# Addressing the Environmental Mercury Problem in Watersheds: Remediation in the Guadalupe River Watershed, San Jose, California

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**Abstract** Mercury pollution in watersheds has become an urgent problem and within the last thirty years, has been identified as a serious risk for human health. Mercury can be converted to methyl mercury by bacteria in waterway sediments. Methyl mercury is up to a thousand times more toxic than elemental mercury due to its ability to cross cell membranes and interact in biological systems, causing brain damage, paralysis and even death in humans. Remediation of elemental and methyl mercury within watersheds is currently being addressed as a major priority in water quality management, but there are several legal and technical obstacles to mercury clean up. This paper reviews current remediation methods for mercury contamination, and then evaluates these methods as possible means of cleaning up the heavily mercury-polluted Guadalupe River Watershed in San Jose, California. Parameters influencing decisions to implement different remediation methods are discussed, along with key factors influencing successful remediation.

## Introduction

**Uses of Mercury** Mercury and its principal ore, cinnabar (HgS), have been utilized by human cultures for over three thousand years. It has been used by ancient Chinese, Hindu, Egyptian, Greek and Roman civilizations for a variety of purposes including as a medicine, an aid in religious ceremonies and as a pigment or dye. Mercury was identified as having a toxic nature by a number of ancient authors such as Hippocrates, Pliny, Galen and Avicenna (D'Itri 1972).

Mercury found in the environment comes from two major sources. First, there are sources that originate in the earth's crust and account for naturally occurring background levels of mercury in the environment and exist as part of a global geo-chemical cycle. This mercury is transported to surface waters by soil erosion and is circulated into the atmosphere by a natural degassing of the Earth's crust and oceans (D'Itri 1972, Merian 1991). The second source of mercury is from rocks that have been extracted from the Earth and redistributed globally as a direct result of anthropogenic activities.

Anthropogenic activities have resulted in the release of various types of both inorganic and organic mercury into the environment. The electrical industry, chloralkali industry, and the burning of fossil fuels release elemental mercury into the atmosphere (D'Itri 1972, Merian 1991). Metallic mercury has also been released directly into fresh water by chloralkali plants, and both phenylmercury and methylmercury compounds have been released into fresh and sea water – phenylmercury by the paper and pulp industries, and methylmercury by chemical manufacturers (Merian 1991). Perhaps the most important source of human influenced mercury pollution is the mining industry, which will be discussed in detail (D'Itri 1972, Merian 1991).

**The Chemistry of Mercury** Environmentalists and toxicologists have not always drawn distinctions between the various chemical forms (speciation) of mercury although each form exhibits a very different environmental behavior, bioavailability, and effect on exposed organisms. Different species of mercury also have different types of interactions with other substances. It is generally accepted that metallic mercury, mercury vapor, inorganic mercury (I) and (II), alkyl mercury, and phenyl mercury must be distinguished from one another in order to most accurately and efficiently address the complex reactivity of mercury pollution (Merian 1991). The most important forms of mercury to which living organisms are exposed can be placed into three broad categories having different pharmokinetic properties with regard to absorption, bodily distribution, accumulation and toxic hazards (Merian 1991), and they are summarized in Table 1.

| TYPE OF MERCURY | FORM OF MERCURY | RISK LEVEL | HEALTH EFFECTS | LOCALE IN THE ENVIRONMENT |
|---|---|---|---|---|
| Elemental | Vapor in atmosphere; metallic as a liquid | Low to medium | Usually converted to ionic or organic form to be toxic; causes headaches, loss of memory | In the atmosphere as a vapor |
| $Hg^{2+}$ (mercuric salts); $Hg^{+}$ (mercurous salts) | Ionic combinations in general; HgS is cinabar | Medium to High; $Hg^{2+}$ more risky because readily complexes with organic ligands | Corrosive to skin and mucous membranes, nausea, kidney and liver dysfunction | $Hg^{2+}$ prominent in marine and fresh water |
| Organic Mercury Compounds | Arylmercurials (phenylmercury)<br><br>Alkoxyalkyl mercury | Medium to High; Form salts with organic and inorganic acids and reacts readily with biologically important ligands | Health effects are similar to those for the salts because they are quickly metabolized by organisms in biological systems | In sediment/soil, water column |
| | Alkylmercurials (methyl, dimethyl and ethyl mercury) | High to Extremely High; Pass easily across biological membranes; 1000 times more toxic than elemental Hg | Visual impedment, ataxia, dysarthria, paralysis and death | In sediment/soil, water column and bioaccuumulated in fish and other wildlife |

