4.0 ESTIMATED MERCURY LOADS

4.1 DESCRIPTION OF HOW EACH SOURCE IS ASSESSED

The watershed includes six groups of waterbodies with distinct mercury loading characteristics:

- Creeks in New Almaden Mining District (NAMD)
- Upper watershed creeks (outside of NAMD)
- Impoundments
- Creeks below impoundments affected by mercury mining activities
- Urban Creeks
- Guadalupe River

The characteristics of these waterbody groups are discussed in terms of the magnitude of the mercury sources, the importance of these sources to the overall effects on the watershed, and the physical factors that affect either the magnitude of the mercury source or the bioavailability of the mercury. An emphasis is placed on identifying the uncertainties that exist in the load calculations. Data needs that can be incorporated into future adaptive management plans are also identified.

Major non-point sources of total mercury in the waterbodies of the Guadalupe River Watershed include natural background loads (of which atmospheric deposition is a major part), erosion of historic mine wastes, urban runoff, and erosion within stream banks. Methylmercury sources, particularly for this watershed, differ from total mercury sources in that significant production usually occurs within waterbodies during the warm summer months, and the most important sources are primarily internal. In addition to the non-point sources to creeks, reservoirs have distinctive characteristics and thus were considered separately for source assessment.

In general, mine-derived mercury loads are the most distinctive feature of the Guadalupe River watershed, although other sources, such as urban runoff, and background loads, including atmospheric deposition, are also present. Historic mines exist in the upper watershed and are a source of mercury to Almaden and Guadalupe

Reservoirs and also to the creeks below them. Downstream of the four major reservoirs, urban runoff loads are more significant in the creeks as well as in the river. Besides these loads, the other known source of mercury includes atmospheric deposition and water transfers to Calero Reservoir from the Central Valley. Load diagrams presented later in this chapter illustrate the sources and flow of mercury through the watershed. Mercury loads are related to impairment within the Guadalupe River and also to impairment in San Francisco Bay where the river discharges.

Loads were assessed separately for the wet and dry season based on the knowledge that most mercury transport occurs during the wet season, and most methylmercury production occurs in the warm, dry season. A large part of the wet season data collection for the mercury TMDL was focused on measurements of flow and mercury speciation at different locations and different times in the watershed. The data analysis approach used was to infer the loads from non-point sources indirectly from the measured concentrations and flows in the streams of the watershed. Using representative sub-watersheds that were affected principally by one type of mercury source, we estimated the areal contribution of background, historic mines, and urban areas. These loads were expressed in units of $\mu g/m^2$ over the wet season. This source analysis was limited to the wet season. For the dry season, the sampling was focused on the measurements of mercury species at different depths in the two reservoirs most affected by mining (Almaden and Guadalupe) and these data were used to infer methylmercury production. In this section, we explain the approach used to determine the contribution of each of these sources to the loads flowing through the watershed.

For the purpose of this discussion, all loads are estimated as net loads, which includes the potential effects of losses that may occur. Thus, within streams, sediment erosion is a source of mercury, and settling is a loss. However, when we speak of loads, we imply net loads (sources minus losses) at the point of interest.

4.1.1 BACKGROUND LOAD

Soda Spring in the watershed of Lexington Reservoir was used to estimate the background load. The watershed for this creek has practically no development and no mercury mines. Wet weather daily flows were estimated using the SWAT hydrologic model, using the topography, precipitation, and vegetation specific to this watershed. Using the flow estimates, total suspended solids, total mercury, methylmercury, and dissolved mercury concentrations in flowing water were estimated from regressions for the non-mining creeks in the upper watershed (see Figure 6-1 of the Final Data Collection Report, Tetra Tech, 2005a, which shows the curve for creeks upstream of the reservoirs). The load calculation approach, and the data used are discussed more fully in Section 6 of Tetra Tech (2005a). Loads were estimated from the flows and concentrations, and were found to be 1.16 $\mu g/m^2/yr$ for total mercury, 0.33 $\mu g/m^2/yr$ for dissolved mercury, and 0.012 $\mu g/m^2/yr$ for methylmercury over the wet season. This background load consists of wet and dry deposition, transport of past dry deposition, and loads from the erosion of natural geologic materials of the area. Given the data, however, it is not possible to decompose the total background loads into these specific constituents. However, the loads may be compared with total mercury atmospheric deposition estimates. The atmospheric deposition input was estimated as a daily load using wet and dry deposition data collected by SFEI at various locations around San Francisco Bay. Wet deposition was estimated using a rainfall concentration of 9.7 ng/l (SFEI, 2001) and a rainfall amount of 48 inches in the watersheds tributary to the reservoirs, and a rainfall amount of 14 inches for the rest of the watershed. Annual wet deposition was estimated as 11.6 $\mu g/m^2/yr$ in the upper watershed and 3.4 $\mu g/m^2/yr$ in the lower watershed. The annual dry deposition was estimated as 19 $\mu g/m^2/yr$ (SFEI, 2001) throughout the system. Thus, the total deposition is approximately 30 $\mu g/m^2/yr$ and about 3% is exported from land into waterbodies. This is generally consistent with a recent review that reports total export fractions in stream runoff of approximately 5%, with the remainder being sequestered in the watershed or volatilized (Grigal, 2002).

The rainfall received in the vicinity of Lexington reservoir was 30 inches over October 2003 to May 2004. When these background loading rates were applied to other parts of the Guadalupe Watershed, which had more or less rain, they were scaled proportionally to the amount of rainfall. This is because the transport of these background loads occurs via runoff, which is expected to be roughly proportional to rainfall.

4.1.2 Loads from Historic Mines

North Los Capitancillos Creek was used to estimate the load from historic mining areas. This creek was selected for the historic mine load estimate because, unlike other creeks upstream of Almaden and Guadalupe Reservoirs, the watershed for this creek is almost entirely within Almaden Quicksilver County Park, the area with significant historic mining activity.

Wet weather daily flows were estimated from the hydrologic model described in the Final Data Collection Report (Tetra Tech, 2005a). Using the flow estimates, TSS concentrations were estimated in the watershed. Total mercury concentrations were calculated by multiplying the TSS load by the particulate mercury concentration (average of 17.5 mg/kg for all mine sites), and methylmercury and dissolved mercury concentrations were estimated from regressions for the mining creeks in the upper watershed. Loads were estimated from the flows and concentrations, and were found to be 54.5 $\mu g/m^2$ for total mercury, 14.8 $\mu g/m^2$ for dissolved mercury, 0.11 $\mu g/m^2$ for methylmercury over the wet season. These loads are more than 40 times greater than the background for total and dissolved mercury, and about 10 times greater than background for methylmercury. It should be pointed out, however, that concentrations observed at the North Los Capitancillos Creek station were not the highest among those observed for all the mining creeks. It is indicative of an average value for all the mine areas, although it is possible that the mine loading rates are significantly higher from certain locations within the Almaden Quicksilver County Park.

An important source of error and uncertainty in the calculated loads are the limited range of the TSS values that were encountered during wet weather sampling in 2004 (see Figure 6-1 of the Final Data Collection Report, Tetra Tech, 2005a, which shows the curve for creeks upstream of reservoirs). The highest TSS values encountered in this calculation, including modeled flows in the 2003-2004 wet season, are not much higher than 10 mg/l, largely driven by the flow-TSS relationship shown in the figure cited above. In particular, the slope of the flow-TSS relationship is relatively flat because of the absence of TSS data corresponding to higher flows. These values may be too low for representing the entire wet season because a set of data analyzed by the Park staff indicate TSS levels more than two orders of magnitude larger. However, the Park data indicate lower mercury concentrations on particulates. If, on the other hand, the particulate Hg concentrations are as high as 17.5 mg/kg as used in this calculation, and the peak TSS values are 10 to 100 times greater than what we observed, the calculated loads may be much higher. At this time, because of the absence of flow data associated with the Park mercury and TSS measurements, detailed load calculations cannot be performed using these concentration data. However, the low TSS values in our data set are known to be a major source of uncertainty and must be quantified in future work. An example of the significance of large winter storm loads is provided in Section 4.9.

Of particular significance to the mercury TMDL, although the *relative* loads from different sources and water bodies are well-represented in these calculations, the absolute magnitudes of these loads may have been underestimated because of the absence of large rain storms during the our sampling. Thus, sampling in wetter years or during large storm events may result in greater transported loads than those reported in the sections below.

