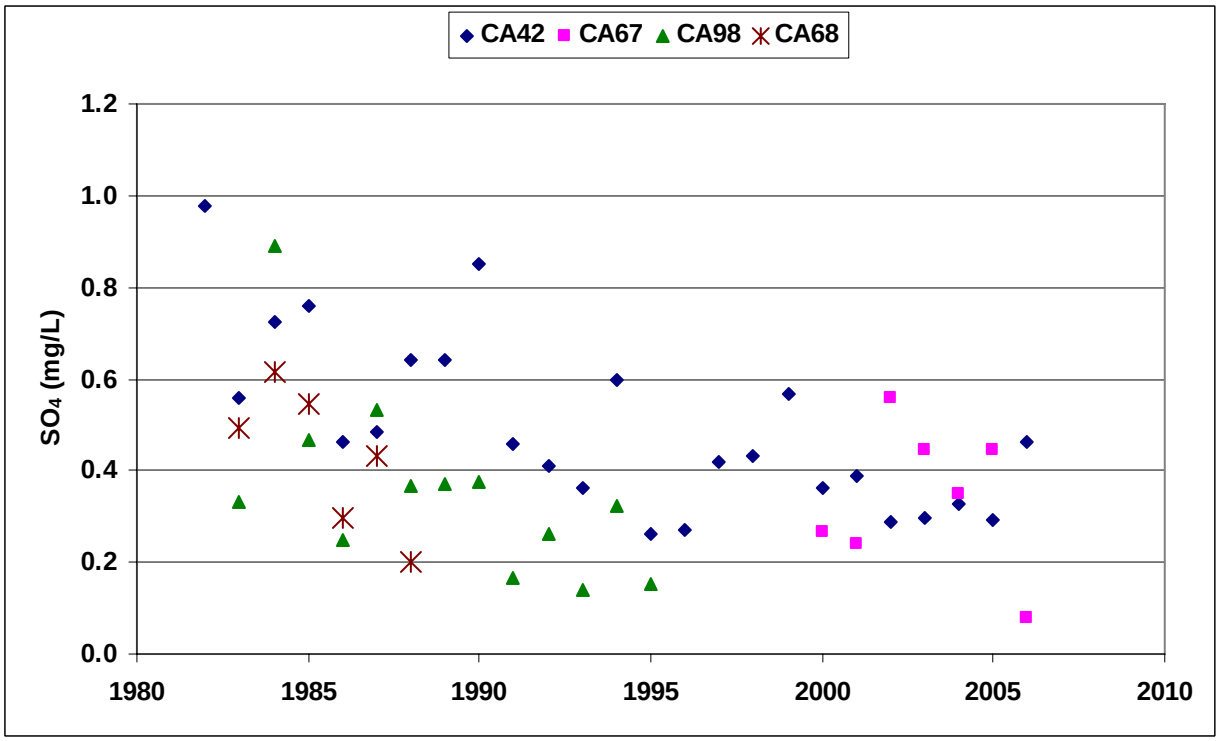

Figure 12. Annual Precipitation-Weighted Sulfate Concentrations at Four Locations in Southern California

Regression analyses combining the elevation of each station along with year resulted in the following equations for predicting annual precipitation-weighted nitrate and sulfate concentrations:

$$LOG_{10}(NO_3, mg/L) = 110.69 - 35.52\ LOG_{10}(Year) - 1.178\ LOG_{10}(Elevation, m),\ R^2 = 31.5\%.$$

$$LOG_{10}(SO_4, mg/L) = 245.57 - 73.82\ LOG_{10}(Year) - 0.783\ LOG_{10}(Elevation, m),\ R^2 = 38.2\%.$$

These equations were then be used to predict the annual precipitation-weighted nitrate and sulfate concentrations at Big Bear Lake (2,053 m). Table 12 presents the concentrations estimated for each year for this location.

Table 12. Predicted Annual Precipitation-Weighted Nitrate and Sulfate Wet Deposition Concentrations at Big Bear Lake

Year	NO_3 (mg/L)	SO_4 (mg/L)
1980	0.375	0.396
1981	0.368	0.381
1982	0.362	0.367
1983	0.357	0.354
1984	0.351	0.341
1985	0.345	0.329
1986	0.339	0.317
1987	0.334	0.305
1988	0.329	0.294
1989	0.323	0.283
1990	0.318	0.273
1991	0.313	0.263
1992	0.308	0.253
1993	0.303	0.244
1994	0.298	0.235
1995	0.293	0.227
1996	0.288	0.219
1997	0.284	0.211
1998	0.279	0.203
1999	0.275	0.196
2000	0.270	0.189
2001	0.266	0.182
2002	0.262	0.175
2003	0.257	0.169
2004	0.253	0.163
2005	0.249	0.157
2006	0.245	0.151
2007	0.241	0.146

Precipitation-weighted annual concentrations of mercury can then be estimated from the equation developed from the CA94 mercury, nitrate, and sulfate data. Precipitation monitoring at Big Bear Lake Dam allows for computation of the annual mercury wet deposition rate to Big Bear Lake. Table 13 presents the calculated annual precipitation-weighted mercury concentration, the total precipitation measured at the dam, and the estimated wet deposition rate to the lake surface. The wet deposition load is based on a lake surface area of 2,971 acres (12.02 km^2).

Table 13. Mercury Concentrations and Resulting Wet Deposition Rates to Big Bear Lake

Year	Hg (ng/L)	Annual Precipitation (mm)	Hg Wet Deposition Rate ($g/km^2/yr$)	Hg Wet Deposition Load (g/yr)
1980	8.44	1600.20	13.50	162.3
1981	8.27	423.42	3.50	42.1
1982	8.11	1248.16	10.12	121.6
1983	7.95	1447.04	11.50	138.2
1984	7.79	512.83	3.99	48.0
1985	7.64	568.96	4.34	52.2
1986	7.48	893.06	6.68	80.3
1987	7.34	698.25	5.12	61.6
1988	7.19	614.17	4.42	53.1
1989	7.05	439.93	3.10	37.3
1990	6.91	563.88	3.90	46.9
1991	6.78	977.14	6.62	79.6
1992	6.64	1118.36	7.43	89.3
1993	6.51	1874.77	12.21	146.8
1994	6.39	807.21	5.15	62.0
1995	6.26	1244.60	7.79	93.7
1996	6.14	1042.42	6.40	76.9
1997	6.02	685.80	4.13	49.6
1998	5.90	1280.16	7.55	90.8
1999	5.78	335.79	1.94	23.3
2000	5.67	630.43	3.57	43.0
2001	5.56	777.75	4.32	52.0
2002	5.45	381.51	2.08	25.0
2003	5.34	823.98	4.40	52.9
2004	5.24	1003.30	5.26	63.2
2005	5.14	1390.40	7.14	85.9
2006	5.04	964.18	4.86	58.4
2007	4.94	409.19	2.02	24.3

4.3.4 Dry Deposition

Although there are few direct measurements to support well-characterized estimates, dry deposition of mercury often is assumed to be approximately equal to wet deposition (e.g., Lindberg et al., 1991; Lindqvist et al., 1991). This assumption is not always valid in the southwest. Dry and wet deposition was measured in the Pecos River basin of eastern New Mexico in 1993–1994 (Popp et al., 1996). Average weekly deposition rates were calculated to be 140 ng/m^2-wk of mercury from dry deposition and 160 ng/m^2-wk of mercury from wet deposition. These data demonstrate the importance of both dry and wet deposition as sources of mercury. Early throughfall studies in a coniferous forest indicate that dry deposition beneath a forest canopy could be on the order of 50 percent of the wet deposition signal (Lindqvist et al., 1991). However, the local university cooperator at the Caballo, NM MDN station (NM10) estimated dry deposition as up to six times wet deposition at this arid site (Caldwell et al., 2003).

Atmospheric dry deposition involves three groups of mercury species: reactive gaseous mercury (RGM), aerosol particulate mercury (Hg-P), and gaseous elemental mercury (Hg(0)). All three forms may deposit to land and water surfaces, but there are significant differences in chemistry and rates. Hg(0) is the dominant species in terms of ambient concentration; however, net deposition rates are much higher for the other forms (Lindberg et al., 1992).

Dry mercury deposition to water surfaces is typically comprised of the reactive gaseous and particulate forms of mercury only. Elemental mercury contributes to the loading to land surfaces as it is accumulated in vegetation through stomatal vapor uptake (Eriksen et al., 2003). Contributions to soil systems occur as vegetative material falls and decays on the soil surface.

No direct measurements of dry deposition are available for this watershed. As an initial estimate, the CMAQ 2002 simulation results may be used to estimate the rate of total mercury deposition to the land (41.66 g/km^2/yr). Subtracting the average annual wet deposition rate for this watershed (3.45 g/km^2/yr) leaves an estimate of total dry deposition (38.21 g/km^2/yr).

The TMDL process for mercury loading generally divides loading into two components: watershed loading and direct atmospheric deposition to the water surface. Though the watershed load typically originates from atmospheric sources, whether historic, recent, near, or distant, delivery to the waterbody depends on runoff, erosion, and sedimentation processes that occur on the land surface and in the tributary network. In some cases, direct sources of mercury loading may be present in a watershed, such as mine tailings or geological formations with naturally high mercury concentrations. Watershed loading models that predict runoff and sediment delivery to a receiving waterbody are typically coupled with direct measurements of mercury concentrations in the sediments and water column of major tributaries to estimate mercury loading from the watershed.

The direct loading from the atmosphere to water surfaces may be estimated as the wet deposition plus total dry deposition minus the foliar accumulation component. Foliar accumulation typically accounts for approximately 7 g/km^2/yr in the southwest region (Tetra Tech, 2008a). The total dry deposition rate to Big Bear Lake may be approximated as 31 g/km^2/yr. With a lake surface area of 12.02 km^2, the direct dry deposition loading rate is approximately 372.6 grams per year.

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5 Linkage Analysis

The linkage analysis defines the connection between numeric targets and identified pollutant sources and may be described as the cause-and-effect relationship between the selected indicators, the associated numeric targets, and the identified sources. This provides the basis for estimating total assimilative capacity and any needed load reductions. Specifically, models of watershed loading of mercury are combined with an estimated rate of bioaccumulation in the lake. This enables a translation between the numeric target (expressed as a fish tissue concentration of mercury) and mercury loading rates. The loading capacity is then determined via the linkage analysis as the mercury loading rate that is consistent with meeting the target fish tissue concentration.

5.1 The Mercury Cycle

Development of the linkage analysis requires an understanding of how mercury cycles in the environment. Mercury chemistry in the environment is quite complex. Mercury has the properties of a metal (including great persistence due to its inability to be broken down), but also has some properties of a hydrophobic organic chemical due to its ability to be methylated through a bacterial process. Methylmercury is easily taken up by organisms and tends to bioaccumulate; it is very effectively transferred through the food web, magnifying at each trophic level. This can result in high levels of mercury in organisms high on the food chain, despite nearly unmeasurable quantities of mercury in the water column. While mercury can be toxic to fish and other aquatic organisms, the primary concern is neurological and developmental effects in higher animals and humans. Wildlife that habitually eat contaminated fish are at risk of accumulating mercury at toxic levels, and the mercury in sport fish can present a potential health risk to humans.