Table1. Types of Mercury in the Environment. Information in this table is from Merian 1991, Porcella 1994, D”Itri 1972, Clarkson 1994.

**Mining for Mercury** Historic hydraulic mining and the use of mercury has left many watersheds of the Western United States with a legacy of eroding hillsides, heavy mercury loads and excess sediment. The United States Geological Survey (USGS) estimates that up to 8 million of the 26 million pounds of mercury used in the gold mining in the Sierra Nevada Mountains may have been “lost” to the environment during gold recovery. Mercury was integral to the process of gold mining. Usually, the mercury was mined in the Coastal ranges of the Western United States and then exported to the Central ranges where the gold was mined. As a result, mercury pollution in both the central and coastal mountain ranges of the Western United States is widespread.

In most California mines, the mercury was extracted from the cinnabar ore by a process called calcination (Abu-Saba 2000). After the ore was mined, it was crushed and roasted in the presence of air where the mercury sulfide decomposed, and the sulfur was removed while the heat volatilized the mercury. The mercury vapors were then condensed into a liquid in a series of water-cooled condensers, and the resulting liquid mercury was then drained into collection tanks. This process involves the creation of waste rock known as calcine. The calcine waste that was ultimately discarded in areas surrounding the mines still contains some soluble elemental mercury that can leach into surface waters and flow through the watersheds. In addition, elemental mercury pollution also resulted from the atmospheric deposition of gaseous mercury emissions from mine furnaces (Abu-Saba 2000).

**The Guadalupe River Watershed and The New Almaden Mine** There are many watersheds in the Western United States, and especially California, which have been heavily polluted by mining activity. The Guadalupe River Watershed in one of the most mercury-polluted watersheds in California and is the single largest contributor of mercury loading into the San Francisco Bay (Abu-Saba 2000). Guadalupe Creek originates in the steep terrain of the Santa Cruz Mountains and flows north to the Santa Clara Valley where Guadalupe Creek meets Alamitos Creek to form the Guadalupe River. Mt. Umunhum, at 3,486 feet, is the highest point in the Guadalupe Creek Basin. About 90% of the basin is located in the Santa Cruz Mountains and 10% in the Santa Clara Valley. Maps of the Guadalupe River Watershed are available in Appendix A.

The New Almaden Mine located in the higher elevations of the Guadalupe River Watershed operated from the 1840's until the 1970's. By 1970, the decline in the price of mercury and the realization of mercury's environmental toxicity caused the mines to close. By 1975, the County of Santa Clara acquired all of the New Idria Mining Company property and converted the land into the Almaden Quicksilver County Park. This transfer into a public county park involved some clean up of the area, but the calcine waste still contains mercury that pollutes the areas that surround the mine (Abu-Saba 2000). This mercury is transported by erosion and runoff in various chemical forms, attached to particles, and as droplets of the metal. Once in the waterways, certain biological and/or physical processes can then convert elemental mercury into the highly toxic methyl mercury. Metals such as mercury often travel hundreds of miles downstream and end up in the San Francisco Bay, interacting with the environment the entire way. The dangerous levels of mercury that are found within the Guadalupe River Watershed, as well as the San Francisco Bay, are effected by this history of mercury waste pollution at the New Almaden Mine which poses a significant threat to both wildlife and human populations (Merian

1991). The impacts and extent of mercury pollution in the Western United States and in California are not fully understood, but it is clear that the clean-up of mercury pollution should be a priority.