4.1.3 URBAN LOADS

The watershed for Ross Creek was used to estimate the load from urban areas. The watershed for this creek is almost entirely urbanized with no mining activity. Wet weather daily flows were obtained from the flow gauge near the downstream end of the creek. Using the flow data, total suspended solids, total mercury, methylmercury, and dissolved mercury concentrations in flowing water were estimated from regressions for urban creeks (see Figure 6-1 of the Final Data Collection Report, Tetra Tech, 2005a, which shows the curve for urban creeks). The load calculation approach, and the data used are discussed more fully in Section 6 of Tetra Tech (2005). Loads were estimated from the flows and concentrations, and were found to be 1.6 $\mu g/m^2$ for total mercury, 0.61 $\mu g/m^2$ for dissolved mercury, and 0.02 $\mu g/m^2$ for methylmercury over the wet season. The rainfall in the vicinity of the Ross Creek Watershed was 12.9 inches in 2003-2004. The loads are considerably higher than the background loads, especially when those loads are scaled to the lower rainfall in this watershed. These loads are also roughly an order of magnitude lower than the historic mine loads.

4.1.4 Loads to Reservoirs

Based on the watershed area for each reservoir, and the fraction of the area that was comprised of either undeveloped land or historic mines, loads were added according to the values discussed above. An exception was made for Calero Reservoir, which in addition to watershed loads, also receives occasional flows from Almaden Reservoir and from the Central Valley Project. Wet weather flows from Almaden Reservoir were estimated to average 7.5 cfs during the wet season, based on SCVWD data for 2001 and 2002. This average flow was multiplied by the average concentration measured at the outlet of the Almaden-Calero Canal to obtain an estimate of the load from Almaden Reservoir. For Calero Reservoir, which receives inflows from the Central Valley Project and Almaden Reservoirs, the inflow volumes were based on data provided by the District. The Central Valley flow was assumed to be 3,700 acre-feet (average of 2001 and 2002 values) and was applied only during the summer months. The mercury concentration in this source was assumed to be 1 ng/l.

4.1.5 Reservoir Loads to Downstream Creeks

Because reservoirs contain a substantial amount of storage, and because their outflows are controlled, it is thought that mercury concentrations in their outlets are less variable than in creeks, especially during the wet season. For this reason, the reservoir loads were computed in a manner simpler than that applied to streams: outflows were multiplied by the average mercury concentrations obtained in the wet weather sampling.

4.1.6 Dry Season Methylmercury Production and Export from Reservoirs

The primary data source for these calculations was the monthly to biweekly sampling of Almaden and Guadalupe Reservoirs conducted between May and August of 2004. Load calculations for mercury considered the measured mercury concentrations and the reservoir stored-water volumes, both of which changed over time. Besides the mercury concentration data, other data required for the load calculations are the volumes of water stored in the reservoir in the hypolimnion and the epilimnion, and the outflows from the reservoirs. The depth to the hypolimnion was estimated from the temperature and DO profiles that were taken during the mercury sampling. The calculation of the hypolimnion and epilimnion volume was based on detailed bathymetric maps of the reservoirs. The reservoir stored water volumes were obtained from automated gauges that are associated with SCVWD's online ALERT system (http://alert.valleywater.org). The concentrations over the sampling period were multiplied by the volume of the hypolimnion or the epilimnion to determine the mass of total or methylmercury in either compartment. Because concentration data were obtained less frequently than depth data, concentrations at dates without measurements were estimated by interpolation from the two nearest values with measurements.

The loads of mercury exported to Guadalupe Creek and Alamitos Creek were calculated as the product of mercury concentrations in the reservoir outflows, and the flow rate data routinely collected by SCVWD and reported on the ALERT system. Daily average flow data were used (computed from 24-hourly values). Actual measured total and methylmercury concentration data were used when available; for dates without mercury data, values were interpolated from the nearest two dates of sampling.

4.2 APPROACH TO ESTIMATING LOADS AND UNCERTAINTIES

Using gauged flow data over the entire 2003-2004 wet season, and relationships between flow and concentrations of total suspended solids, total mercury, and methylmercury, loads were computed across the entire watershed. When the inflows originated on land, they were estimated from land-based loading rates described above, and using GIS-based information on the distribution of land uses within the appropriate sub-watershed. Reservoir loads were estimated separately from creek loads as described above. The outflow loads from the creeks were calculated based on the flow (either modeled or gauged), and using the relevant correlations for TSS, total mercury, dissolved mercury, and methylmercury. Loads were identified separately for total and dissolved mercury, and for methylmercury.

In the discussion that follows, we first address the issue of uncertainty in all load calculations presented, followed by an overview of the estimated loads throughout the watershed. Finally, we discuss the estimated loads for each group of waterbodies in the Guadalupe River Watershed: the creeks draining the watershed upstream of the reservoirs, the major reservoirs/impoundments, the creeks downstream of the impoundments, the urban creeks, and the main stem of the Guadalupe River to San Francisco Bay.

Loads of constituents over defined time periods are obtained as a product of the flow volumes and the concentrations. When both flow and concentrations are highly variable over short durations, as is the case for most creeks in the Guadalupe River Watershed, accurate load estimates are strongly dependent on the availability of temporally detailed data. Although the mercury sampling for the TMDL consisted of a large effort to obtain mercury species and flow data through the watershed in the wet season, the data are still not sufficient to fully quantify the loads at all locations sampled, i.e., define the average loads and the variability associated with each load. Therefore, the numerical values of the loads presented in this section must be considered as estimates that can be used for comparing the relative magnitudes of different sources in the watershed.

To facilitate interpretation of the data, we have classified the uncertainty in the estimated loads into three categories:

- **High:** when flow data were limited to the mercury sampling time and location, and calculations were based on modeled flow
- **Medium:** when continuously gauged flow data were available

- **Low:** When continuously gauged flow *and* supporting information, such as total suspended solids data were available.

Guadalupe River fell in the low-medium uncertainty category above because of the presence of a multi-decade continuous flow record and an independent station monitored for total suspended solids and mercury by San Francisco Estuary Institute.

4.3 Transported Loads Throughout the Watershed (Wet Season)

Total mercury, methylmercury, and dissolved methylmercury loads for the major waterbodies in the Guadalupe River Watershed are shown in graphical form in Figures 4-1 through 4-3. For total mercury loads, shown in Figure 4-1, all reservoir outflows appear to be of roughly the same magnitude except Calero Reservoir. Although concentrations flowing out of Lexington Reservoir are lower than from Guadalupe and Almaden Reservoirs, this is compensated by the substantially larger volume of outflows. Further downstream, the largest loads to Guadalupe River originate from Alamitos Creek, followed by Los Gatos and Guadalupe Creek. Alamitos Creek loads, upstream of Calero Creek, are substantially higher than Almaden Reservoir outflow loads, indicating the mobilization of internal sediment loads. Although Los Gatos Creek does not contain any mines, the relatively high loads are a consequence of its larger watershed compared to Guadalupe Creek. The loads exiting Guadalupe River to San Francisco Bay are far higher than the total loads entering from all the tributary creeks and from its watershed. This is a strong indication of uncertainties in the upstream contributing loads, loads from the highly urbanized area, and the mobilization of internal sediment loads.

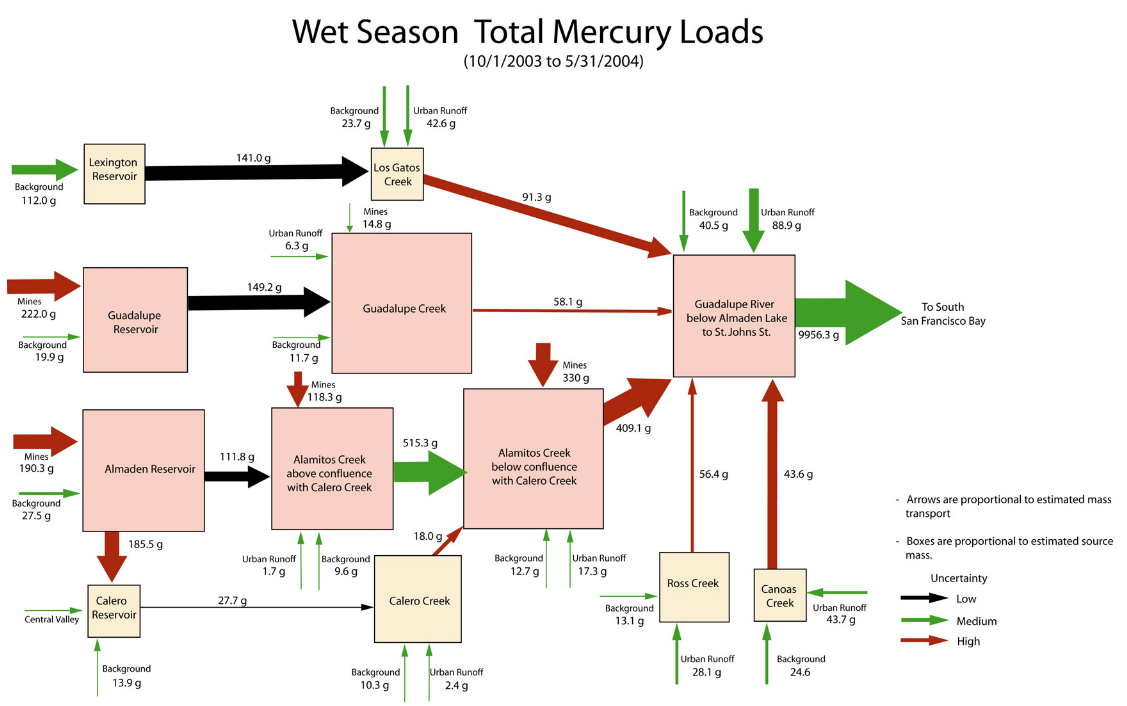

Figure 4-1. Estimates of total mercury loads in the Guadalupe River Watershed. All loads are in grams. See text for discussion of uncertainty of numerical estimates.