Methylmercury is highly toxic to mammals, including people, and causes a number of adverse effects. Health studies and information showing neurotoxicity, particularly in developing organisms, are most abundant. The brain is the most sensitive organ for which suitable data are available to quantify a dose-response relationship. A study by the National Academy of Science (NRC, 2000) concluded that the population at highest risk is the children of women who consume large amounts of fish and seafood during pregnancy, and that the risk to that population is likely to be sufficient to result in an increase in the number of children who have to struggle to keep up in school and who might require remedial classes or special education (USEPA, 2001b). Methylmercury is also toxic to fish-eating wildlife, including both mammals and birds. In addition to neurotoxic effects, methylmercury is implicated in reduced reproductive success in wildlife such as eagles, osprey, otter, and mink (Wiener et al., 2002).

Selected aspects of the lake and watershed mercury cycle are summarized schematically in Figure 13, based on the representations discussed in Hudson et al. (1994) and Tetra Tech (1999c). The boxes represent stores of mercury, and the arrows represent fluxes. The top of the diagram summarizes the various forms of mercury that may be loaded to a lake.

Lake Mercury Cycle

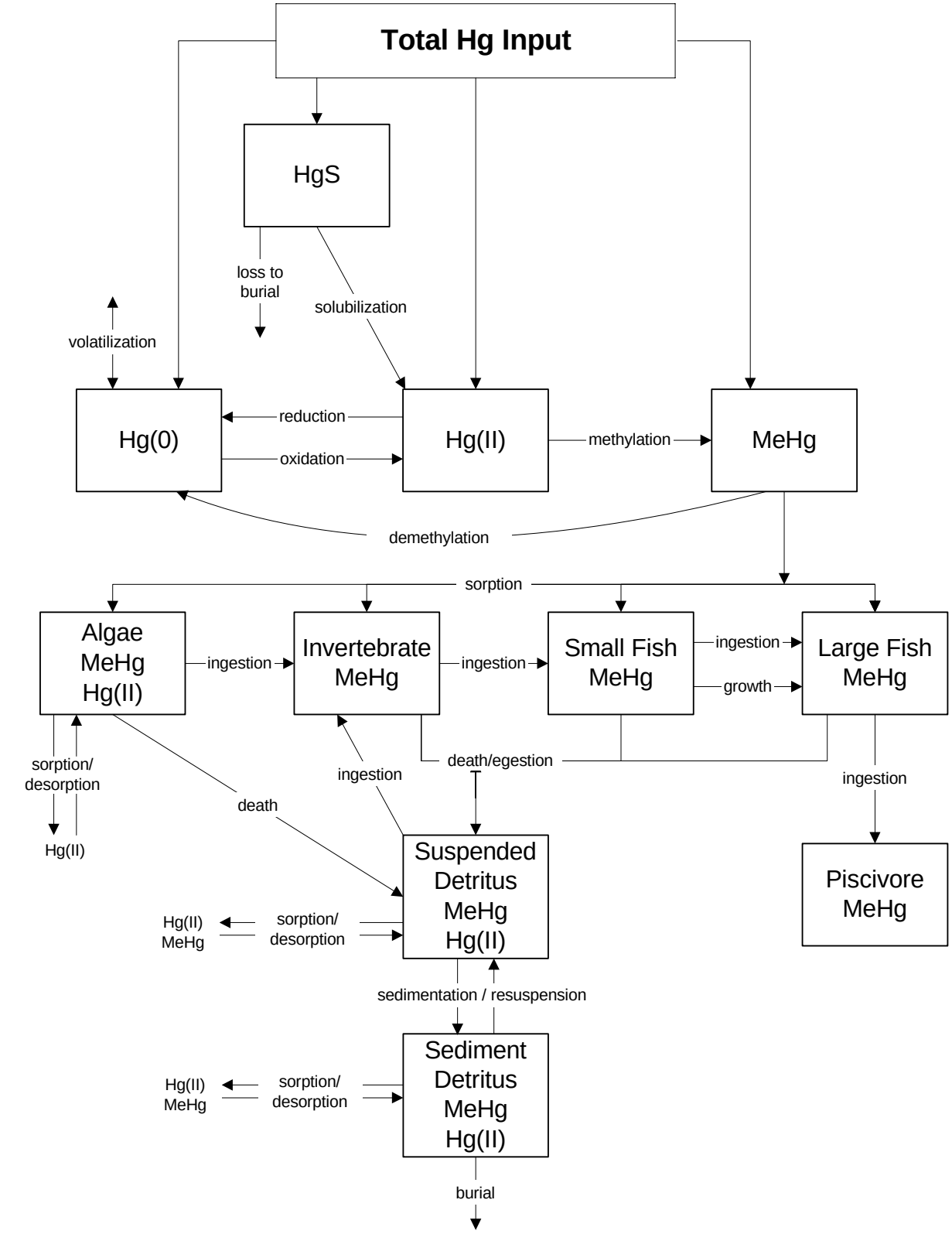

Figure 13. Conceptual Diagram of Lake Mercury Cycle

It is important to recognize that mercury exists in a variety of forms, including elemental mercury (Hg(0)), ionic mercury (Hg(I) and Hg(II)), and compounds in which mercury is joined to an organic molecule.

In the figure, Hg(I) is ignored because Hg(II) species generally predominate in aquatic systems. Mercuric sulfide (HgS or cinnabar) is a compound formed from Hg(II) but is shown separately because it is the predominant natural ore. Organic forms of mercury include methylmercury (CH_3Hg or "MeHg"), and other natural forms such as dimethylmercury and man-made compounds such as organic mercury pesticides. (Where sorption and desorption are indicated in Figure 13, "Hg(II)" and "MeHg" refer to the same common pools of water column Hg(II) and MeHg shown in the compartments at the top of the diagram.)

Dimethylmercury (CH_3-Hg-CH_3) is also ignored in the conceptual model shown in Figure 13, because this mercury species seems to occur in measurable quantities only in marine waters. Organic mercury pesticides also have been ignored in this TMDL study, because such pesticides are not currently used in this country and past use is probably insignificant as there is little cropland in the Big Bear Lake watershed.

Mercury and methylmercury form strong complexes with organic substances (including humic acids) and strongly sorb onto soils and sediments. Once sorbed to organic matter, mercury can be ingested by invertebrates, thus entering the food chain. Some of the sorbed mercury will settle to the lake bottom; if buried deeply enough, mercury in bottom sediments will become unavailable to the lake mercury cycle. Burial in bottom sediments can be an important route of removal of mercury from the aquatic environment.

Methylation and demethylation play an important role in determining how mercury will accumulate through the food web. Hg(II) is methylated by a biological process that appears to involve sulfate-reducing bacteria. Rates of biological methylation of mercury can be affected by a number of factors. Methylation can occur in water, sediment, and soil solutions under anaerobic conditions, and to a lesser extent under aerobic conditions. In lakes, methylation occurs mainly at the sediment-water interface and at the oxic-anoxic boundary within the water column. The rate of methylation is affected by the concentration of available Hg(II) (which can be affected by the concentration of certain ions and ligands), the microbial concentration, pH, temperature, redox potential, and the presence of other chemical processes. Methylation rates appear to increase at lower pH. Demethylation of mercury is also mediated by bacteria.

Both Hg(II) and methylmercury (MeHg) sorb to algae and detritus, but only the methylmercury is readily passed up to the next trophic level (inorganic mercury is relatively easily egested). Invertebrates eat both algae and detritus, thereby accumulating any MeHg that has sorbed to these. Fish eat the invertebrates and either grow into larger fish (which continue to accumulate body burdens of mercury), are eaten by larger fish or other piscivores, or die and decay.

Typically, almost all of the mercury found in fish (greater than 95 percent) is in methylmercury form. Studies have shown that fish body burdens of mercury tend to increase concurrently with increasing size or age of the fish, under conditions of constant exposure.

Although it is important to identify external sources of mercury to the reservoir, there may be fluxes of mercury within the reservoir that would continue for some time even if all external sources of mercury load were eliminated. The most important store of mercury within the reservoir is the bed sediment. Mercury in the bed sediment may cause exposure to biota by being:

- Resuspended into the water column, where it is ingested or it adsorbs to organisms that are later ingested.

- Methylated by bacteria. The methylmercury tends to attach to organic matter, which may be ingested by invertebrates and thereby introduced to the lake food web.

5.2 STRUCTURE OF THE WATERSHED LOADING COMPONENT OF THE TMDL

While mercury load can originate from a wide variety of source types, information to characterize many of these sources is limited for the Big Bear watershed. Lake water and sediment monitoring for mercury by modern ultra-clean analytical methods consists primarily of one sampling event conducted in May 2008. Tributary water monitoring by clean techniques are available for October 2002, December 2007, May 2008, and two events in June 2008. Sediment sampling of the tributaries in the watershed occurred in June 2008 as well. These sampling events achieved good spatial coverage, but one point in time for the lake is not enough to establish reliable averages, and cannot resolve seasonal trends. Better coverage is available for the tributaries.

The stream sediment mercury concentrations are assumed to be relatively stable in time, although highly variable in space. Thus, the one sample event for the lake and tributary network may be adequate to approximate sediment concentrations. Five sampling events do not provide a very clear basis for inference regarding long-term average water column loads, since water concentrations are likely much more variable in time. They do indicate, however, a seasonal trend for total mercury concentrations, and a simple approach is to assume that the average of the water column samples for the wet and dry seasons provide a "best available" estimate of the (exclusively) water column transport, while observed surface sediment concentrations provide an indication of the mercury moving in sediment bedload transport. This could lead to some double counting, to the extent that some samples include particle-associated mercury mobilized from the sediment, but the error is (1) expected to be small relative to total mercury transport, and (2) errs on the side of conservatism.

Accordingly, the watershed ("external") loading of mercury is estimated using two components, described below. Each of these components is assessed on a geographic basis, and tied to individual source areas where data allow.

1. Water column loading of dissolved and suspended particulate mercury: The water column transport of mercury is estimated directly from the seasonal average of total mercury concentrations measured during the tributary sampling events coupled with an estimation of flow provided from the HSPF model output. Mercury transport is potentially enhanced during the melt of the winter snowpack, as this may release atmospheric deposition load accumulated and stored over the winter. The wet season concentrations of mercury should account for this increase as they are more than an order of magnitude greater than those measured during the dry season.
2. Watershed sediment-associated mercury load: Much of the mercury load from the watershed likely moves in association with sediment during a few high-flow scour events. The available sampling represents this mercury in terms of concentrations in bed sediments. Approximating the mercury load associated with the sediment loads estimated from the HSPF model is based on an approach used successfully in the TMDL studies for Arivaca and Peña Blanca lakes in Arizona and McPhee and Sanchez reservoirs in Colorado (Tetra Tech, 1999a; 1999b; 2001; 2008b). This methodology makes the following arguments:
    - The amount of sediment moving through the major streams is equivalent (as a long-term average) to the rate of sediment loading to those streams, as estimated by a sediment load model.
    - The concentration of mercury in sediment moving through the system is equivalent to the concentration measured in stream sediment samples.
    - Mercury may be treated as approximately conservative in the stream sediments.