Remediation can take place at a variety of spatial scales. A remediation area may be small with one set of site parameters (i.e. Temperature, pH, flow rate, sediment type, etc.) that deals with one chemical form of mercury. Alternatively, a remediation area may cover a much larger area, have more than one chemical form of mercury present, and would most likely have a wide range of mercury-relevant site parameters that vary from location to location within the total remediation area (Horne 2000, Rugh, et al. 2000, Salt et al. 2000). Because the Guadalupe River Watershed covers an area of over one hundred square miles, it falls into the latter category above. Because of this complexity, multiple remediation methods will need to be utilized at a variety of sites. These multiple sites within the total remediation area will require individualized response plans that require more detailed information.

The purpose of this project is to identify possible mercury remediation methods that can be used to formulate a remediation plan for contaminated sites within the Guadalupe River Watershed. This process involved reviewing known and developing technologies in order to find the most efficient and compatible methods available for generalized types of areas found within the watershed. This project also addresses identification of what information needs to be collected about the watershed in order to effectively plan more specialized remediation. This work will then be utilized by the Natural Heritage Institute of Berkeley, California in order to plan and implement remediation strategies at specific sites in the Guadalupe River Watershed.

**Methods**

Potential remediation methods were examined through literature review and consultation with researchers who are in the process of improving known methods of remediation as well as developing altogether new ones. The literature review also encompassed the topics of mercury chemistry and the corresponding health risks that vary depending on the chemical form of mercury, or its speciation, and how this influences the selection of the proper remediation plan. Available resource information about the Guadalupe River Watershed was also reviewed.

Six main categories of remediation techniques are reviewed and applied to the Guadalupe Watershed Remediation Area, which is divided into generalized area based on hydrologic qualities of the river. These six categories, removal, treatments of the medium, immobilization, microbial remediation, phytoremediation, and water quality management, are then evaluated for a potential to succeed in each section of the watershed. Effective methods are finally determined based on cost effectiveness, scope of remediation required and overall compatibility of the method with geomorphology and available parameter information.

## Results

**Focusing on Methyl Mercury** Selection of a remediation strategy is strongly influenced by the fact that it is not economically feasible or within the constraints of known and tested technologies to set a goal of total removal of all mercury. Often, the mercury that is located at a site can be dispersed and of different speciation. Therefore, it is important to understand mercury chemistry and the corresponding health risks to both the entire ecosystem, including but not limited to humans. In this way, the most dangerous types of mercury contamination can be pinpointed and addressed so that a given remediation project can be both effective in reducing health risks and feasible in an economic and technological sense.

Although $Hg^{2+}$ (mercuric salts) is the predominant form of mercury present in marine and fresh water, and elemental mercury is the predominant form in the atmosphere, methyl mercury is by far the most toxic form (Abu-Saba 2000)). Methyl mercury represents only a small fraction of the total global mercury, much of its presence due to the biomethylation of inorganic mercury, and it presents the greatest risk of irreversible functional damage to human and animal life (Merian 1991). Needless to say, any approach to remediate mercury from the environment should prioritize methyl mercury as the most critical type of mercury poisoning to address (Meagher, R.B., et al. 2000).

Methyl mercury is formed when bacteria in sediments with the right chemical, and physical conditions can enzymatically add a chemical group with carbon (“methyl”) to the relatively inert form of elemental mercury. This chemical transformation, know as methylation, enables mercury to cross cell membranes and enter the food chain. Once it is taken up by bacteria and algae (the base of the food chain), this form of mercury can become concentrated as aquatic insects consume this “food”; other insects, frogs and small fish in turn eat these insects. Large mouth bass, trout, and other predators will bioaccumulate large amounts of methyl mercury if they are exposed to it regularly in their diet. Methyl mercury becomes a health concern when upper trophic level fish from contaminated areas are consumed and the mercury then accumulates in humans, causing a variety of illnesses (Merian 1991, Kudo 1999, Turner et al. 1999).