For methylmercury loads, shown in Figure 4-2, Guadalupe Reservoir is the largest contributor in the wet season, followed by Lexington and Almaden Reservoirs at somewhat lower levels, with Calero Reservoir being the lowest. Further downstream, with the exception of Alamitos Creek, the methylmercury loads to Guadalupe River from the different creeks are not too dissimilar, indicating that even small amounts of total mercury can produce enough methylmercury if the right aquatic chemistry conditions are present. As with total mercury, the methylmercury loads exiting Guadalupe River to San Francisco Bay are somewhat higher than the total loads entering from all the tributary creeks and from its watershed.

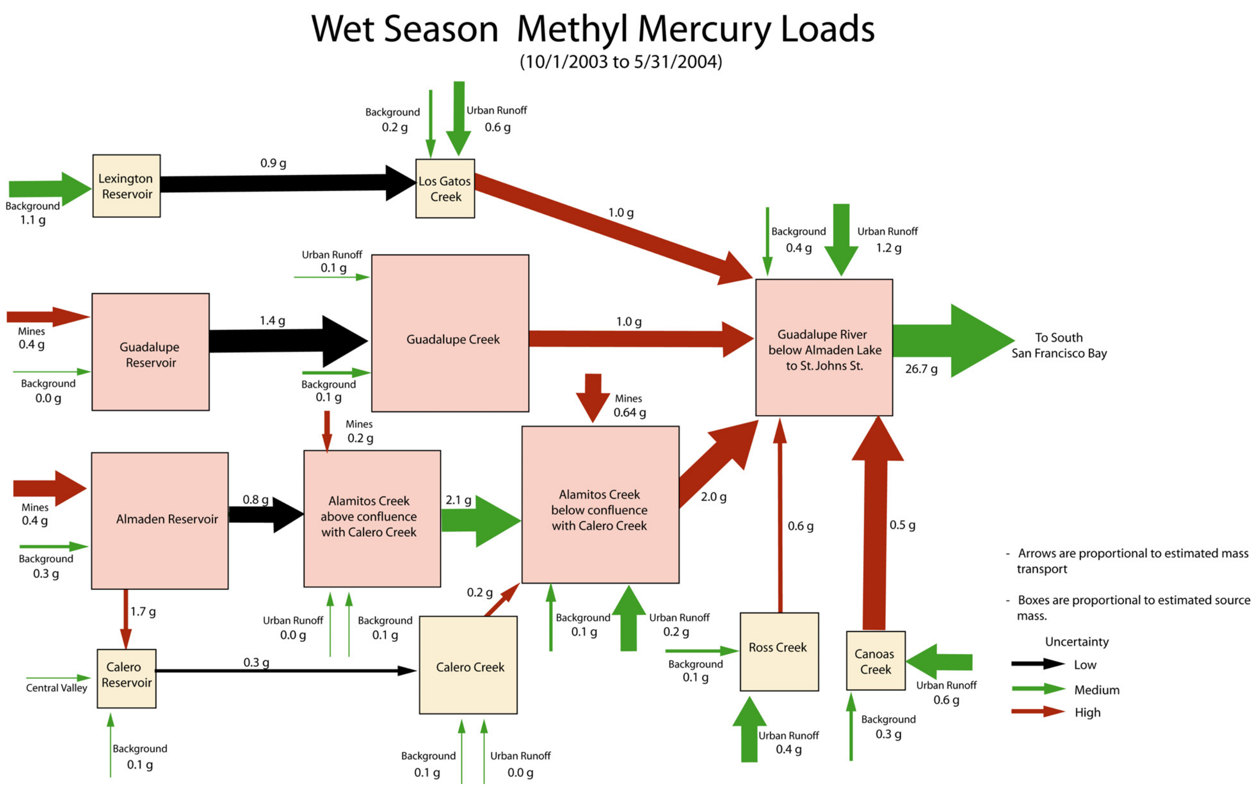

Figure 4-2. Estimates of methylmercury loads in the Guadalupe River Watershed. All loads are in grams. See text for discussion of uncertainty of numerical estimates.

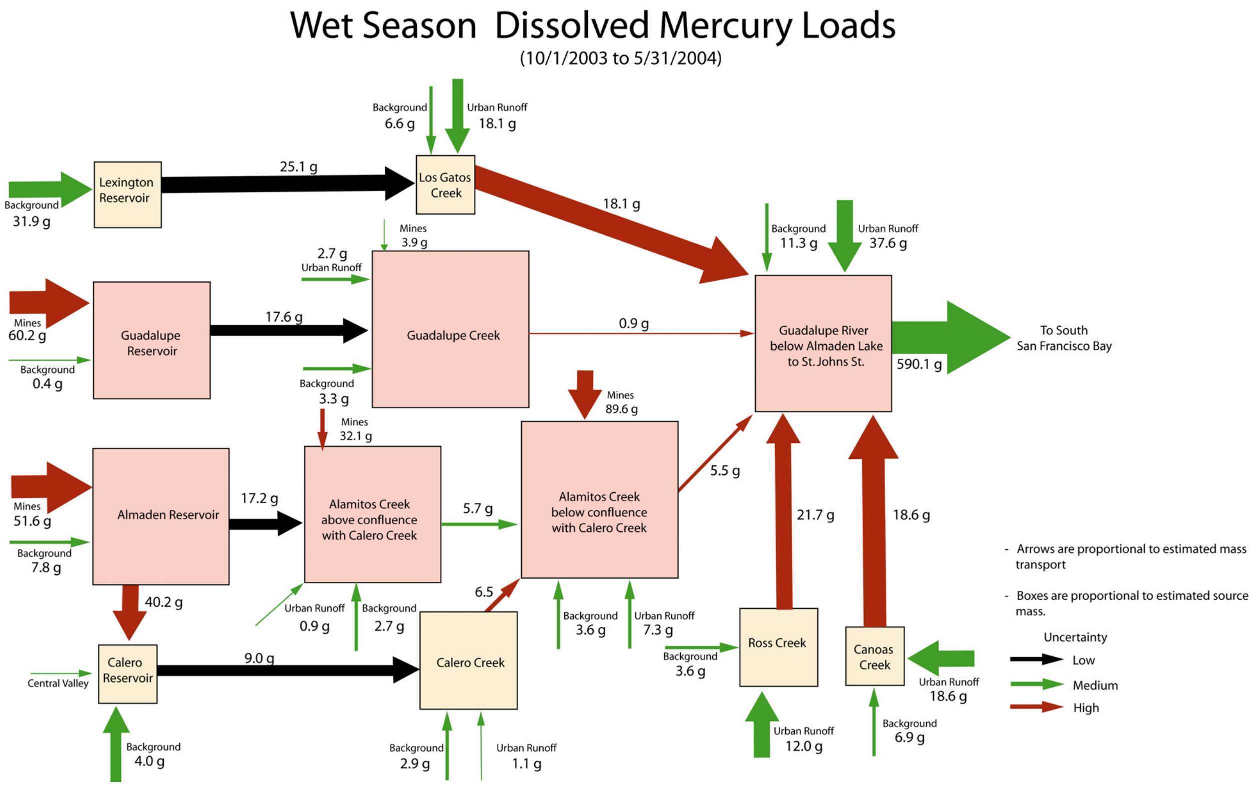

Figure 4-3. Estimates of dissolved mercury loads in the Guadalupe River Watershed. All loads are in grams. See text for discussion of uncertainty of numerical estimates.