Each of these assumptions is a rough approximation only; however, they may be combined to provide an order-of-magnitude estimate of sediment-associated mercury delivery.

5.3 EXISTING WATERSHED HYDROLOGIC AND SEDIMENT LOADING MODEL

To facilitate completion of sediment and nutrient TMDLs for Big Bear Lake, the Santa Ana Regional Water Quality Board has developed an HSPF model of the 37 mi^2 watershed (Boyd, 2005). The simulation period for the modeling includes years 1990 through 2003, and output was generated for 83 modeling subwatersheds. The Regional Water Quality Board provided Tetra Tech with monthly flows and sediment loads aggregated for 11 larger subwatersheds.

Mercury may be transported from the watershed to Big Bear Lake in either the water column (associated with flows) or bound to sediment. As part of the TMDL allocation process, loads are calculated for MS4 wasteload allocations (WLAs) and nonpoint source load allocations (LAs). Following the format of the sediment and nutrient TMDLs developed for the watershed, the WLAs will be comprised of loads originating from urban land uses (residential and high density urban) subject to Municipal Separate Storm Sewer System (MS4) permits; loads originating from forest and resort areas will make up the LA. Thus, for each of the 11 drainages, loads must be calculated for water column and sediment fractions of the urban and rural land uses.

5.4 ESTIMATION OF WATERSHED MERCURY LOADING

Ultimate sources of mercury in the watershed include release from the parent rock, mercury residue from waste disposal, and atmospheric deposition onto the watershed, including deposition and storage in snowpack. Monitoring in streams and stream sediments typically reflect the combined impact of a number of these sources. Estimated mercury loads transported in the water column were calculated by multiplying the estimated annual runoff volume by the average observed water column concentration. Sediment scour and bedload transport of mercury were calculated by multiplying sediment yield estimates by the average sediment concentration at a station.

5.4.1 Water Column Loads

The mercury loads transported from each drainage to Big Bear Lake are estimated from 1) simulated, annual flow volumes, and 2) water-column mercury concentrations measured in the watershed. Because HSPF flow values were provided through September 2003, the monthly flows estimated by the Regional Board (provided with the HSPF output files) from bathymetry data measured in October, November, and December of 2003 were used to approximate flows from each major tributary during those months. Flows were apportioned based on average contributions from MS4 and non-MS4 areas over the simulation period. Annual flow volumes originating from MS4 and non-MS4 areas for each of the 11 drainages are presented in Appendix A.

Mercury concentrations measured in the major tributaries of the watershed (Section 3.3.1) were used to estimate the delivered mercury load. Based on the tributary water column measurements collected in the watershed, typical concentrations of mercury during the wet season (as indicated by December 2007 measurements) range from 10.1 ng/L to 17.8 ng/L with an average of 15.0 ng/L. Drier months have observed concentrations ranging from non-detect to 1.8 ng/L (October 2002 and May and June 2008). The average of all dry season values greater than the detection limit is 1.1 ng/L.

Average monthly precipitation depths were extracted from the weather input files used to drive the HSPF model. Figure 14 shows that November through March are typically wet months while April through October are usually dry. Tetra Tech, therefore, applied a tributary mercury concentration of 15 ng/L to

HSPF simulated flows from November to March and a value of 1.1 ng/L for flows simulated during April through October.

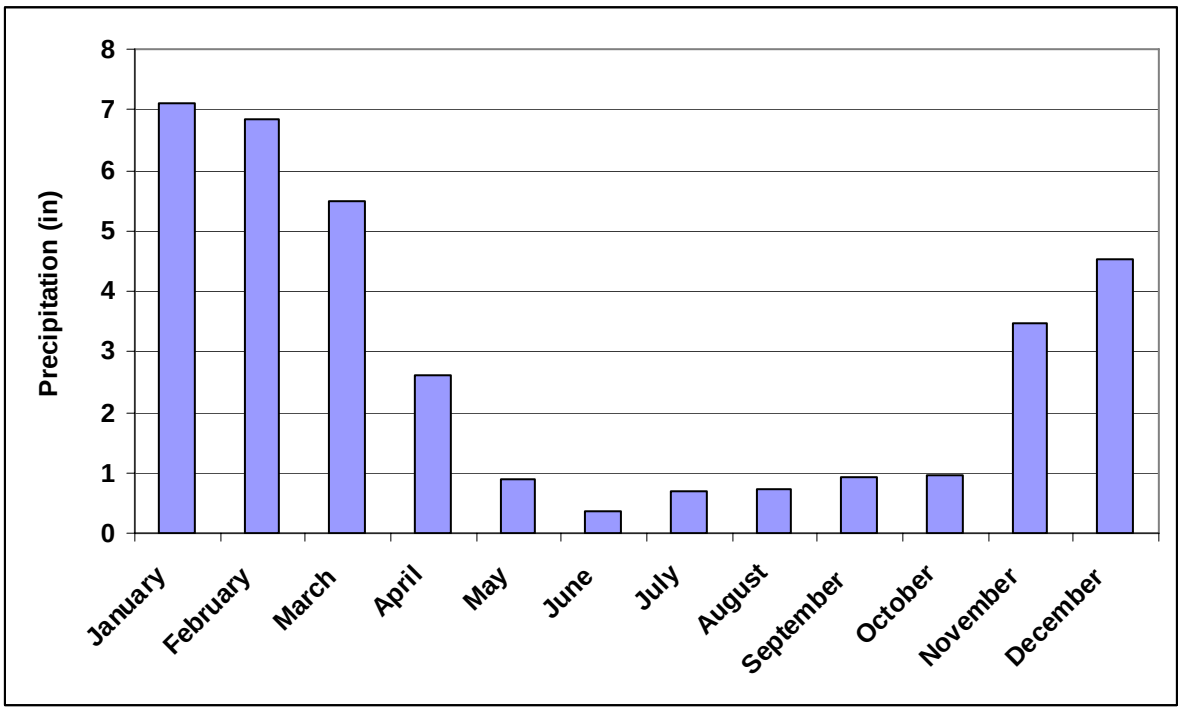

Figure 14. Average Monthly Precipitation in the Big Bear Lake Watershed

Table 14 and Table 15 present the mercury loads associated with flow from MS4 and non-MS4 areas, respectively. Average annual mercury loads associated with flow from MS4 areas are approximately 86.6 grams and from non-MS4 areas are approximately 137.3 grams.

5.4.2 Sediment-Associated Loads

The HSPF model was also used to simulate sediment loads from each major drainage and land use. The annual sediment loads from 1990 through 2003 from urban and rural land uses are presented in Appendix A. Sediment concentrations of mercury are based on measurements collected on six tributaries in June 2008. Direct measurements are available for Grout, Metcalf, Rathbun, Knickerbocker, West Summit, and Minnelusa Canyon. The following assumptions gathered from the sediment TMDL report developed for this watershed (Boyd, 2005) were used to assign sediment concentrations to the remaining major drainages:

- The Boulder Creek watershed has similar soil and land use composition as the Metcalf Creek watershed. Mean annual precipitation, aspect, elevation, and simulated rates of sediment yield are also similar. Boulder Creek sediment mercury concentration will be assumed equivalent to Metcalf Creek observations.
- The Division Creek watershed does not have similar soil types, mean annual precipitation, or land use types to any other drainage in the watershed. It is located adjacent to the Rathbun Creek drainage and also has similar rates of sediment yield. Division Creek is assumed to have a similar sediment mercury concentration as Rathbun Creek.

- Red Ant Canyon has a similar composition of soils and land use as well as similar mean annual precipitation and aspect/elevation as Knickerbocker Creek. In addition, sediment yields for these two watersheds are similar. Red Ant Canyon will therefore have an assumed sediment mercury concentration equivalent to that observed in Knickerbocker Creek.
- The local north drainage includes the area along the north shore of Big Bear Lake that is outside the Grout and Minnelusa Canyon Creek watersheds. Aspect, elevation, soil types, land use patterns, and sediment yields are similar to those seen in the Minnelusa Canyon Creek watershed. Sediment mercury concentrations for the local north area are assumed equivalent to those observed on Minnelusa Canyon Creek.
- The local south drainage includes all land draining to the south side of the lake not represented by one of the other major drainages. Soil types, land use patterns, aspect, elevation, and sediment yields are similar to those seen in the Rathbun Creek watershed. Sediment mercury concentrations for this drainage will therefore be set equivalent to those observed in Rathbun Creek.

Table 16 and Table 17 present the resulting loads for the MS4 and non-MS4 areas, respectively. MS4 areas in the watershed are estimated to contribute an average of 7.9 grams of mercury per year, and non-MS4 areas contribute approximately 21.2 grams of mercury per year.

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Table 14. Water Column Mercury Loads (g-Hg/yr) from MS4 Areas

Year	Boulder	Division	Grout	Knicker-bocker	Local North	Local South	Metcalf	Minnelusa Canyon	Rathbun	Red Ant Canyon	West Summit	Total
1990	0	2.42	0.66	1.55	4.62	15.34	0.46	0.14	7.44	0.52	1.39	34.54
1991	0	5.04	1.38	3.15	9.55	31.51	0.94	0.29	15.36	1.06	2.86	71.13
1992	0	6.05	1.62	3.43	11.07	35.72	1.03	0.35	17.83	1.15	3.21	81.45
1993	0	40.74	9.77	12.22	62.72	175.85	4.10	2.51	101.14	3.82	14.96	427.84
1994	0	4.46	1.19	2.56	8.20	26.52	0.77	0.26	13.20	0.86	2.39	60.41
1995	0	15.03	3.72	5.59	24.32	71.32	1.80	0.91	39.20	1.80	6.18	169.86
1996	0	5.10	1.38	3.04	9.51	31.05	0.91	0.29	15.30	1.02	2.80	70.41
1997	0	3.94	1.02	1.89	6.84	21.23	0.58	0.23	11.02	0.62	1.88	49.25
1998	0	9.56	2.42	4.09	16.05	48.55	1.28	0.57	25.86	1.34	4.26	113.98
1999	0	0.41	0.12	0.29	0.82	2.79	0.09	0.02	1.32	0.10	0.26	6.20
2000	0	3.27	0.89	2.02	6.17	20.30	0.60	0.19	9.93	0.68	1.84	45.89
2001	0	3.72	1.00	2.15	6.85	22.20	0.65	0.21	11.03	0.72	2.00	50.53
2002	0	1.20	0.34	0.86	2.40	8.18	0.25	0.07	3.86	0.29	0.75	18.21
2003	0	0.83	0.23	0.57	1.63	5.51	0.17	0.05	2.62	0.20	0.50	12.31
Average	**0**	**7.27**	**1.84**	**3.10**	**12.20**	**36.86**	**0.97**	**0.43**	**19.65**	**1.01**	**3.23**	**86.57**