In addressing methyl mercury sinks in an ecosystem, the chemical reactivity pathway that produced it must also be explored, identified and counteracted if possible because methyl mercury is produced in the environment from the methylation of inorganic mercury (Merian 1991). Methylation/demethylation can occur in both oxic and anoxic conditions, in lakes or reservoirs, in the water column, and in watershed soils. Therefore, conditions that favor methyl mercury production should be identified within the watershed. These areas would include sites with acidic conditions, low photosynthetic activity, high dissolved oxygen, or sediment/soil with rich humic content (EOA, Inc. 2000).

The unlikelihood that all the mercury compounds can be eliminated from a polluted site due to the high cost and the extensive effort required remediating mercury (Ebinghaus 1999), means a remediation plan that addresses mercury pollution should look to methylmercury sinks and production pathways as the most critical target for clean up. Currently, methyl mercury production and cycling, as well as the ability to accurately measure and detect methyl mercury in the environment is not fully developed, and there is a serious need for better understanding of methyl mercury in order to accurately address the problem within watersheds.

**Methods of Mercury Remediation** The six methods of mercury remediation reviewed for this project are removal of the contaminated medium, treatment of the contaminated medium, immobilization of the contaminated medium, microbial degradation of the contaminant, phytoremediation of the contaminant, and water quality management that can aid in reducing health risks from the contaminant. Table 2 summarizes these six methods and displays both advantages and disadvantages of each method, as well as parameters that are important to consider when implementing each method.

| METHOD | DESCRIPTION | COST | ADVANTAGES | DISADVANTAGES | SPECIAL REQUIREMENTS |
|---|---|---|---|---|---|
| Removal | Dredging and pumping out contaminated materials | $1,000,000 / acre | Well-tested and effective | Expensive, lengthy process; disposal sites can leak and re-release contaminant; significant disturbance of the environment | Expensive equipment; must be monitored periodically and followed by either treatment and/or burial and containment in other location |
| Treatment | Physical treatment (i.e. sorting) | $500,000 / acre | Good for large quantities of sediment (20-40 tons / hour) | Does not work with high silt, clay content soils/sediments | These methods often are best applied off site in contaminated medium that has been removed |
| | Thermal treatment resulting in volatilization | | Mercury compounds are highly volatile at low temperature | Causes more atmospheric mercury pollution | |
| | Chemical treatment on site or off site | | Mercury reacts with other compounds and can be made biologically unavailable | Adding foreign chemicals into an ecosystem can be dangerous when you aren't sure of the outcome | |
| Immobilization | Physical barriers placed on site to contain the contaminant so it can no longer spread through the ecosystem | $50,000 / acre | Well-tested and effective | High cost, barriers are of questionable permanence, unknown unintended ecological effects from the destruction of the benthic ecosystem | Barriers can be top, bottom or lateral side barriers; Sometimes barriers can be natural and not man made |
| Microbial Action | Using microbes that can demethylate mercury to clean contaminated mediums | Not Applicable | Effective in sludges, wastewater and controlled environments like the laboratory | Not proven for on site remediation | Forms the basis of phytoremediation |

| | | | | | |
|---|---|---|---|---|---|
| Phytoremediation | Various techniques using plants to remove mercury from the environment or immobilizing it within the environment; Methods include degredation, extraction, containment or a combo of all three | $16,700 / acre | Cost effective, less intrusive than other methods, pollution captured can be recycled and reused instead of mining more | Plants grow slow and results take a while, mercury captured in the plant may be available to wildlife feeding on the plant, not well tested, environment must be suitable to the accumulating plant | Best for sites with low to medium levels of contamination |
| Water Quality Management | Manipulating the water quality such as oxygen content or pH to ensure methyl mercury production will not occur | Varies, but inexpensive in comparison to other methods | Cost effective, less intrusive, not highly technical | Manipulations need to be monitored, and may likely need manipulation often; may disrupt some ecosystem functioning | Most easily implemented by current water managing agencies |

Table 2. Summary of Remediation Methods. Information in this table is from (US EPA 2000, Turner 1999, D"Itri 1972, Charlton 1994).