4.4 Reservoir Production and Export of Methylmercury (Dry Season)

The internal methylmercury loads and the methylmercury exports for Guadalupe and Almaden Reservoirs are shown in Figures 4-4 and 4-5. Depending on the reservoir, there is 3 to 10 times as much methylmercury accumulated in the hypolimnion than in the epilimnion. There is a substantial increase in methylmercury beginning in July, particularly for Guadalupe Reservoir. Methylmercury exports from Almaden Reservoir were similar to that from Guadalupe Reservoir (7.2 g vs. 5 g). In both instances more of the methylmercury produced was exported than retained in the reservoirs. More methylmercury is exported during the dry than during the wet season (Figure 4-2 and Table 4-6).

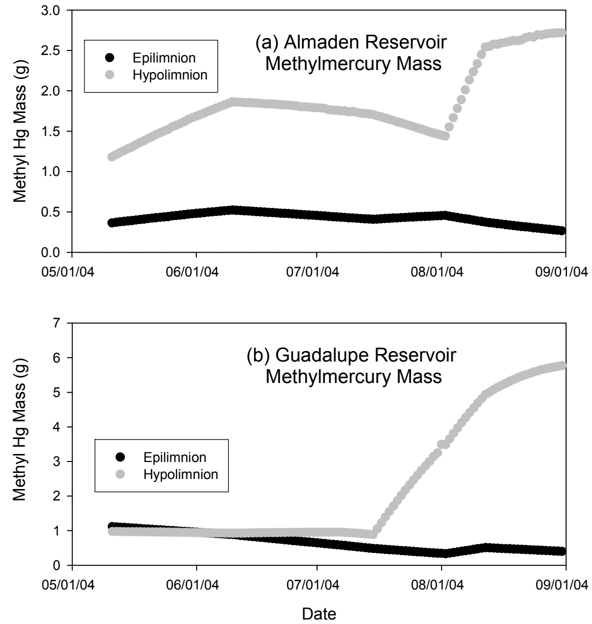

Figure 4-4. Estimates of internal methylmercury production in Almaden and Guadalupe Reservoir during the 2004 dry season.

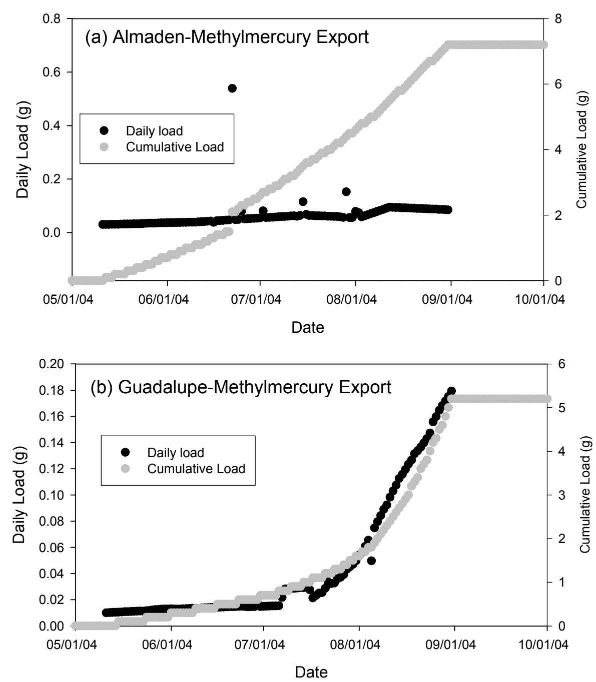

Figure 4-5. Estimates of downstream exports of methylmercury from Almaden and Guadalupe Reservoir during the 2004 dry season.

4.5 UPPER WATERSHED CREEKS

The creeks draining into the reservoirs in the upper Guadalupe River watershed can be divided into two groups: those affected by past mercury mining and those not affected (Table 4-1). Most of the subwatersheds are undeveloped open-space, parks, or areas with minimal development, except for one subwatershed to Lexington Reservoir, Upper Los Gatos, which has more development along Highway 17. Atmospheric wet and dry deposition, transport of past dry deposition, and erosion and transport of natural geologic materials represent mercury sources to all the subwatersheds. The susceptibility of the creeks to erosion and sediment transport varies depending on whether the slopes are forested or grass covered, the extent of landslides, and faults. Faults are common in the upper watersheds, which can trigger landslides. Mercury deposits may be associated with fault zones.

Table 4-1.
Creeks Affected by Mining in Upper Watershed

Reservoirs	Creeks Affected by Mining
Almaden	Jacques Gulch and West Tributary to Reservoir
Calero	Only Almaden-Calero Canal
Guadalupe	N. Los Capitancillos
Lexington	None*

*Limekiln Canyon has limited silica carbonate outcrops but no historic mines.

Estimated total mercury loads to the four larger reservoirs are shown in Table 4-2 as described in Technical Memorandum 5.3.2 Data Collection Report. The loads have been divided into two components: 1) background loads from atmospheric wet and dry deposition, transport of past dry deposition, and erosion and transport of natural geologic materials; and 2) mining loads from transport of exposed mine wastes and mine seeps. Mine-related loads were estimated to Almaden, Calero, and Guadalupe Reservoirs. For each of these reservoirs, the contribution from transport of mine wastes was larger than the background load.

Table 4-2.
Estimated Wet-Season Total Mercury Loads from Upper Watershed Creeks

Loads to Reservoir	Background Load, g	Mine-related Load, g	Uncertainty
Almaden	27.5	190.3	High
Calero	13.9	185.5	High
Guadalupe	19.9	222.0	High
Lexington	112.0	none	High

Uncertainties in the total mercury loads derive from the variable rainfall over annual and inter-annual cycles and from use of limited data to estimate the mercury content of the particulate and total load (one or two sampling events of low runoff events in the wet-season of 2004). Most of the upper watershed creeks, including those draining former mining areas, are dry in the summer. Additional sampling of the mine-related creeks during high flow events in the wet-season could reduce the uncertainty. The upper watershed creeks contribute to the downstream waterbodies only from the reservoir outlets. Thus, quantification of these outlets only is necessary for development of mercury loadings to the downstream waterbodies.

The estimated methylmercury loads from the upper watershed creeks to the reservoirs are small in the wet-season, as shown in Table 4-3. The loads from the creeks influenced by mining contributed more methylmercury than the non-mining creeks. Because most of the creeks are dry in the summer, higher methylmercury loads are not expected. Three creeks that continue flowing in the summer (Rincon and Herbert Creek and Barret Canyon) are fed by springs at low flows, and the conditions for methylation are not expected. Upper Los Gatos Creek has flow during the summer from Lake Elsman, but because of the distance from the lake to Lexington Reservoir, and the demethylation that occurs in the creeks in the watershed, Lake Elsman is not expected to contribute significant methylmercury in the summer. Thus, the upper watershed creeks do not represent a major source of methylmercury to the reservoirs, which is primarily due to internal sources such as methylation in the anoxic water column and/or sediment in the reservoirs.

Table 4-3.
Estimated Wet-Season Methylmercury Loads from Upper Watershed Creeks

Loads to Reservoir	Background Load, g	Mine-related Load, g	Uncertainty
Almaden	0.3	0.4	High
Calero	0.1	1.7	High
Guadalupe	0.0	0.4	High
Lexington	1.1	None	High

4.6 Creeks Below Impoundments

4.6.1 Creeks Affected by Mercury Mining Activities

Mercury loads were estimated for two creeks affected by mining: Alamitos and Guadalupe Creeks. Alamitos Creek begins at the outlet of Almaden Reservoir and ends at Lake Almaden, where deposition of gravel and coarse sediment occurs. As seen in Figure 4-6, Alamitos Creek and Guadalupe Creek join below Lake Almaden, and then flow downstream forming the Guadalupe River. Following the wet season, flashboards are installed at the Alamitos Drop Structure, shown in Figure 4-6, to raise the level of both Lake Almaden and an impounded section between the lake outlet and the drop structure. A fish ladder allows for fish passage across the drop structure. Sediment can build-up behind the flashboards over the dry season, and in the wet season when the boards are removed, sediment can be transported downstream. Where Guadalupe Creek joins Alamitos Creek below the lake, there is also a significant deposition zone, as seen in Figure 4-6. Sediment samples from both of these deposition areas had high mercury concentrations (16.4 to 18.8 mg/kg) Tetra Tech, 2005a).