Table 15. Water Column Mercury Loads (g-Hg/yr) from non-MS4 Areas

Year	Boulder	Division	Grout	Knicker-bocker	Local North	Local South	Metcalf	Minnelusa Canyon	Rathbun	Red Ant Canyon	West Summit	Total
1990	0.31	0.21	3.68	0.50	8.40	0.93	0.82	0.53	2.44	0.31	0.33	18.45
1991	0.75	0.52	9.41	1.10	21.74	2.14	2.01	1.38	5.29	0.70	0.64	45.68
1992	1.41	0.91	14.73	2.05	32.55	4.30	3.65	2.06	10.22	1.29	1.22	74.39
1993	16.29	10.41	166.66	22.68	365.75	49.49	42.14	23.17	112.74	14.34	12.68	836.36
1994	0.91	0.60	10.39	1.39	23.51	2.73	2.39	1.49	6.83	0.86	0.87	51.96
1995	12.43	6.86	77.71	13.73	139.56	40.42	30.07	8.73	72.73	9.03	5.51	416.80
1996	3.65	1.93	19.16	3.84	30.69	12.11	8.67	1.90	20.77	2.54	1.42	106.69
1997	3.15	1.71	18.46	3.44	31.93	10.33	7.56	1.99	18.36	2.26	1.37	100.56
1998	3.10	2.03	33.94	4.50	75.87	9.32	8.11	4.81	22.19	2.83	2.64	169.33
1999	0.02	0.01	0.08	0.02	0.13	0.06	0.04	0.01	0.13	0.01	0.02	0.52
2000	1.61	0.90	10.71	1.83	19.88	5.21	3.93	1.25	9.64	1.20	0.78	56.94
2001	0.67	0.46	8.36	1.10	19.30	1.99	1.80	1.23	5.35	0.68	0.73	41.66
2002	0.04	0.02	0.24	0.07	0.39	0.16	0.10	0.02	0.38	0.04	0.05	1.52
2003	0.04	0.02	0.19	0.06	0.30	0.13	0.09	0.02	0.30	0.03	0.04	1.21
Average	**3.17**	**1.90**	**26.69**	**4.02**	**55.00**	**9.95**	**7.96**	**3.47**	**20.53**	**2.58**	**2.02**	**137.29**

Table 16. Sediment-Bound Mercury Loads (g-Hg/yr) from MS4 Areas

Year	Boulder	Division	Grout	Knicker-bocker	Local North	Local South	Metcalf	Minnelusa Canyon	Rathbun	Red Ant Canyon	West Summit	Total
1990	0	0.50	0.11	0.09	0.70	1.80	0.03	0.03	1.13	0.03	0.15	4.6
1991	0	0.51	0.12	0.13	0.76	2.06	0.05	0.03	1.22	0.04	0.17	5.1
1992	0	0.81	0.18	0.15	1.14	2.93	0.06	0.05	1.84	0.04	0.24	7.4
1993	0	3.12	0.83	1.75	5.70	18.34	0.53	0.18	9.18	0.59	1.65	41.9
1994	0	0.53	0.12	0.10	0.75	1.94	0.04	0.03	1.21	0.03	0.16	4.9
1995	0	1.09	0.30	0.72	2.11	7.04	0.21	0.06	3.39	0.24	0.64	15.8
1996	0	0.54	0.13	0.13	0.79	2.12	0.05	0.03	1.27	0.04	0.18	5.3
1997	0	0.46	0.11	0.10	0.68	1.79	0.04	0.03	1.09	0.03	0.15	4.5
1998	0	0.87	0.22	0.34	1.43	4.24	0.11	0.05	2.30	0.11	0.37	10.0
1999	0	0.10	0.02	0.02	0.14	0.37	0.01	0.01	0.23	0.01	0.03	0.9
2000	0	0.21	0.05	0.08	0.35	1.02	0.03	0.01	0.56	0.03	0.09	2.4
2001	0	0.67	0.15	0.11	0.94	2.38	0.04	0.04	1.52	0.03	0.19	6.1
2002	0	0.17	0.04	0.03	0.25	0.64	0.01	0.01	0.40	0.01	0.05	1.6
2003	0	0.08	0.02	0.02	0.11	0.30	0.01	0.01	0.19	0.00	0.02	0.8
Average	**0**	**0.69**	**0.17**	**0.27**	**1.13**	**3.35**	**0.09**	**0.04**	**1.82**	**0.09**	**0.29**	**7.9**

Table 17. Sediment-Bound Mercury Loads (g-Hg/yr) from non-MS4 Areas

Year	Boulder	Division	Grout	Knicker-bocker	Local North	Local South	Metcalf	Minnelusa Canyon	Rathbun	Red Ant Canyon	West Summit	Total
1990	0.37	0.21	2.70	0.43	5.24	1.18	0.91	0.33	2.25	0.28	0.19	14.1
1991	0.27	0.16	2.38	0.35	5.00	0.84	0.68	0.32	1.78	0.22	0.18	12.2
1992	0.66	0.37	4.28	0.75	7.87	2.14	1.60	0.49	3.95	0.49	0.32	22.9
1993	2.49	1.48	20.35	3.01	41.44	7.79	6.23	2.61	15.36	1.95	1.38	104.1
1994	0.39	0.22	2.81	0.46	5.42	1.25	0.96	0.34	2.39	0.30	0.21	14.7
1995	1.13	0.62	6.92	1.25	12.26	3.70	2.73	0.77	6.64	0.82	0.50	37.3
1996	0.46	0.26	3.04	0.52	5.64	1.48	1.11	0.35	2.74	0.34	0.22	16.2
1997	0.52	0.28	3.02	0.57	5.17	1.72	1.26	0.32	3.03	0.37	0.22	16.5
1998	0.66	0.37	4.54	0.78	8.59	2.14	1.61	0.54	4.09	0.51	0.36	24.2
1999	0.06	0.04	0.60	0.08	1.31	0.18	0.15	0.08	0.40	0.05	0.04	3.0
2000	0.22	0.12	1.28	0.25	2.21	0.73	0.53	0.14	1.33	0.16	0.11	7.1
2001	0.43	0.25	3.37	0.54	6.75	1.37	1.07	0.43	2.77	0.34	0.27	17.6
2002	0.09	0.05	0.86	0.11	1.86	0.26	0.22	0.12	0.57	0.07	0.06	4.3
2003	0.06	0.03	0.45	0.07	0.91	0.19	0.15	0.06	0.36	0.05	0.03	2.3
Average	**0.56**	**0.32**	**4.04**	**0.65**	**7.83**	**1.78**	**1.37**	**0.49**	**3.40**	**0.43**	**0.29**	**21.2**

5.5 SUMMARY OF MERCURY LOADS TO BIG BEAR LAKE

Because HSPF output is available to estimate flow and sediment loading for the years 1990 through 2003, mercury loads to Big Bear Lake originating from atmospheric deposition and watershed loading are also compared over this period. Table 18 summarizes the total loads from each source category. The average annual load based on this period is 692.2 grams per year. The largest load (1,929.6) was delivered in 1993 due to abnormally high precipitation recorded that year (73.8 inches).

Table 18. Yearly Mercury Loads (g-Hg/yr) by Source to Big Bear Lake

Year	Sediment non-MS4	Sediment MS4	Water Column non-MS4	Water Column MS4	Wet Dep. to Lake	Dry Dep. to Lake	Total
1990	14.1	4.6	18.4	34.5	46.9	372.6	491.1
1991	12.2	5.1	45.7	71.1	79.6	372.6	586.3
1992	22.9	7.4	74.4	81.5	89.3	372.6	648.1
1993	104.1	41.9	836.4	427.8	146.8	372.6	1,929.6
1994	14.7	4.9	52.0	60.4	62.0	372.6	566.6
1995	37.3	15.8	416.8	169.9	93.7	372.6	1,106.1
1996	16.2	5.3	106.7	70.4	76.9	372.6	648.0
1997	16.5	4.5	100.6	49.3	49.6	372.6	593.0
1998	24.2	10.0	169.3	114.0	90.8	372.6	780.9
1999	3.0	0.9	0.5	6.2	23.3	372.6	406.6
2000	7.1	2.4	56.9	45.9	43.0	372.6	527.9
2001	17.6	6.1	41.7	50.5	52.0	372.6	540.5
2002	4.3	1.6	1.5	18.2	25.0	372.6	423.2
2003	2.3	0.8	1.2	12.3	52.9	372.6	442.2
Average	**21.2**	**7.9**	**137.3**	**86.6**	**66.5**	**372.6**	**692.2**

The annual loads simulated for Big Bear Lake may be divided by the lake volume (73,320 ac-ft) for a rough prediction of the total mercury concentration in the lake due to external sources. This calculation also serves as a cross-check that simulated mercury loads to the lake are reasonable. The resulting concentrations are conservative estimates since volatilization, ingestion, adsorption, and sedimentation are not accounted for. Based on the simulated loads to Big Bear Lake, the concentrations range from 4.5 to 21.3 ng/L with an average value of 7.7 ng/L. Even the highest simulated load does not result in an average concentration above the State's water quality standard (50 ng/L). As expected, these concentrations are higher than those observed in the lake which range from 2.3 to 3.6 ng/L (based on samples collected and analyzed with clean techniques) reflecting mercury losses from the water column.

Figure 15 presents the loads from each source by year to the lake. Note that estimates of dry deposition do not vary by year because they were estimated from a single CMAQ model run. During most years, dry deposition to the lake surface contributes the majority of loading, followed by water column loads from

rural and urban land uses, respectively. In extremely wet years, such as 1993 and 1995, water column loads from urban and rural land uses dominate mercury loading to Big Bear Lake.