The most well known case of mercury pollution and its remediation was the disastrous mercury contamination of Minamata Bay, Japan due to releases from a chemical manufacturing plant that took place between 1950 and 1971. Due to the extent of the mercury contamination, all of the fish in the area had accumulated this mercury, resulting in an epidemic scale disaster of human mercury poisoning. The scale of the various illnesses and defects associated with this pollution lead to the creation of the term Minamata disease (Kudo, et al. 1999). In 1974, the government began planning the restoration of the bay, to remove mercury-laden sediments and restore the historically strong fishing economy. The remediation was not started until the early 1980's and took over a decade to complete. The most heavily polluted sediments covered 2 km of the bay, and this area was chosen as the focus of the clean-up effort that consisted of a combination of dredging bay materials and relocating them to one small area of the bay where they were contained with barriers. The overall cost to clean up this 2 km of bay was around 500 million dollars, but to remediate a similar area today, the overall costs would exceed this amount (Kudo, et al. 1999). Although, 2 $km^2$ would be an expensive area to remediate, even smaller areas could be considered too large to dredge depending on the funding of the remediation project and its goals. Usually the dredging or pumping process is viable only for projects where the cost to remediate the total area is not overwhelming. While the Minamata Bay area was remediated effectively, it was an extremely lengthy and expensive process.

In the case of Minamata bay, there was a great effort to place boundary barriers around the 2 km site so that the polluted sediment could not disburse into cleaner areas of the bay, and contaminated fish would remain in the polluted area and not venture out to be caught be fisherman. There was also an intense fish monitoring system that carefully watched the levels of mercury in different fish around the bay to make sure that the remediation process was not increasing available mercury to other areas of the bay. Expensive turbidity control devices were implemented to reduce the negative impact of dredging on the overall ecosystem (Kudo et al. 1999). The Minamata Bay experience proved that to dredge effectively and in a manner that does not cause significant further disturbances is important, but often prohibitively costly.

One of the problems in Minamata Bay was that no other proven clean-up technique was available for such a large-scale project upon which thousands of human lives were at stake (Kudo, et al. 1999). The Minamata Bay experience opened the world's eyes to presence and danger of mercury pollution, the creation and peril of methyl mercury, as well as the need to better understand mercury and how to clean-up mercury-polluted ecosystems. This new awareness inspired creative and intensely needed research on how methylation of mercury occurs in the environment, and this has led to a better understanding of the relationship between microbial activity and mercury.

Certain microbes are capable of methylating mercury to form methyl mercury or dimethyl mercury, while other microbes are capable of reducing inorganic divalent mercury to elemental mercury that can subsequently evaporate into the air. For example, *Pseudomonas aeruginos* and *Proteus* ssp. can convert mercuric ion to elemental mercury, and some can even decompose various types of organomercurials and produce metallic mercury (D'Itri 1972).

Finding the microbes that methylate mercury can often lead to areas that are potential methyl mercury "hot spots." This is important, since historically analysis of sediment and soil have not often been dependable in accurately giving levels of methyl mercury (Kudo et al. 1999). In addition, finding microbial methods for remediation of mercury *in situ* may prove valuable in the development of less intrusive and more cost efficient methods of mercury remediation, but currently microbial action is only used for *ex situ* remediation (Da Costa, A.C.A 1999, van der Lelie, D. et al 2000).

Applying microbial action to remediation involves isolating the genes of microbes that actually transform methyl mercury or other mercury compounds into elemental mercury. Isolating these genes and putting them into certain plants that may or may not have had mercury-accumulating properties already has lead to a revolution in remediation techniques. Current remediation research is centered on this process of creating biological mercury accumulating plants to remove mercury from the environment (Meagher, R.B. et al. 2000). For example, researchers have isolated and identified the *merA* and *merB* genes, which detoxify charged mercurials, as well as *merP* and *merT*, which are mercury-transport genes (Rugh et al. 2000). This technology and advancement in the understanding of how mercury interacts with the environment has made phytoremediation possible.