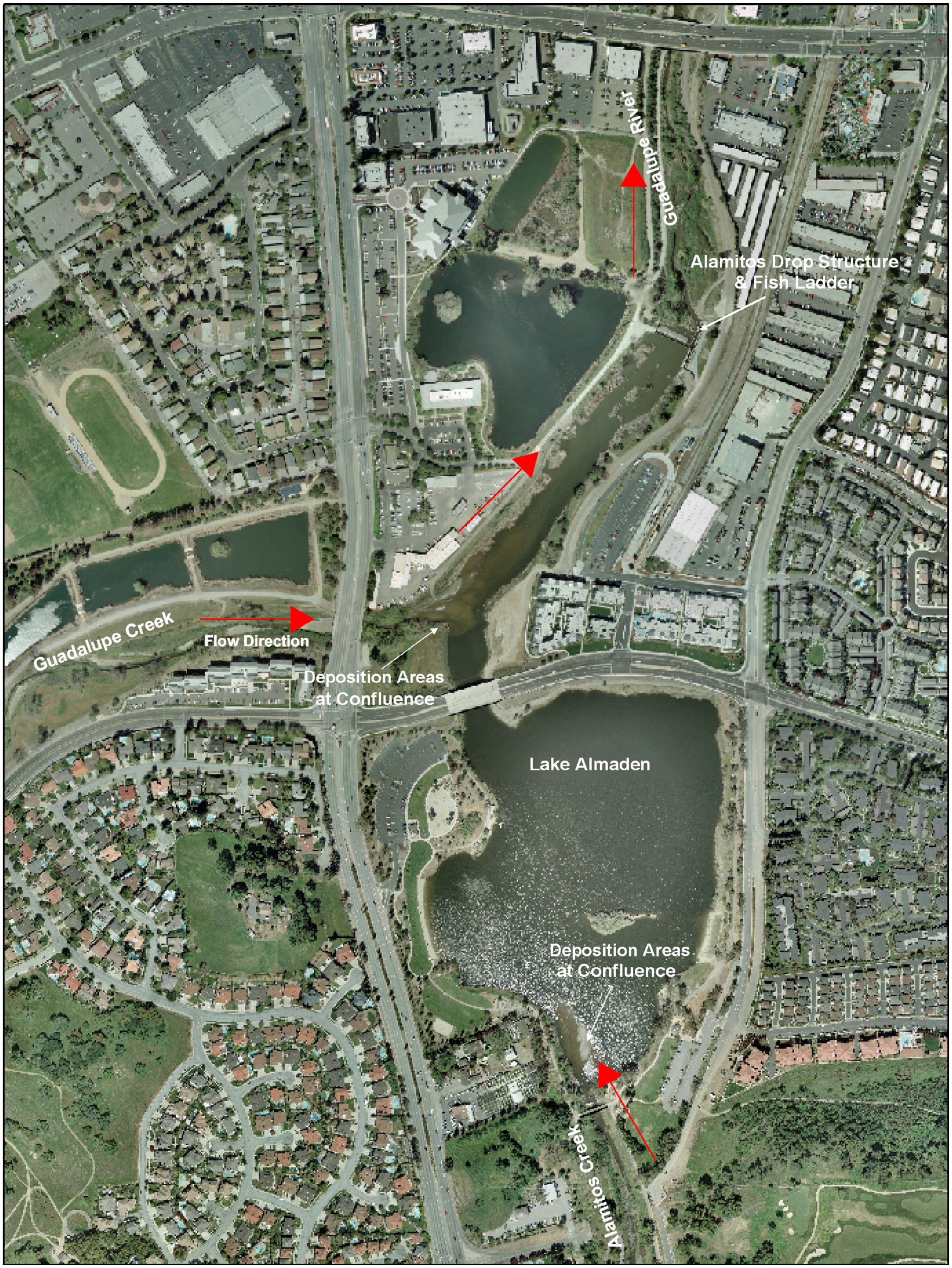

Figure 4-6. Aerial photograph of Lake Almaden and vicinity showing deposition areas at mouths of Guadalupe and Alamitos Creeks

Both Alamitos and Guadalupe Creeks have inflows from reservoirs and tributaries with varying land uses including past mining activities. Alamitos Creek has three tributaries that drain part of the Almaden County Quicksilver (AQC) Park, McAbee Creek (a tributary of Golf Creek), Randol Creek, and Greystone Creek. A series of small drop structures and a debris dam reduces the mercury load from these creeks that ultimately reaches the main stem of Alamitos Creek. Other tributaries to Alamitos Creek are Calero Creek and its tributary, Santa Teresa Creek. Guadalupe Creek has limited mining activities on a tributary to Cherry Springs Creek and flows along part of the former Guadalupe Mine, which is outside of the AQC Park boundary. Mine wastes were disposed to both Alamitos and Guadalupe Creeks, but especially to Alamitos, because extensive furnaces and retorts were located along its bank near the Hacienda Furnace Yard above the town of New Almaden.

The estimated total mercury loads to both creeks are shown in Table 4-4. The load to both creeks from the upstream reservoirs is significant. However, the importance of erosion of past mine wastes along the creek is seen in the internal load generated from the upper part of Alamitos Creek above its confluence with Calero Creek. The wet-season inflows from the reservoirs were the major source of methylmercury to the two creeks, which is also true for the dry season. Uncertainties in these loads are due to the variability of rainfall, which in turn results in changing levels of erosion, and differences in extent of the mine contribution to various parts of the watershed.

4.7 Urban Creeks

There are three urban creeks, Los Gatos, Ross, and Canoas, which discharge into the Guadalupe River. Los Gatos Creek has the largest flows, because it has a larger watershed and receives inflow from Lexington Reservoir. Ross Creek is a short creek with minimal to no flow in the summer. Canoas Creek is longer than Ross Creek but also has minimal flows in the summer. Sources to these creeks include atmospheric deposition, stormwater runoff, and erosion of stream bank materials.

The estimated total mercury and methylmercury loads into these creeks are shown in Table 4-5. These loads were calculated on an areal basis, where GIS data were used to define the fraction of each subwatershed that was covered by urban land. The areal loading rate for urban lands was based on the calculation described in section 4.1.3. The largest total mercury and methylmercury loads from the urban creeks to the Guadalupe River were from Los Gatos Creek. Los Gatos Creek is dominated by the reservoir outflow, particularly for methylmercury. For all three creeks, the urban contribution was larger than the background.

Table 4-4
Estimated Mercury Loads in Alamitos and Guadalupe Creek
(in grams over the wet season, (10/1/2003 to 5/31/2004)

Alamitos Creek (up to confluence with Calero Creek)

	Loads In				**Total Inflows**	**Loads to Alamitos Creek**
	Background	Urban	Almaden Reservoir	Historic Mine Loads		
Total Hg	9.6	1.7	111.8	118.3	**241.4**	**515.3**
Methyl Hg	0.1	0	0.8	0.16	**1.1**	**2.1**
Uncertainty in loads	Medium	Medium	Low	High	**High**	**High**

Calero Creek, a tributary to Alamitos Creek

	Loads In			**Total Inflows**	**Loads to Alamitos Creek**
	Background	Urban	Calero Reservoir		
Total Hg	10.3	2.4	27.7	**40.4**	**18**
Methyl Hg	0.1	0	0.3	**0.4**	**0.2**
Uncertainty in loads	Medium	Medium	Low	**High**	**High**

Alamitos Creek (below confluence with Calero Creek)

	Loads In					**Total Inflows**	**Loads to Guadalupe River**
	Background	Urban	Upper Alamitos Creek	Calero Creek	Historic Mine Loads		
Total Hg	12.7	17.3	515.3	18	330	**893.3**	**409.1**
Methyl Hg	0.1	0.2	2.1	0.2	0.64	**3.3**	**2**
Uncertainty in loads	Medium	Medium	High	High	High	**High**	**High**

Guadalupe Creek

	Loads In				**Total Inflows**	**Loads to Guadalupe River**
	Background	Urban	Guadalupe Reservoir	Historic Mine Loads		
Total Hg	11.7	6.3	149.2	14.8	**182**	**58.1**
Methyl Hg	0.1	0.1	1.4	0	**1.6**	**1**
Uncertainty in loads	Medium	Medium	Low	High	**High**	**High**

Table 4-5.
Mercury Loads in Urban Creeks in the Guadalupe River Watershed
(in grams over the wet season, (10/1/2003 to 5/31/2004)

Los Gatos Creek

	Loads In			Total Inflows	Loads to Guadalupe River
	Background	Urban	Lexington Reservoir		
Total Hg	23.7	42.6	141.0	**207.3**	**91.3**
Methyl Hg	0.2	0.6	0.9	**1.7**	**1.0**
Uncertainty in loads	Medium	Medium	Medium	**Medium**	**High**