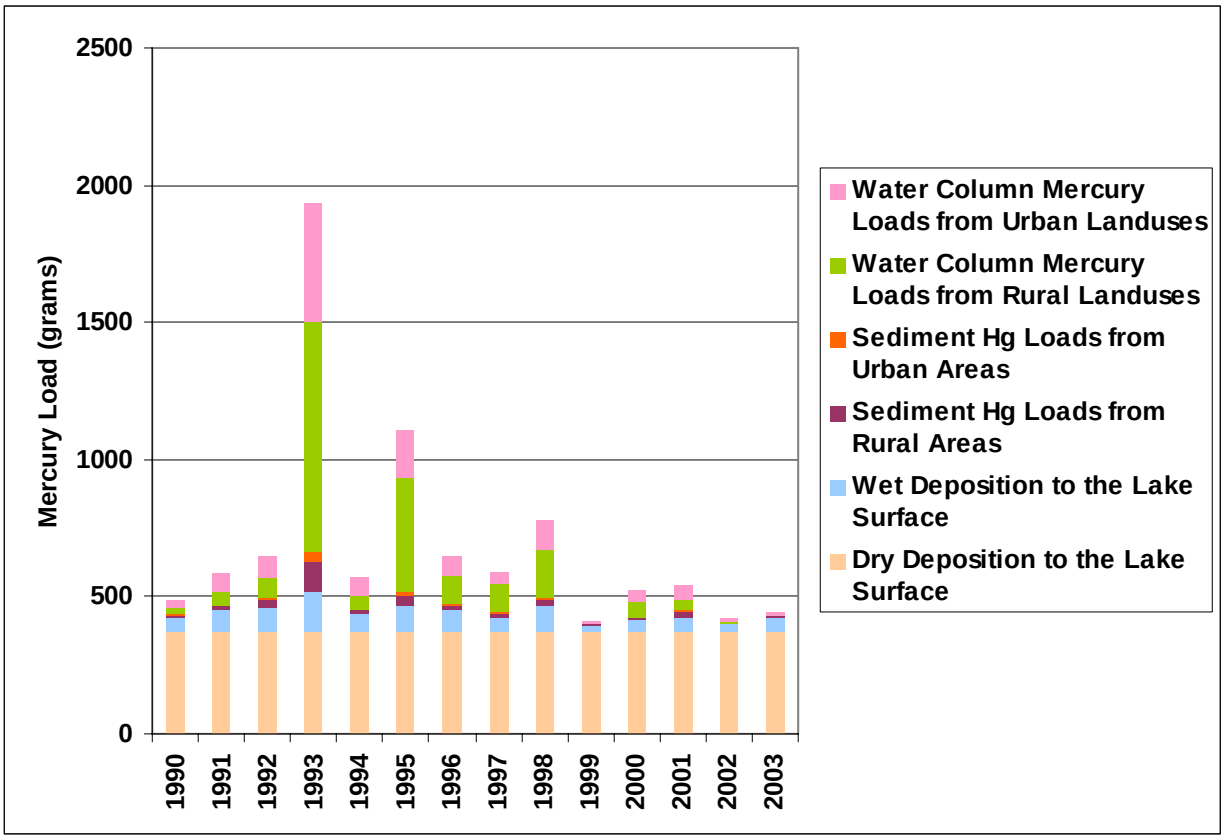

Figure 15. Yearly Inputs of Mercury Loading to Big Bear Lake

Table 19 lists the mercury loads from each drainage as an average over the simulation period (1990 through 2003). On average, deposition to the lake surface contributes over 63 percent of the mercury load to Big Bear Lake.

Table 19. Summary of Average Annual Mercury Loading (g-Hg/yr) to Big Bear Lake

Drainage	Urban Load	Rural Load	Sum	Percent of Total Load
Boulder Creek	0.0	3.7	3.7	0.54
Division Creek	8.0	2.2	10.2	1.47
Grout	2.0	30.7	32.7	4.73
Knickerbocker	3.4	4.7	8.0	1.16
Local North	13.3	62.8	76.2	11.00
Local South	40.2	11.7	51.9	7.51
Metcalf Creek	1.1	9.3	10.4	1.50
Minnelusa Canyon	0.5	4.0	4.4	0.64
Rathbun Creek	21.5	23.9	45.4	6.56
Red Ant Canyon	1.1	3.0	4.1	0.59
West Summit Creek	3.5	2.3	5.8	0.84
Lake Surface	**Wet**	**Dry**	**Sum**	**Percent of Total Load**
Direct Atmospheric Deposition	66.5	372.6	439.2	63.45
Total (watershed loading plus direct deposition)	**161.1**	**531.1**	**692.2**	**100.00**

5.6 LAKE RESPONSE

Neither data nor resources are available at this time to create and calibrate a detailed lake response model for mercury cycling in Big Bear Lake. The key to the TMDL target is achieving acceptable concentrations in fish. The responses of biota are determined by MeHg concentrations, not total Hg. These concentrations reflect both methylation within the lake and external loading of MeHg. In the Big Bear Lake watershed, methylmercury concentrations have not been measured in the lake or tributaries to determine if inlake or watershed processes are causing the mercury burden.

Methylation of mercury occurs under oxygen-poor, reducing conditions. Wetland areas are particularly likely sites for methylation in the watershed. Other likely sites include shallow riparian groundwater, the bottom waters and sediment of small impoundments that stratify and go anoxic, and beaver ponds and their associated wetlands. Thus, the marsh area located on the eastern side of the lake as well as the sedimentation basins on the mouths of some of the tributaries may be increasing methylmercury concentrations in the lake.

Precipitation events following recent forest fires also result in increased loads of total and methylmercury from the watershed and release of elemental mercury to the atmosphere which is then available for deposition.

Dredging activities to remove accumulated sediment from lakes and sedimentation basins may have significant impacts on total and methyl mercury loading to lake waters. In theory, removal of accumulated sediment should reduce the amount of total and methylated mercury stored in the sediments. Unfortunately, the removal process may disturb and release methylated mercury into the water column and increase the bioavailability of the metal. Additionally, removal of the top layers of sediment may

uncover layers deposited during the 1960s through 1980s when air emissions of mercury were less adequately controlled.

In midwestern and eastern lakes, methylation in lake sediments is often the predominant source of MeHg in the water column. However, in western lakes with high sedimentation rates, rapid burial tends to depress the relative importance of regeneration of MeHg from lake sediments. For instance, in McPhee Reservoir in Colorado (Tetra Tech, 2001), 71 percent of the MeHg present in the water column was estimated to derive from watershed inflows, while much of the MeHg created in lake sediment was apparently buried. Lakes with high sedimentation rates are therefore likely to respond approximately linearly to reductions in the watershed MeHg and total Hg load – although there may well be a delay in the response to load reductions, as found for McPhee Reservoir (Tetra Tech, 2001).

Big Bear Lake is known to experience high sediment loads, and a TMDL for sediment has been proposed. Boyd (2005) noted: "Excessive sediment deposition in Big Bear Lake has resulted in a decrease in lake capacity, which directly affects municipal, habitat and recreational beneficial uses." Boyd also reports that lake capacity has decreased by about 15 percent over the last 80 years due to sedimentation.

The available evidence thus suggests that high sedimentation rates in Big Bear Lake are likely to diminish the relative importance of MeHg recycling from lake sediment compared to tributary loading. This in turn suggests that MeHg exposure concentrations in Big Bear Lake should respond approximately linearly to reductions in tributary mercury load. While this is the best assumption that can be made with the current data, two caveats should be mentioned. First, the burial and sequestration of MeHg due to sedimentation may be counteracted by dredging activities, as noted above. Second, the potential role of peripheral wetlands as a locus of mercury methylation and subsequent loading to Big Bear Lake is currently unknown. It is clear that reductions in watershed mercury loads to the lake will be beneficial, although a program of adaptive implementation may need to be pursued if elevated fish tissue concentrations persist.

Nationally, authors such as Brumbaugh et al. (2001) have shown a log-log linear relationship between MeHg in water and MeHg in fish tissue normalized to length. However, this relationship is well-approximated by a linear relationship for the ranges of fish tissue concentration of concern here.

Until such time as a lake response model for mercury is constructed, and sufficient calibration data collected to develop it, an assumption of an approximately linear response of fish tissue concentrations to changes in external loads is sufficient for the development of a TMDL.

6 TMDL, Load Allocations, and Wasteload Allocations

The linkage analysis provides the quantitative basis for determining the loading capacity of Big Bear Lake. This in turn allows estimation of the Total Maximum Daily Load (TMDL), and allocation of that load to urban sources (wasteload allocations) and rural sources (load allocations). The TMDL also contains a Margin of Safety, which is described in detail in Section 7.1.

The mercury TMDL for Big Bear Lake may be developed in a similar fashion to the sediment TMDL, which was based on an average of the simulated HSPF loads to the lake. This analysis provided a mechanism for incorporating wet, normal, and dry simulation years into the TMDL. This technical support document will present the TMDL components for each major drainage as well as the lake to provide the Regional Board with the information needed to proceed with the formal TMDL.

6.1 Determination of Loading Capacity

A waterbody's loading capacity represents the maximum rate of loading of a pollutant that can be assimilated without violating water quality standards (40 CFR 130.2(f)). This is the maximum rate of loading consistent with meeting the numeric target of 0.3 ppm for mercury in largemouth bass.

For Big Bear Lake, a model of lake response and fish bioaccumulation has not been created at this time. Rather, it is assumed that, in the long term, fish tissue concentrations will respond approximately linearly to reductions in mercury load. This assumption has been found to be a reasonable first-order approximation in other systems with high burial rates, such as McPhee and Narraguinnep reservoirs in Colorado (Tetra Tech, 2001). For McPhee in particular, a detailed model of lake mercury cycling and bioaccumulation was created (using the D-MCM model -Tetra Tech, 1999c). The calibrated model yielded predictions that were well approximated by the assumption of a linear response of fish tissue concentration to reductions in external mercury loads.

Calculating the loading capacity first requires an estimate of the existing mercury concentration in largemouth bass. To do this, a linear regression analysis was performed on tissue concentrations versus length. The resulting regression equation is

$$Hg(fish) = 0.013027 + 0.0008148 \cdot Len, \quad R^2 = 0.25$$

where *Hg(fish)* is the total mercury concentration in largemouth bass (ppm) and *Len* is length in mm. The regression analysis is shown in Figure 16, along with the one-sided 95 percent upper confidence limit on mean predictions about the regression line (95 percent UCL) and the 95 percent upper prediction interval on individual predicted concentrations (95 percent UPI). The UPI gives the confidence limit on the individual predictions for a given length while the UCL gives the confidence limit on the average of the predictions for a given length. The regression has a non-zero intercept and should not be considered valid for a length less than 200 mm.

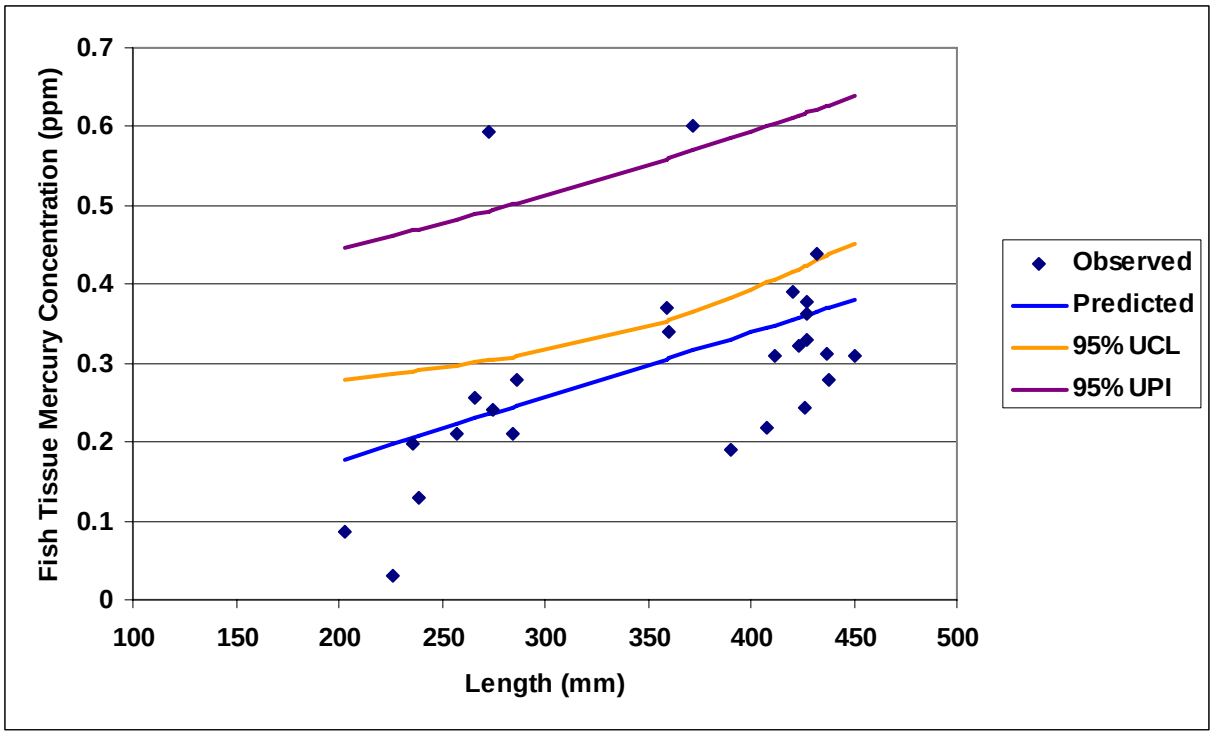

Figure 16. Regression Analysis of Mercury in Big Bear Largemouth Bass

For mercury, long-term cumulative exposure is the primary concern. Therefore, it is appropriate to use the 95 percent UCL rather than the UPI to provide a Margin of Safety on the appropriate age class. Use of the UCL provides a Margin of Safety because it represents an upper confidence bound on the long-term exposure concentration.