Phytoremediation is defined as the clean up of pollutants primarily mediated by photosynthetic plants (Horne 2000). There are two main reasons emphasis has been placed on phytoremediation as the great hope for the future of remediation. First, phytoremediation is a cheaper method of removing contamination from an area because it involves the use of inexpensive green plants and solar energy to clean-up hazardous wastes. Second, it is considered a "Green Revolution" in the field of innovative cleanup strategies, meaning it does not use harsh or environmentally debilitating chemicals or destructive processes to remediate, but instead applies principles of nature to utilize a less invasive and destructive clean-up effort. The foundation of phytoremediation is based upon the microbial community, and the contaminated soil/water environment (Horne 2000). Complex biological, physical and chemical interactions occurring within the soil allow for remediation of contaminated sites. The various phytoremediation techniques that can be applied to mercury pollution clean up are summarized in table 3. Only three of the nine phytoremediation methods outlined in the EPA's "Introduction to Remediation" (2000) are applicable to situations that involve the clean up of mercury within the environment. The methods identified to be effective in cleaning up mercury by the US EPA include rhizofiltration, phytoextraction and some properties of phytovolatilization.

| MECHANISM | GOAL | MEDIA | PLANTS | STATUS |
|---|---|---|---|---|
| Phytoextraction | Mercury extraction and capture | Soil, sludges, sediment and sometimes water | Indian mustard, pennycress, alyssum sunflowers, hybrid poplars | Laboratory, pilot projects and field applications |
| Rhizofiltration | Mercury extraction and capture | Groundwater and surface water | Indian mustard, hybrid poplars and water hyacinth | Laboratory and pilot projects |
| Phytovolatilization | Mercury extraction from medium and release to air | Groundwater, soil, sediment and sludges | Poplars, alfalfa, Indian mustard | Laboratory and field application |

Table 3. Summary of Phytoremediation Methods for Mercury. Information in table summarized from US EPA's "Introduction to Phytoremediation" (2000).

Rhizofiltration is primarily used to remediate extracted groundwater, surface water, and wastewater with low contaminant concentrations (Ensley 2000). It is defined as the use of plants, both terrestrial and aquatic, to absorb, concentrate, and precipitate contaminants from polluted aqueous sources in their roots. Rhizofiltraton of mercury from surface and groundwater has been successful using Indian Mustard, and to a lesser extent, water hyacinth (US EPA 2000).

Phytovolatilzation involves the use of plants to take up contaminants from the soil, transforming them into volatile forms and transpiring them into the atmosphere (Rugh et al. 2000). Mercuric mercury is the primary metal contaminant that this process has been used for, and the advantage of this method is that the contaminant, mercuric ion, maybe transferred into a less toxic substance (i.e., elemental mercury). As with regular volatilization, the disadvantage of phytovolatilization is that the mercury released into the atmosphere is likely to be recycled by precipitation and then redeposited back into lakes and oceans, potentially repeating the production of methyl mercury by anaerobic bacteria (Rugh et al 2000). The use of poplar trees and Indian Mustard have been shown effective in removing mercury pollution through phytovolatilization (US EPA 2000, Rugh et al. 2000).

For areas where phytovolatilization is not desirable due to he hazards of releasing elemental mercury, an alternate option is to deploy plants that sequester high mercury loads in harvestable tissues (Rugh et al. 2000). This process, called Phytoextraction, can be used with plants that naturally accumulate large amounts of mercury, or with plants that have been modified by the *merA* and *merB* genes of mercury degrading microbes. Various plants can be used for phytoextraction in general, but for the best results with mercury contamination, Indian Mustard or hybrid poplars are the best-tested (US EPA 2000), but tobacco (*Nicotiana tabacum*) and *Brassica napus* have also shown promise (Meagher, R.B. et al. 2000).