Ross Creek

	Loads In		Total Inflows	Loads to Guadalupe River
	Background	Urban		
Total Hg	13.1	28.1	**41.2**	**56.4**
Methyl Hg	0.1	0.4	**0.5**	**0.6**
Uncertainty in loads	Medium	Medium	**Medium**	**High**

Canoas Creek

	Loads In		Total Inflows	Loads to Guadalupe River
	Background	Urban		
Total Hg	24.6	43.7	**68.3**	**43.6**
Methyl Hg	0.3	0.6	**0.9**	**0.5**
Uncertainty in loads	Medium	Medium	**Medium**	**High**

4.8 IMPOUNDMENTS

4.8.1 RESERVOIRS

Mercury loads in four major reservoirs in the Guadalupe River Watershed were assessed as part of this TMDL: Almaden, Calero, Guadalupe and Lexington Reservoirs. Two of these reservoirs, Almaden and Guadalupe, are significantly affected by mining sources. Lexington Reservoir is considered to be unimpacted by mercury mining activities, and may be considered a background reservoir from the standpoint of mercury contamination. Calero Reservoir has mercury impacts in-between the background and the mining-impacted reservoirs, because of water transfers from Almaden Reservoir and mercury-enriched geology in this subwatershed. The reservoirs are all in the upstream portion of the watershed and receive water, and mercury loads, from creeks primarily during the wet season. Mercury in the reservoirs accumulates as sediment (not measured as part of this study) and is also exported downstream. Mercury in the reservoir sediments and water column is methylated and exported downstream during the dry season.

Estimated total and methylmercury exports from the reservoirs during the dry and wet season are shown in Table 4-6. On a mass basis, Almaden, Guadalupe, and Lexington Reservoirs are all significant sources of total mercury in the wet season, the first two as a result of high concentrations and Lexington because it is much larger and has higher outflows on average. The total mercury exports in the dry season are substantially lower than in the wet season, for the two reservoirs where such a comparison could be made. Methylmercury exports in the wet season are relatively low (~1% of total mercury load) and follow the same pattern as the total mercury load. In the dry season however, the picture changes: the methylmercury loads are between 3 and 10 times larger than in the wet season, and furthermore, methylmercury constitutes a much larger fraction of the total mercury load (between 13 and 34 %).

Table 4-6.
Estimated wet and dry season exports of total and methylmercury from the reservoirs.

Reservoir	Total Mercury Export (wet), g	Methylmercury Export (wet), g	Total Mercury Export (dry), g	Methylmercury Export (dry), g	Uncertainty
Almaden	287.3	0.8	21.0	7.2	Low
Calero	27.7	0.3	No data	No data	Low
Guadalupe	149.2	1.4	37.0	5.0	Low
Lexington	141.0	0.9	No data	No data	Low

Of all the loads estimated in this TMDL, it is thought that the uncertainties in the reservoir exports are low. This is because the flows at all outlets are gauged continuously, and more importantly because both flows and total mercury concentrations are relatively uniform. Methylmercury concentrations are variable, but they exhibit a clear seasonal pattern (a buildup over the summer months) that was captured reasonably well during the data collection sampling program in 2004. Thus, in general the concentration and flow data needed for reasonably accurate load estimates are available at the reservoir outlets.

4.8.2 Other Impoundments

Mercury loads for other impoundments in the Guadalupe River watershed were not estimated. Major impoundments downstream of the above four reservoirs are Lake Almaden upstream of the confluence of Alamitos Creek and Guadalupe Creek, Vasona Reservoir on Los Gatos Creek downstream of Lexington Reservoir, and a much smaller impoundment on Guadalupe Creek above Masson Dam. There are also off-stream percolation ponds along some creeks and the Guadalupe River, where flows can be diverted for groundwater recharge.

Lake Almaden has shallow and moderately deep areas, up to about 40 feet, and contains sediment and gravel deposited at the confluence of Alamitos Creek and the lake. The wet-season sampling in 2004 indicated that total mercury concentrations downstream of the lake were less than upstream in the creek, although the suspended solids were higher in the outlet samples. The particulate mercury concentrations were higher in the upstream samples. Methylmercury concentrations were similar in the wet-season samples for both up and downstream samples. Additional sampling of Lake Almaden in the summer would be needed to determine if the elevated methylmercury concentrations found during the Synoptic Survey in July 2003 are representative of summer concentrations. The fish data collected in 2004 suggest that internal methylation in the lake is occurring.

Vasona Reservoir is a small reservoir on Los Gatos Creek and often spills during large storm events, as occurred when sampled on February 27, 2004 as part of the data collection program. The total mercury and suspended solids concentrations during spilling were higher than for a non-spill event when both the Lexington Reservoir and a site downstream of Vasona Reservoir were sampled on the same date. The methylmercury concentrations were similar for the non-storm event. Because this reservoir is shallow, it is less important than the larger upstream reservoirs.

Masson Dam on Guadalupe Creek forms a small, shallow impoundment. A fish ladder allows for fish passage. Previous sampling suggests that methylmercury may increase due to this impoundment, but this source is less important than the large reservoirs.

4.9 UNCERTAINTY IN UPPER WATERSHED LOADS

Loads described in the sections above are primarily based on sampling conducted during the 2003-2004 wet season, with most samples being collected in late February and beyond. Limited large storms during this period precluded sampling at high flows in much of the upper watershed. Further, given the remoteness and inaccessibility of some of the sampling stations, it is unlikely that they can be adequately sampled, on a grab-basis, for the short-duration peak flows that occur in the watershed. The loads presented above must be discussed in light of these constraints in the existing data set. As a general rule, increased flows result in higher suspended solids and therefore, higher mercury transport. This process was accounted for by using flow-TSS correlations to estimate TSS levels at flows higher than those physically sampled. However, because of the absence of high flow data in the upper watershed, it is possible that these correlations were not accurate, and were perhaps underestimated especially at higher flows.

Calculations using data from the Almaden Quicksilver County Park illustrate the significance of high TSS events. Measurements made by the Park on Los Capitancillos Creek on February 25, 2004 indicated TSS values of 8,890 mg/l and mercury values of 5,300 ng/l (reported in Table 2-6 of this report). Flow measurements were not made during this sample collection event. However, based on modeled flow data we have computed using rainfall in the 2003-2004 wet season, the average estimated flow on this date is 57.6 cfs. Assuming that the peak flow is approximately 4 times the average daily flow, and that this flow lasts for 4 hours, the transported load from the Los Capitancillos Creek during this period is estimated to be 490 g, a value much higher than the estimated annual load of mercury from mines to the Guadalupe Reservoir. Although approximate, this calculation highlights the significance of the storm event loads in the upper watershed, and indicates a major source of uncertainty in the estimated loads presented here: the contribution of large winter storms. The absence of adequate flow and TSS data in the upper watershed precludes a more detailed analysis of this uncertainty. Based on this assessment it appears that the calculated loads presented here are more likely to be underestimates rather than overestimates. Further quantification of the upper watershed loads through additional wet weather data collection in future stages of this project is strongly recommended.

4.10 GUADALUPE RIVER

The Guadalupe River begins below Lake Almaden at the confluence of Alamitos and Guadalupe Creeks and discharges into San Francisco Bay. Tributaries to the river include Alamitos and Guadalupe Creeks, the two creeks affected by past mining, and three urban creeks, Ross, Canoas, and Los Gatos. The flow from Alamitos and Guadalupe Creeks is controlled by the Alamitos drop structure and associated fish ladder. However, sediment can build-up behind this drop structure over the dry season, which can then be transported downstream during large storm events in the wet season. Other sources to the river include atmospheric deposition, urban runoff routed to large storm drains that discharge directly into the river, and resuspension and erosion of stream bank material. The flow regime of the lower Guadalupe River will change as a result of the new flood control projects currently under construction. For example, flows above 3,000 cfs will soon be routed to a new underground bypass channel, which will re-enter the river above Alviso Slough. At the junction of the routed flows, channel widening and hardening is expected to limit erosion. Thus, the sediment transport regime may also change due to less bank erosion.

The estimated total mercury and methylmercury loads for the wet-season to the Guadalupe River are shown in Table 4-7. The largest loads for both total mercury and methylmercury were estimated to be from Alamitos Creek. The increased total mercury load to the Bay compared to the inflows is due partly to internally-generated load from resuspension of sediment and bank erosion and from transport of deposited sediment behind gates in the larger storm drains, which discharge to the river. There is also uncertainty in the upstream loads.