The one-sided 95 percent UCL is given by

$$UCL_{0.95} = \mu_{y|x_0} + t_{0.05,n-2} \cdot s_{\mu_y|x_0}$$

where $\mu_{y|x}$ is the predicted value of y given $x=x_0$, t is the Student's t-statistic with n-1 degrees of freedom, and n is the number of observations used in the regression. The variance on the prediction at $x=x_0$, $s^2_{\mu_y|x_0}$, is given by

$$s^2_{\mu_y|x_0} = s^2_{y|x} \cdot \left[1/n + (x_0 - \bar{x})^2 / \sum (x_i - \bar{x})^2 \right],$$

where x_0 is the value of the independent variable (*Len*) at which the prediction is made, $\bar{x}$ is the mean of the observed independent variables, x_i, and $s^2_{y|x}$ is the standard error of the model estimates. For the Big Bear largemouth bass data, this yields

$$UCL_{0.95}[Hg(fish)] = 0.013027 + 0.0008148 \cdot Len + 2.05939 \cdot 0.01458 \cdot \sqrt{1/27 + (Len - 355.7)^2 / 182561.9}$$

This equation expresses the upper 95 percent confidence limit on predicted fish tissue mercury concentrations for any length (*Len*). The first two terms alone would generate the prediction line; the addition of the last term results in the UCL line.

Both the observed data and the predicted concentrations show that mercury concentrations in largemouth bass typically exceed the target of 0.3 ppm at lengths greater than 350 mm. Concentrations in fish ranging in length from 350 mm to 450 mm are predicted to exceed the target and most of the exceedences occur in this range. The TMDL target is established for the midpoint of these lengths (400 mm). At this length, the predicted mercury concentration based on the regression equation is 0.339 ppm and the 95 percent UCL is 0.393 ppm total mercury. Existing mercury loading is estimated at 692 g/yr (Section 5.5). The fraction of existing load consistent with attaining the target (the loading capacity) is then the ratio of the target (0.3) to the best estimate of current average concentrations in the target fish population (0.339), or 0.885. The difference between the direct regression estimate and the 95 percent UCL provides the Margin of Safety. Therefore, the allocatable fraction of the existing load (the loading capacity less the Margin of Safety) is the ratio of the target to 0.393 (0.3 divided by 0.393 equals 0.763). Resulting loading capacity and allocatable load estimates for the target level of 0.3 ppm are summarized in Table 20. The Margin of Safety is 84.4 g/yr, or about 14 percent of the loading capacity.

Table 20. Estimated Total Mercury Loading Capacity, Allocatable Load, and Margin of Safety for Big Bear Lake (for Existing Load of 692 g/yr)

Target (mg-Hg/kg – 400 mm large-mouth bass)	Loading Capacity Fraction of Existing Load	Loading Capacity (g/yr)	Allocatable Fraction of Existing Load	Allocatable Load (g/yr)	Margin of Safety (g/yr)	Percent Reduction
0.3	0.885	612.4	0.763	528.0	84.4	23.7%

It should also be noted that the loading capacity for total mercury is not necessarily a fixed number. The numeric target for the TMDL is expressed as a mercury concentration in fish tissue. This numeric target is linked to the external mercury load through a complex series of processes, including methylation/ demethylation of mercury and burial of mercury in lake sediments. Any alterations in rates of methylation or in rates of mercury loss to deep sediments will change the relationship between external mercury load and fish tissue concentration and would thus result in a change in the loading capacity for external mercury loads.

6.2 TOTAL MAXIMUM DAILY LOAD

Mercury loading to Big Bear Lake does not appear to be driven by any dominant local source. The natural geology presents only a minor risk of mercury loading, and there has been little mining activity in the watershed. Atmospheric deposition appears to be the main source of mercury input to the watershed. The atmospheric deposition does not, however, appear to be solely attributable to nearby sources such as cement plants, but rather represents the regional and global background. While the estimates of Seigneur et al. (2004) that the major anthropogenic source of atmospheric mercury in this part of the country derives from southeast Asia may be an overestimate due to underaccounting for dry deposition, it does appear that atmospheric mercury loading at Big Bear Lake is driven by multiple atmospheric sources across a wide geographic area.

Estimating a TMDL that will result in attainment of uses (specifically, acceptable concentrations of mercury in fish tissue) in Big Bear Lake requires a reduction in the MeHg exposure concentrations in the lake. There are three general ways in which this can be achieved. The first is through a reduction in the total watershed mercury load; the second is through a reduction in the MeHg concentration through

reduction of MeHg production and transport in the watershed; and the third is a reduction in releases of stored MeHg from the lake-bottom sediments. MeHg may be produced both within the lake and in the watershed. The methylated fraction of mercury load in the Big Bear Lake watershed may be relatively high given the exceedences of the fish tissue standard and relatively low total mercury concentrations – suggesting that control of MeHg load from the watershed and disturbed lake sediments may be a potential option for attaining standards. It is not possible, however, to fully investigate this option without a better understanding of mercury cycling and methylation processes within the reservoir, for which a lake mercury model (not included within the scope of the current work) would be needed. Therefore, allocations are focused on total mercury loading in this TMDL, recognizing that a more refined approach to implementation may be possible if additional understanding of mercury cycling in the watershed is obtained.

The current state of knowledge of mercury sources in the watershed and transport to Big Bear Lake requires use of a "gross allotment" approach to the major drainages, rather than assigning individual load allocations to specific tracts or land areas within the watershed. Loading from geological sources has also not been separated from the net impacts of atmospheric deposition onto the watershed. Information is currently available to separate sources for allocations into two components:

a. Direct atmospheric deposition onto the lake surface.

b. Generalized background watershed loading including the impact of atmospheric deposition on the watershed.

Most of the mercury loading contained in either source appears to ultimately derive from atmospheric deposition. However, the two sources differ in that direct atmospheric deposition onto the lake surface reflects only present-day sources, whereas background loading from the watershed reflects both ongoing and historic atmospheric deposition loads to the watershed, in addition to geological background. For this TMDL, needed load reductions are assigned proportionately to both direct atmospheric deposition and watershed background sources.

Fully implementing the needed allocations may be difficult, as the load appears to be driven by diffuse sources, including regional and global mercury transport. These atmospheric sources can only be managed in a regional and global context. USEPA (2005b) indicates that the preferred option under the Clean Air Mercury Rule (CAMR Option 1) would result in only a minimal percent reduction in mercury deposition rates to the Big Bear Lake watershed, whereas the needed reductions identified in Table 20 are approximately 24 percent.

The TMDL represents the sum of all individual allocations of portions of the waterbody's loading capacity. For this watershed, allocations are made to all urban sources (wasteload allocations) and rural sources or atmospheric deposition (load allocations). The TMDL (sum of allocations) must be less than or equal to the loading capacity; it is equal to the loading capacity only if the entire loading capacity is allocated. In many cases it is appropriate to hold in reserve a portion of the loading capacity to allow a Margin of Safety (MOS), as provided for in the TMDL regulation.

Knowledge of mercury sources and the linkage between mercury sources and fish tissue concentrations in Big Bear Lake is subject to many uncertainties. (These uncertainties are discussed in more detail in Section 7.1.) There do not, however, appear to be any significant concentrated sources of mercury in the Big Bear watershed, and a majority of the mercury that is loaded likely derives from atmospheric deposition. The MOS is addressed through the use of an upper confidence limit in the target calculation, which results in a MOS of 84.4 g/yr. Therefore, the TMDL is equivalent to the estimated loading capacity minus the MOS, or 528 g/yr. Though annual loading allocations are more appropriate for bioaccumulating toxins such as mercury, an expression of the TMDL as a daily load is presented in Section 7.4.

6.3 WASTELOAD ALLOCATIONS

Wasteload allocations constitute an assignment of a portion of the TMDL to permitted point sources. Consistent with the sediment and nutrient TMDLs for Big Bear Lake, the wasteload allocation will be comprised of loads from urban land uses which drain to designated MS4 systems. Point sources in the watershed operate under NPDES industrial and construction permits. A query of the USEPA Permit Compliance System indicates that none of these facilities have permitted effluent discharges to waterbodies in the Big Bear Lake watershed. Discharges from these facilities will not be allocated additional loads beyond those addressed by the MS4 allocations. Section 5.4 explains how the loads from MS4 areas were estimated. The wasteload allocations for each major drainage of Big Bear Lake, assuming a mercury load reduction of 23.7 percent, are summarized in Table 21.

Table 21. Summary of Wasteload Allocations for the Major Drainages to Big Bear Lake

Drainage	Existing Load from MS4 Areas (g-Hg/yr)	Wasteload Allocation (g-Hg/yr)
Boulder Creek	0.0	0.0
Division Creek	8.0	6.1
Grout	2.0	1.5
Knickerbocker	3.4	2.6
Local North	13.3	10.1
Local South	40.2	30.7
Metcalf Creek	1.1	0.8
Minnelusa Canyon	0.5	0.4
Rathbun Creek	21.5	16.4
Red Ant Canyon	1.1	0.8
West Summit Creek	3.5	2.7
Total	**94.6**	**72.2**

6.4 LOAD ALLOCATIONS

For the Big Bear Lake watershed, the load allocations represent assignment of a portion of the TMDL to rural sources and atmospheric deposition. Table 22 summarizes the existing loads and load allocations assuming a mercury loading reduction of 23.7 percent for all major drainages as well as atmospheric deposition to the lake surface.

Table 22. Summary of Load Allocations for the Major Drainages to Big Bear Lake and Atmospheric Deposition to the Lake Surface

Drainage	Existing Load from non-MS4 Areas (g-Hg/yr)	Load Allocation (g-Hg/yr)
Boulder Creek	3.7	2.8
Division Creek	2.2	1.7
Grout	30.7	23.4
Knickerbocker	4.7	3.6
Local North	62.8	47.9
Local South	11.7	8.9
Metcalf Creek	9.3	7.1
Minnelusa Canyon	4.0	3.1
Rathbun Creek	23.9	18.2
Red Ant Canyon	3.0	2.3
West Summit Creek	2.3	1.8
Deposition to the Lake Surface	**Existing Load**	**Load Allocation**
Wet	66.5	50.7
Dry	372.6	284.3
Total	**597.4**	**455.8**

6.5 ALLOCATION SUMMARY

Allocations for the Big Bear mercury TMDL are summarized in Table 23, based on the 0.3 ppm target.