Another lesson from the Minamata Bay experience was that a reliance on heavy equipment and expensive remediation methods was not efficient, and that a return to more "gentle" methods or basic water quality management practices should be explored (Gupta, S.K. et al. 2000). These methods include preventing mercury from entering waterways in the first place by combating erosion of channel banks. This is achieved by having adequate riparian vegetation planted along the river channels. Simple manipulations of the watershed parameters like designing stream flow to ensure a high oxygen content, which can reduce methyl mercury production, are also considered "gentle" methods.

**Generalized Remediation Areas Within the Guadalupe Watershed** There are basically three main portions of the watershed that need to be evaluated for remediation: 1) The Upper River that spans from the New Almaden Mine to Masson Dam; 2) The Downtown River that spans from Masson Dam to Almaden Expressway; and 3) The Lower River that spans from Almaden Expressway to the San Francisco Bay. Please see Appendix A for a map showing these divisions. The rationale for separating the river watershed into these three sections is because they have different hydrological qualities that effect possible remediation scenarios. The Upper River is an erosion zone of high-energy flow. This portion of the watershed contain the lakes and reservoirs, as well as the actual mine site. The Downtown section has been heavily channelized and altered due to agricultural and industrial needs, and by the overall influence of urbanization, which makes it unique from either the Upper or Lower sections. This portion of the river watershed is an erosion and transport zone, characterized by various types of flow depending on location. The Downtown section is likely to carry more washload and less bedload than the Upper River section. The Lower River section is a sedimentation zone characterized by a slower, low energy flow that has a wider meander pattern. All areas have different flow rates, sediment load and type, water temperatures, erosion patterns and meander patters, and these hydrological qualities will influence the development of remediation plans (US Army Corps of Engineers 2001).

It is important to note that various water utility operations exist within the Guadalupe Watershed that are overseen by the Santa Clara Valley Water District (SCVWD). These include water conservation reservoirs, percolation ponds and diversion structures (EOA, Inc. 2000). These activities affect flow rates and potentially involve activities that could increase or decrease mercury loading into the watershed. Summaries of these activities are included in Appendix B.

**Mercury in the Guadalupe Watershed** The New Almaden Mine was once the largest producer of mercury in North America, and it remains the most significant source of total mercury to the Guadalupe Watershed (EOA, Inc. 2000). In the mid 1980's the property was transferred to Santa Clara County and the county, along with various other responsible parties, was ordered to clean up the pollution at the mine site. Even though the mine area has been cleaned up and transformed into a public county park, considerable amounts of contaminated waste rocks and sediments still exist on the mine site.

In a draft of the mercury Total Maximum Daily Load report being prepared for the Santa Clara County Water District, the following are six distinct processes that load mercury into the watershed: 1) Erosion and runoff from waste rock piles in the mining district; 2) Erosion of mercury-enriched dust from roads and grades in the mining district; 3) Reservoir releases in the upper watershed; 4) Mobilization of mercury-polluted sediments from the banks and beds of streams in the upper watershed; 5) Erosion of mercury-polluted sediments from lands adjacent to creeks in the upper watershed; and 6) Remobilization of sediments deposited in the lower watershed flood plain.

These processes all contribute to the loading of mercury into the Guadalupe River Watershed as well as the San Francisco Bay. This information, combined with the priority of addressing methyl mercury, leads to two distinct mercury remediation priorities. The first is combating the release and re-release of elemental mercury into the watershed through erosion and disturbance of the ecosystem. The second is reducing the production of methyl mercury within the watershed by removing or remediating the methyl mercury pollution that already exists in the watershed and eliminating or controlling methylation pathways. Addressing both facets of the mercury pollution problem in the Guadalupe River Watershed will require distinct plans of action for each scenario.