Table 4-7.
Estimated Mercury Loads in the Guadalupe River
(in grams over the wet season, (10/1/2003 to 5/31/2004)

	Loads In							
	Background	Urban	Guadalupe Creek	Alamitos Creek	Ross Creek	Los Gatos Creek	Canoas Creek	**Total Inflows**
Total Hg	40.5	88.9	58.1	409.1	56.4	91.3	43.6	**787.9**
Methyl Hg	0.4	1.2	1.0	1.9	0.6	1.0	0.5	**6.6**

4.11 UNCERTAINTY IN GUADALUPE RIVER LOADS TO SAN FRANCISCO BAY

We sought to quantify the uncertainty in Guadalupe River loads by accounting for the residual error in the regressions using Monte Carlo Analysis. The Monte Carlo approach is used to estimate likely ranges of loads, given imperfect knowledge about the needed inputs, particularly flow-concentration relationships and inter-year variability in flows. This is done by assuming probability distributions for the key inputs, and performing the load calculations multiple times where values of inputs are drawn from a specified probability distribution. Each Monte Carlo trial results in an estimate of the load. When this process is repeated several times (typically several hundred or thousand times), one obtains a distribution of the loads that is consistent with the uncertainty in input parameters.

For the specific case of developing the uncertainty-based load estimates of mercury for the Guadalupe River Watershed, where flows are related to TSS, and the TSS to mercury concentrations, we need a method that, given a specific value of flow, provides a probabilistic estimate of TSS, and a probabilistic estimate of the total mercury concentrations. These can be used to generate a probabilistic estimate of the mercury load, and, if the process is repeated a large number of times, can provide a distribution of the load. The statistical approach for doing this is to use the residual errors in the regressions to develop Monte Carlo estimates of key input parameters.[1] This approach was implemented in Microsoft Excel, using the Crystal Ball program. Crystal Ball is a specialized simulation tool for performing Monte Carlo simulations.

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[1] The statistical approach for doing this is to assume that the linear regression models developed by Tetra Tech are expressed as $y = \alpha + \beta x$, where y is the dependent variable and x is the independent variable, and α and β are the intercept and slope. Using N pairs of observed data (X_i, Y_i), a least-squared error estimator was used to determine α and β. Our goal is to develop a Monte Carlo procedure that will generate random values of the dependent variable y for specified values of the independent variable x. The variance of the model error will be computed using the N data samples. An unbiased variance estimator s_m^2 is computed (Bhattacharyya and Johnson, 1977, pages 341-357) as follows:

$$s_m^2 = \frac{SSE}{(N-2)}$$

where *SSE* is the residual sum of squares using *N* data pairs (X_i, Y_i):

$$SSE = \sum_{i=1}^{N} (Y_i - \alpha - \beta X_i)^2 .$$

The Monte Carlo algorithm generates random deviates of the linear model by assuming the dependent y variable of the model has Gaussian distribution $N(\mu_y, \sigma_y)$. The variance of the dependent y variable is assumed to be the same for any value of the independent variable x. The jth deviate y_j of the dependent variable can be generated for the specified dependent value x^* as follows:

$$y^* = \alpha + \beta x^*, \text{ where } y_j \in N(y^*, s_m).$$

The load of total mercury being transported out of the Guadalupe Watershed into San Francisco Bay was used for the uncertainty analysis. The Monte Carlo estimate of wet weather loads was computed using the following steps:

1. The flows, obtained from the USGS flow gauge in the downstream portion of the Guadalupe River, were assumed to be accurately known, i.e., there was no uncertainty associated with them.
2. For a specific day, the flow rate was used to obtain a probabilistic estimate of the TSS using the regression equation for stations on the river, and using the statistical approach above.
3. Using the probabilistic estimate of TSS, a similar probabilistic estimate was obtained for total mercury concentration using the mercury-TSS correlation for the River stations.
4. Multiplying the flow and mercury concentration for each day provided an estimate of the daily load
5. The entire wet weather load was calculated by summing the daily loads from 10/1/2003 to 5/31/2004.
6. Steps 1) through 5) were repeated 1,000 times to obtain a distribution of the wet weather load for 2004.

The distribution of wet season loads for 2003-2004 is shown in Figure 4-7. The distribution shows a somewhat skewed bell curve, with a longer tail on the right-hand side than on the left-hand side, as a consequence of some of the variables being log-transformed in the regressions. Total loads range from approximately 8 to 20 kg. The mid-point of the distribution is about 12 kg.

Although loads for a given year are uncertain, we also know that there is significant year-to-year variability in the flows out of the Guadalupe Watershed. Because flows and mercury loads are related, it is likely that multi-year uncertainty will be significantly greater than the single-year uncertainty estimate. To assess the multi-year uncertainty, we performed a Monte Carlo analysis using daily average flows from 1960-2002, where a single year over this period was randomly sampled to compute total wet weather loads from October through May. The distribution of loads for the multi-year analysis is shown in Figure 4-8. It can be seen that the multi year uncertainty is considerably greater than the single year uncertainty, with values ranging from near zero for the extremely low flow years to almost 100 kg for the high flow years. Although this is not an unexpected result, the Monte Carlo analysis permits quantification of the process, and can be used to relate individual-year loads, and potential load reductions, to the overall distribution of loads.

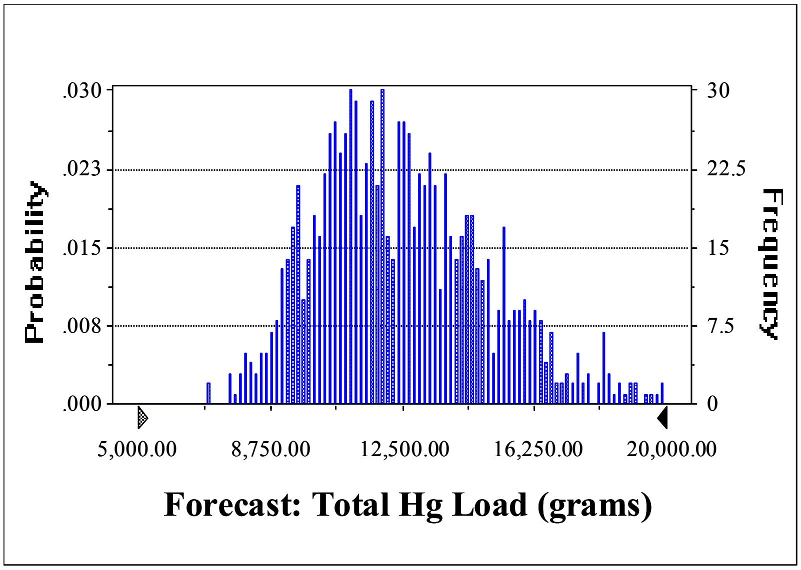

Figure 4-7. Uncertainty in the single-year estimate (2003-2004 wet season) of total mercury loads from Guadalupe River to South San Francisco Bay. The calculations were obtained using the uncertainty in the flow-TSS and the TSS-total Hg relationships using a Monte Carlo simulation with 1000 trials. The average estimated wet weather load for 2003-2004 is about 10 kg.

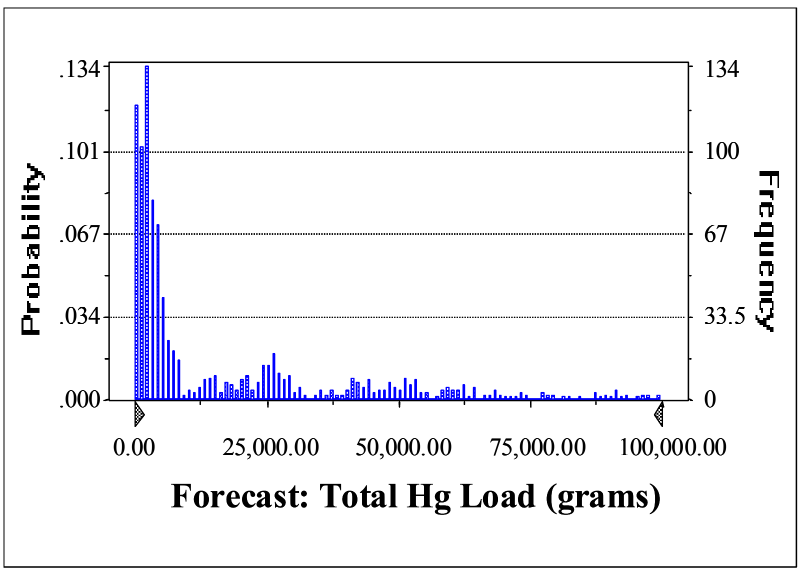

Figure 4-8. Uncertainty in the multi-year estimate (1960-2001 wet seasons) of total mercury loads from Guadalupe River to South San Francisco Bay. The calculations were obtained using the uncertainty in the flow-TSS and the TSS-total Hg relationships and using a Monte Carlo simulation with 1000 trials. The distribution of loads is much wider than for the single year estimate, driven by the large year-to-year variability in flows.