Table 23. Summary of TMDL Allocations (g-Hg/yr) for Big Bear Lake

Drainage	Wasteload Allocation	Load Allocation	Total
Boulder Creek	0.0	2.8	2.8
Division Creek	6.1	1.7	7.8
Grout	1.5	23.4	24.9
Knickerbocker	2.6	3.6	6.2
Local North	10.1	47.9	58
Local South	30.7	8.9	39.6
Metcalf Creek	0.8	7.1	7.9
Minnelusa Canyon	0.4	3.1	3.5
Rathbun Creek	16.4	18.2	34.6
Red Ant Canyon	0.8	2.3	3.1
West Summit Creek	2.7	1.8	4.5
Deposition to the Lake Surface	**Wasteload Allocation**	**Load Allocation**	**Total**
Wet	0.0	50.7	50.7
Dry	0.0	284.3	284.3
Total (Watershed plus Atmospheric Deposition)	**72.2**	**455.8**	528.0
Margin of Safety	**–**	**–**	84.4

6.6 IMPLEMENTATION AND MONITORING

The mercury TMDL for Big Bear Lake concludes that a reduction in total mercury loading to the lake of 23.7 percent will result in compliance with the fish tissue criterion of 0.3 ppm. Over the past decade, several sediment reduction BMPs have been implemented throughout the watershed to decrease sediment loading to the lake. Source reduction and pollutant removal BMPs designed to reduce sediment loading should continue to be implemented throughout the watershed as these management practices will also reduce mercury loading associated with sediments. However, sedimentation basins or water quality ponds that go anoxic at the sediment-water interface may actually result in increased concentrations of methylmercury. Monitoring of dissolved oxygen levels in these ponds and measurement of total and methylmercury concentrations during warm summer months will assist in the management of these basins to reduce methylmercury loading to Big Bear Lake.

During wetter years, dissolved loading associated with storm event runoff is assumed to dominate mercury loading to Big Bear Lake. Some of the sediment reduction BMPs may also result in decreased

concentrations of mercury in the runoff water. Storage of storm flows in wet or dry ponds may allow for adsorption and settling of mercury from the water column. BMPs that provide filtration or infiltration processes may retain dissolved mercury in the upland areas.

Unfortunately, sediment reduction BMPs will not mitigate mercury loading from one of the largest sources in the watershed. During dry and normal precipitation years, dry deposition to the lake surface constitutes the majority of loading. Mercury available for dry deposition in the southwest region typically originates from both local and global sources. In the US, mercury emissions from most facilities have been reduced over the past few decades as the best available technology has improved over the years. In other regions of the world where environmental regulations are not as strict, mercury emissions to the atmosphere have increased over the years with increasing development and coal-fired power generation. Thus, controlling the rates of dry (and wet) deposition to the lake surface will require global policies that reduce emissions around the world.

Another potential source of mercury loading, particularly methylmercury, is the dredging of Big Bear Lake and the sedimentation basins located at the mouths of major tributaries. Removal of the top layers of sediment from the lake bottom may stir up and distribute methylmercury buried over the years. It would be prudent to conduct a test of this potential source by monitoring total and methylmercury concentrations prior to and immediately following a small dredging activity to determine if concentrations increase following disturbance. The location of this small test area should not coincide with recent dredging locations where release of methylmercury stores may have already occurred. Measurements of both total and methylmercury should occur at several depths and locations in the area above and surrounding the test area.

Although estimates of the loading capacity and allocations are based on best available data and incorporate a Margin of Safety, these estimates may potentially need to be revised as additional data are obtained. To provide reasonable assurances that the assigned allocations will indeed result in compliance with the fish tissue criterion, a commitment to continued monitoring and assessment is warranted. The purposes of such monitoring will be (1) to evaluate the efficacy of control measures instituted to achieve the needed load reductions, (2) to document trends over time in mercury loading, and (3) to determine if the load reductions proposed for the TMDL lead to attainment of water quality standards. It may also be necessary to investigate potential sources of methylmercury loading in the watershed, such as wetlands, sedimentation basins, and areas impacted by forest fires. It is recommended that a detailed plan for continued monitoring be incorporated as part of the implementation plan for this TMDL.

7 Margin of Safety, Seasonal Variations, and Critical Conditions

7.1 SOURCES OF UNCERTAINTY

The analysis for this TMDL contains numerous sources of uncertainty, and allocations must be proposed as best estimate "gross allotments" in keeping with the TMDL regulation at 40 CFR 130.2(g). Key areas of uncertainty have been highlighted in the Source Assessment and Linkage Analysis sections and are summarized below.

The sources of uncertainty can be divided into two groups. The first group consists of sources of uncertainty that directly affect the ability of the linkage analysis to relate the numeric target fish tissue concentration to environmental mercury exposure concentrations in the lakes. These sources of uncertainty propagate directly to uncertainty in estimation of the loading capacity and TMDL. The second group consists of uncertainty in the estimation of external loads. These have their primary impact on allocations. The loading capacity estimate (when expressed as a fraction of existing loads) is much more sensitive to uncertainty in the first group and relatively robust to uncertainty in the second group.

The first group includes the following:

- Fish data from the lake are sparse. While the presence of problem concentrations of mercury in fish has been confirmed, the limited number of samples and limited number of collection times leads to uncertainty regarding the average population response as a function of fish weight/age.
- No data are available on small forage fish and invertebrates, which drive the food chain pathways leading to bioaccumulation in sport fish.
- Sediment mercury concentrations are characterized by a limited number of samples.
- No water column or sediment methylmercury data has been collected in the lake or tributaries.
- Information on the vertical distribution of mercury in the water column and associated water chemistry is not available for the May 2008 sampling event (the only lake sampling event using ultra-clean sampling and analysis techniques).
- The processes in the watershed and lake leading to increased concentrations of methylmercury in the water column have not been quantified.
- Neither available resources nor available data allowed for the development and calibration of a detailed lake mercury cycling model for Big Bear Lake. Instead, the estimates of loading capacity for Big Bear Lake are based on the assumption of an approximately linear relationship between mercury loading and MeHg exposure concentrations in the reservoir. This assumption was found to be reasonable in the lake modeling for McPhee Reservoir (Tetra Tech, 2001) due to the high sedimentation rates characteristic of southwestern reservoirs, but cannot be explicitly evaluated in Big Bear Lake without creation of a lake model.

The second group includes the following:

- Watershed background loading of mercury is estimated using a simple water balance/sediment yield model. While the concentrations in tributary sediments are based on measured data, the estimated actual rates of movement of this sediment to the lake are not validated by field measurements at this time.

- Estimates of atmospheric wet deposition of mercury are based on a limited period of mercury monitoring at the Converse Flats MDN station along with interpolation based on acid deposition monitoring at four NADP stations and EPA air modeling. Actual deposition of mercury at or near the reservoir has not been measured and may well differ significantly from the estimates used.
- Estimates of dry deposition are based on one model run of the CMAQ model for year 2002 meteorological conditions. This estimate may not be accurate, particularly for the other simulation years (1990 to 2003).
- While atmospheric deposition appears to be the major source of mercury in the Big Bear Lake watershed, the extent to which mercury loads are due to past (as opposed to ongoing) mercury deposition is not known.

There are thus many sources of uncertainty in the estimation of the mercury TMDL for Big Bear Lake. It is evident, however, that existing loads of mercury are too high to support beneficial uses, as shown by the tissue concentrations measured in fish.

The TMDL regulation requires that estimates of loading capacity be made even where there is uncertainty in load estimates, and only "gross allotments" are possible for nonpoint loads. The present TMDL provides a best estimate of the loading capacity for mercury, and the needed load reductions, for Big Bear Lake –but the uncertainty in these estimates is high. This uncertainty is addressed in part through use of a Margin of Safety (Section 7.2). The level of uncertainty, however, suggests the need for ongoing, adaptive management to meet water quality standards. In particular, a monitoring program should be part of any implementation plan. Such a monitoring program would allow tracking of progress in attaining acceptable fish tissue concentrations in response to management actions. It would also provide the basis for potential revision (upward or downward) of the estimated load allocations consistent with attaining the standard in the reservoir.

7.2 MARGIN OF SAFETY

All TMDLs are required to include a Margin of Safety to account for uncertainty in the understanding of the relationships between pollutant sources and impacts on beneficial uses. The Margin of Safety may be provided explicitly through an unallocated reserve or implicitly through use of conservative assumptions in the analysis.

The TMDL presented in this document incorporates an implicit Margin of Safety through use of the upper 95th percentile confidence limit on the predicted response of target sport fish tissue concentrations to mercury loads. This component of the Margin of Safety is equal to about 14 percent of the loading capacity (see Table 20), and will result in a high probability that the average fish tissue concentrations in fish consumed by humans will be held below levels necessary to protect human health. An additional implicit, but unquantified, component of the Margin of Safety is provided by the interpretation of the 0.3 ppm methylmercury fish tissue concentration as an 0.3 ppm total mercury concentration.

7.3 SEASONAL VARIATIONS AND CRITICAL CONDITIONS

A TMDL is required to address fish tissue concentrations associated with bioaccumulation of mercury within Big Bear Lake. There is no clear evidence of exceedences of ambient water quality standards for mercury in the lake. Because methylmercury is a bioaccumulating toxin, concentrations in tissue of game fish integrate exposure over a number of years. As a result, annual mercury loading is more important for the attainment of standards than instantaneous or daily concentrations, and the TMDL is proposed in terms of annual loads. It is not necessary to address standard wasteload allocation critical conditions, such as concentrations under 7Q10 flow, because it is loading, rather than instantaneous concentration

that is linked to impairment. However, because mercury load is primarily delivered to the reservoir during storm washoff events, high flows do represent a critical condition. This is addressed in Section 7.4.

The impact of seasonal and other short-term variability in loading is damped out by the biotic response. The numeric target selected is tissue concentration in piscivorous game fish of edible size, which represents an integration over several years of exposure, suggesting that annual rather than seasonal limits are appropriate. Nonetheless, the occurrence of loading that impacts fish does involve seasonal components. First, watershed mercury loading, which is caused by infrequent major washoff events in the watershed, is highly seasonal in nature, with most loading occurring during the wet season (November through March). Second, bacterially mediated methylation of mercury is also likely to vary seasonally. However, it is most important to control average annual loading, rather than establishing seasonal limits, to establish a TMDL consistent with supporting beneficial uses.

7.4 DAILY LOAD EXPRESSION

USEPA recommends inclusion of a daily load expression for all TMDLs to comply with the 2006 D.C. Circuit Court of Appeals decision for the Anacostia River. Although it is long-term cumulative load rather than daily loads of mercury that are driving the bioaccumulation of mercury in fish in Big Bear Lake, this TMDL does present a maximum daily load according to the guidelines provided by USEPA (2007). The daily maximum allowable load of mercury to Big Bear Lake is calculated from the estimated 99th percentile flow to the reservoir multiplied by the event mean concentration for mercury consistent with achieving the long-term loading target.