A further cause of uncertainty may be that the Tetra Tech data used to develop the flow-TSS correlations are not based on the full range of flows in the system. As an alternative, a flow-TSS relationship for the Guadalupe River based on the 2002-2003 wet season developed by the San Francisco Estuary Institute (SFEI, McKee et al., 2004) was used to estimate total mercury loads. This has the benefit of being based on a continuous record of flow and TSS for a period of several months. The loads estimated between the 1960 wet season and the 2001 wet season for the Tetra Tech and SFEI relationships are shown in Figure 4-9. It is clear in these plots that the nature of the correlations used to estimate TSS can make a large difference to the estimates of mercury loads in the system. In general, the greatest discrepancies occur in the high flow years, and the loads estimated using the SFEI approach are consistently higher. A comparison of this nature for locations in the upper watershed would be very valuable; however, the absence of enough monitoring data precludes such an assessment.

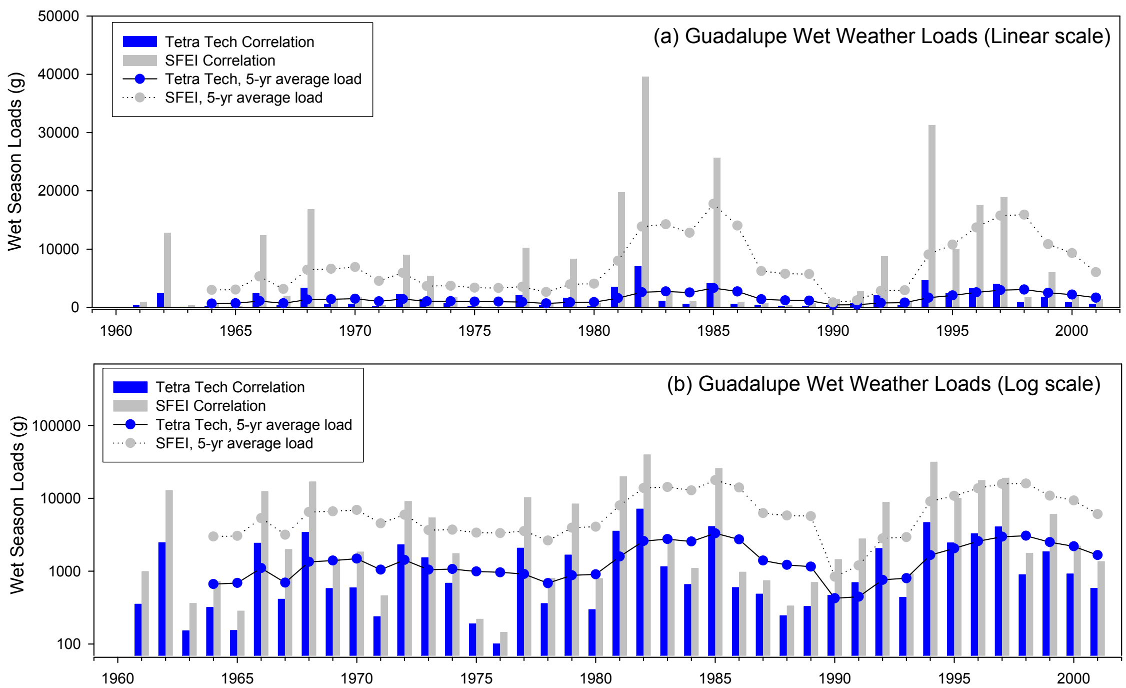

Figure 4-9. Uncertainty in the multi-year estimate (1960-2001 wet seasons) of total mercury loads from Guadalupe River to South San Francisco Bay using two different correlations between flow and suspended solids.

4.12 Recommended Averaging Time for Guadalupe River Loads to San Francisco Bay

Mercury loads exiting the Guadalupe River Watershed vary substantially depending on the volume of flow. Given the historical variability of flows in the river, it is appropriate to define an averaging period to define a baseline for loads against which any future loads must be considered. The averaging period must be chosen based on local site and climate characteristics: an averaging period that is too long will be insufficient to detect trends in changing loads, whereas an averaging period that is too short will be overwhelmed by year-to-year variability.

As a starting point, a five-year averaging period has been proposed by the Water Board. Figure 4-10 shows a comparison of the estimated loads as a function of the averaging period (3 years, 5 years, 7 years, and 10 years) for the Tetra Tech and SFEI correlations used in Figure 4-9. The use of longer averaging periods has the benefit of smoothing out peaks caused by occasional very high flow years, which are typical of this watershed. However a long averaging period (i.e., 10 years) has the effect of elevating the average load for a long period of time. It is conceivable that watershed changes could occur over time frames shorter than 10 years particularly those associated with modification of the flow channel, as proposed in San Jose, or removal of high-mercury containing sediments from dams and river channels. For this reason, a 10-year averaging period is rejected as being too long, and a 5- to 7-year averaging period is considered acceptable.

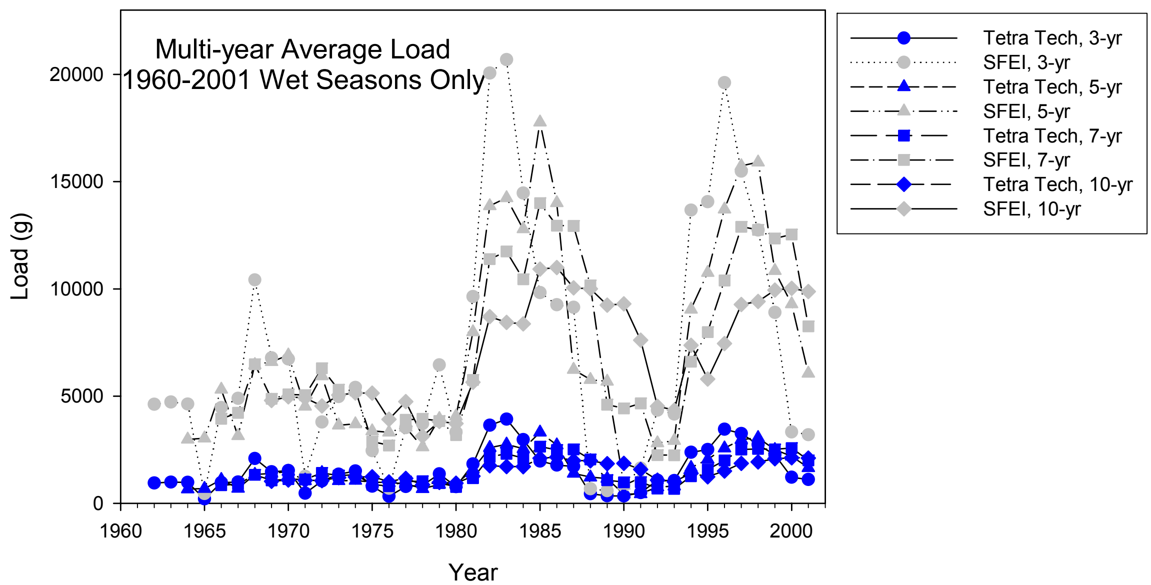

Figure 4-10. Average annual mercury loads as a function of averaging period. Loads were calculated using the Tetra Tech and SFEI correlations between flow and TSS.

4.13 Conclusions

Using mercury concentration and flow data from the data collection effort in 2004, wet and dry season loads were estimated throughout the Guadalupe River Watershed. The wet weather sampling included measurements on all major streams in the watershed and was used to develop an estimate of the movement of mercury. The dry season water column measurements were focused on the two most mercury-contaminated reservoirs and were used to estimate the internally generated methylmercury loads and the downstream exports. The nature of wet season transport, with substantial water, sediment, and mercury moving during specific short-duration storm events introduced some special concerns with respect to the magnitudes of the estimated loads. In particular, during the wet season sampling that forms the basis of this report, there were few instances of large storms during which flows and concentrations could be measured in the upper watershed. Measured wet season concentrations of suspended solids reported here are lower than what others have reported (especially in the Almaden Quicksilver County Park). Given the close association of mercury and suspended sediment transport, the limited high flow and high suspended concentration data in this sampling, it appears, on balance, that the estimated loads in this chapter, although accurately represented on a relative basis, may be lower in magnitude than the actual loads. It is hoped that future wet season sampling as part of the mercury TMDL in the watershed will help reduce these uncertainties.