No USGS gage currently exists in the Big Bear Lake watershed. Calibration of the HSPF model was based on a surrogate gage on Plunge Creek (USGS 1105500), which has a drainage area of 16.9 mi^2 and a period of record over 89 years. The 99th percentile flow was chosen to represent the peak flow for this drainage. Choosing the 99th percentile flow eliminates errors due to outliers and is reasonable for development of a daily load expression.

The USGS StreamStats program was used to determine the 99th percentile flow for Plunge Creek (101 cfs). To estimate the peak flow to Big Bear Lake, the 99th percentile flow for Plunge Creek was scaled up by the ratio of drainage areas (37.0/16.9). The resulting peak flow estimate for Big Bear Lake is 221 cfs.

The event mean concentration for mercury was calculated from the allowable load (528.0 g-Hg/yr) and the average annual simulated stream flow generated by HSPF (14,302 ac-ft). The resulting concentration (29.9 ng/L) times the peak flow to Big Bear Lake (221 cfs) yields a total maximum daily load of 16.2 g-Hg/d. For comparison, the existing load (692 g-Hg/yr) would yield an event mean concentration of 39.2 ng/L and a daily load of 21.2 g-Hg/d.

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Appendix A. Summary of HSPF Model Output

To facilitate completion of sediment and nutrient TMDLs for Big Bear Lake, the Santa Ana Regional Water Quality Board has developed an HSPF model of the 37 mi^2 watershed. The simulation period for the modeling includes years 1990 through 2003, and output was generated for 83 modeling subwatersheds. The Regional Water Quality Board provided Tetra Tech with monthly flows and loads aggregated for 11 subwatersheds. Table A-1 and Table A-2 present the simulated flow volumes from MS4 and non-MS4 areas, respectively, for each of the 11 drainages. Table A-3 and Table A-4 display the sediment loads generated from MS4 and non-MS4 areas, respectively, for each of the 11 drainages.

Table A-1. Simulated Flow Volumes (ac-ft) from MS4 Areas

Year	Boulder	Division	Grout	Knicker-bocker	Local North	Local South	Metcalf	Minnelusa Canyon	Rathbun	Red Ant Canyon	West Summit	Total
1990	-	149.3	41.0	95.2	285.0	945.5	28.3	8.5	458.6	32.2	85.8	2,129.5
1991	-	430.7	111.1	205.7	746.7	2,315.9	63.6	25.4	1,202.7	68.0	205.2	5,375.0
1992	-	368.4	98.0	204.9	670.2	2,153.2	62.0	21.4	1,079.1	68.6	193.3	4,919.0
1993	-	2,260.0	541.8	675.8	3,477.0	9,743.7	227.2	139.2	5,606.8	211.2	828.6	23,711.2
1994	-	269.7	71.9	151.6	492.4	1,586.1	45.8	15.6	792.8	50.8	142.5	3,619.3
1995	-	882.5	217.9	325.8	1,425.4	4,174.0	105.0	53.5	2,297.3	104.8	361.6	9,947.7
1996	-	302.8	82.0	182.5	566.4	1,854.3	54.7	17.4	911.7	61.5	167.6	4,200.9
1997	-	239.3	62.2	118.8	419.8	1,313.7	36.5	14.1	676.1	39.4	116.8	3,036.7
1998	-	653.0	164.2	269.7	1,086.0	3,259.6	85.3	39.2	1,749.8	87.9	285.2	7,679.8
1999	-	51.9	14.7	37.3	103.7	353.7	10.9	2.9	166.8	12.7	32.4	787.0
2000	-	207.0	56.4	127.7	390.4	1,285.2	38.1	11.8	628.4	43.1	116.4	2,904.6
2001	-	235.7	63.2	136.2	434.4	1,408.1	41.0	13.6	699.3	45.7	126.8	3,204.1
2002	-	67.3	19.0	48.2	134.2	457.5	14.1	3.8	215.9	16.4	41.9	1,018.5
2003	-	97.4	27.4	68.5	192.9	655.0	20.2	5.4	310.4	23.3	59.9	1,460.5
Average	-	443.9	112.2	189.1	744.6	2,250.4	59.5	26.6	1,199.7	61.8	197.4	5,285.3

Table A-2. Simulated Flow Volumes (ac-ft) from non-MS4 Areas

Year	Boulder	Division	Grout	Knicker-bocker	Local North	Local South	Metcalf	Minnelusa Canyon	Rathbun	Red Ant Canyon	West Summit	Total
1990	19.1	12.9	227.0	31.0	518.0	57.9	50.7	32.9	152.6	19.1	20.5	1,141.8
1991	98.3	68.7	1,276.7	159.7	2,971.8	286.6	265.8	188.8	771.5	98.7	103.9	6,290.4
1992	91.9	58.7	939.6	132.5	2,061.9	282.6	237.7	130.6	661.5	83.1	77.9	4,758.1
1993	1,155.6	697.5	9,950.5	1,467.7	20,667.0	3,606.0	2,910.0	1,305.2	7,462.6	942.3	734.7	50,899.0
1994	57.0	37.8	645.3	86.9	1,455.4	172.0	150.0	92.3	428.2	54.1	53.9	3,232.8
1995	814.2	442.9	4,786.4	876.4	8,286.3	2,662.0	1,956.4	517.3	4,676.5	579.2	334.5	25,931.9
1996	204.2	108.7	1,093.1	216.3	1,775.4	676.4	486.1	110.3	1,167.3	143.2	80.6	6,061.6
1997	179.1	97.3	1,046.1	195.7	1,804.1	588.3	429.9	112.6	1,045.8	128.8	77.8	5,705.4
1998	261.0	162.5	2,474.0	354.0	5,307.3	806.8	666.8	335.8	1,780.3	224.6	193.4	12,566.4
1999	1.9	1.0	10.0	3.0	16.3	6.9	4.4	1.0	16.3	1.8	2.1	64.8
2000	91.9	52.0	632.1	106.8	1,194.2	296.6	224.8	75.0	559.4	69.5	47.1	3,349.5
2001	44.4	30.3	540.9	71.8	1,241.0	133.1	118.6	78.8	351.4	44.3	47.0	2,701.6
2002	2.5	1.3	13.3	3.9	21.8	9.1	5.8	1.4	21.1	2.3	2.7	85.1
2003	3.9	2.1	19.9	6.0	31.0	14.5	9.3	1.9	33.0	3.7	4.1	129.4
Average	216.1	126.7	1,689.6	265.1	3,382.2	685.6	536.9	213.1	1,366.2	171.0	127.2	8,779.8

Table A-3. Simulated Sediment Loads (tons) from MS4 Areas

Year	Boulder	Division	Grout	Knicker-bocker	Local North	Local South	Metcalf	Minnelusa Canyon	Rathbun	Red Ant Canyon	West Summit	Total
1990	-	221.1	50.3	40.1	311.7	798.1	15.4	14.0	503.1	11.3	65.1	2,030.3
1991	-	224.9	53.0	58.1	336.0	915.1	20.2	14.0	542.1	17.7	76.8	2,258.0
1992	-	358.3	81.7	66.6	506.9	1,302.6	25.3	22.6	818.1	18.9	106.4	3,307.3
1993	-	1,388.4	370.1	778.5	2,533.1	8,153.6	235.2	80.4	4,078.2	260.7	732.5	18,610.7
1994	-	235.4	53.8	44.5	333.9	860.3	16.8	14.9	538.8	12.7	70.4	2,181.5
1995	-	486.5	134.3	318.1	937.0	3,127.0	94.3	27.5	1,507.9	107.7	284.5	7,024.8
1996	-	238.1	55.6	57.2	351.0	942.7	20.2	14.9	566.2	17.2	78.7	2,341.7
1997	-	206.3	47.9	46.3	300.6	797.7	16.7	12.9	485.1	13.7	66.2	1,993.5
1998	-	386.6	96.4	152.0	634.6	1,884.2	48.5	23.3	1,022.7	49.3	164.1	4,461.7
1999	-	45.1	10.3	8.1	63.5	162.3	3.1	2.9	102.6	2.3	13.2	413.4
2000	-	93.9	23.3	36.3	153.4	453.6	11.6	5.7	247.2	11.7	39.5	1,076.1
2001	-	299.2	67.7	50.4	417.7	1,056.9	19.8	19.0	674.2	13.9	85.7	2,704.4
2002	-	76.1	17.5	15.4	109.1	284.3	5.7	4.8	176.0	4.5	23.4	716.8
2003	-	35.9	8.2	6.9	51.1	132.2	2.6	2.3	82.5	2.0	10.8	334.5
Average	-	306.8	76.4	119.9	502.8	1,490.8	38.3	18.5	810.3	38.8	129.8	3,532.5

Table A-4. Simulated Sediment Loads (tons) from non-MS4 Areas

Year	Boulder	Division	Grout	Knicker-bocker	Local North	Local South	Metcalf	Minnelusa Canyon	Rathbun	Red Ant Canyon	West Summit	Total
1990	163.8	94.3	1,198.4	192.5	2,331.2	522.4	403.6	146.6	999.7	125.3	86.0	6,263.9
1991	119.9	72.9	1,059.3	155.9	2,220.4	373.8	303.0	140.3	790.7	99.6	80.8	5,416.5
1992	292.6	163.2	1,904.2	333.2	3,497.6	950.3	710.7	219.2	1,757.5	217.7	142.5	10,188.7
1993	1,108.8	658.3	9,046.6	1,336.5	18,417.4	3,460.4	2,770.9	1,161.7	6,829.4	867.5	614.1	46,271.6
1994	173.5	99.4	1,248.6	203.8	2,410.9	555.3	426.5	151.6	1,060.9	132.5	91.3	6,554.2
1995	503.1	276.2	3,074.9	555.5	5,451.2	1,642.7	1,213.8	340.8	2,951.5	365.1	224.1	16,599.1
1996	203.5	114.0	1,350.8	231.3	2,507.2	657.7	495.4	157.2	1,216.6	151.3	98.2	7,183.3
1997	233.1	126.2	1,343.7	251.6	2,297.6	765.3	558.9	143.3	1,346.1	166.1	97.2	7,329.0
1998	292.9	165.8	2,018.4	346.8	3,817.6	949.1	716.2	239.7	1,818.0	224.8	159.2	10,748.4
1999	26.1	16.6	265.2	35.8	580.6	79.2	67.5	36.8	177.9	22.7	19.6	1,328.0
2000	97.3	52.9	569.9	110.5	984.5	322.5	233.6	61.4	591.0	72.0	48.0	3,143.5
2001	191.0	112.1	1,497.3	238.7	3,000.4	608.8	474.7	189.1	1,231.0	153.3	118.3	7,814.6
2002	38.6	24.3	380.5	51.0	826.1	116.8	99.2	52.3	254.1	32.6	26.6	1,902.2
2003	26.1	15.2	202.1	31.1	403.1	82.3	64.7	25.4	160.2	20.2	14.1	1,044.5
Average	247.9	142.2	1,797.1	291.0	3,481.9	791.9	609.9	219.0	1,513.2	189.3	130.0	9,413.4