While measurements of methyl mercury have not been comprehensive, there have been a number of studies that have sampled sediments and soils, as well as water and biota for levels of elemental mercury. These studies have stemmed from the multiple and continuing projects that take place within the Guadalupe River Watershed. For sediment and soil samples, the California Hazardous Waste Criteria for Mercury levels is not to exceed 20 mg/kg wet weight (EOA, Inc. 2000). For water sampling, the mercury criteria lowest level standard for a 30-day averaging period is 0.15 ug/l (EOA,Inc. 2000). Comprehensive determinations of methyl mercury in the Guadalupe River Watershed are in the process of being developed, and promising preliminary data suggests that tracking methyl mercury within the watershed should be possible soon (Abu-Saba 2000). The available information for elemental mercury levels in both the water column and in soils/sediments is summarized in table 4, and is explained further in Appendix C.

| SECTION | MERCURY | RAIN (average) (inches/year) | SEDIMENT TYPE | FLOW | EROSION | DEPOSITION PATTERNS | WATER TEMPERATURE |
|---|---|---|---|---|---|---|---|
| **Mine Site** | 0-1000 ppm in soils, with an average of 100 ppm in the overall mine area | 44 | Rocks, gravel and dry soil | N/A | N/A | N/A | N/A |
| **Upper River**: New Almaden Mine to Masson Dam | 2-52 mg/kg in sediments; 2-25 ug/l in water | 30 | Data not conclusive, but tends to have larger % of bedload (particles > .0625 mm in diameter) than other areas of the watershed; Washload still is the majority out of total sediment | More data needed to quantify, but high energy, quick moving flow | Steep eroded banks with a high potential for erosion | Varied over the years, but not as much as in lower section of the watershed; may have mercury deposits in soils surrounding current channel | No data available, but expected to be cooler than either the downtown or lower section of the river |
| **Downtown River**: Masson Dam to Almaden Expressway | 2-69 mg/kg with one site at Los Capitancillos at 160 mg/kg; no conclusive data available for water levels | 15 | Varies depending on time of year and flow rate, but a mixture of bedload and washload with a larger % being washload | Average of 1 cubic foot per second (cfs) fromMay - Nov and 9 cfs from Dec - April | Sediment starved with potential to erode; current project work to restore channel and bank stability | Currently highly controlled and channelized, but flood plains and historical meander patterns may have deposited mercury contamination | July – August has 70°F, March – May has 55°F -70°F, and Sept – Feb has 50°F - 60°F |
| **Lower River**: Almaden Expressway to San Francisco Bay | 0-150 mg/kg n soils and sediments; water levels average 1 ug/l | 14 | Both washload and some bedload depending on the season, with the majority being washload that ends up being deposited here | No data but on slower and of lower energy than the Upper River | Erosion not a large factor due to lessening of slope of channel and slower flow | Varies greatly both historically and presently, surrounding areas should be evaluated for mercury deposition | No data available but expected to be higher than the Upper River and nearly consistent with Downtown River |

Table 4. Summary of Parameter Information Available for Generalized Areas of the Guadalupe River Watershed. Information from US Army Corps of Engineers (2001), EOA, Inc. (2001).

**Description of Generalized Guadalupe Parameter Information** In evaluating sites within the Guadalupe River Watershed for possible remediation, the parameters of precipitation, flow, sediment type, depth of water column, erosion and deposition patterns, pH, type of mercury pollution and temperature should be considered. While not all of this data has been collected for the Guadalupe Watershed, the available data concerning these parameters was evaluated, along with evaluations of cost and feasibility, in order to identify potential remediation methods for the watershed. The available data concerning parameters affecting remediation projects is summarized in table 4. For more detailed information concerning these parameters, see Appendix D.

**Proposed Remediation Methods for Generalized Sites** In general, the ideal remediation method will effectively remove contaminants, cause the least disturbance to the ecosystem, and be cost-efficient. Due to the widespread nature of the mercury problem in the Guadalupe River watershed, a reliance on more expensive methods of remediation such as large-scale dredging is prohibitive, and an emphasis on the less costly and less invasive methods like phytoremediation is generally recommended. The estimated 30-year costs (1998 dollars) for various remediation strategies for a 12-acre lead polluted site were: $12,000,000 for excavation and disposal; $6,300,000 for soil washing; $600,000 for a soil cap; and $200,000 for phytoextraction (US EPA 2000). These figures are evidence that phytoremediation is the most plausible method along cost lines. Also, methods of phytoremediation are not intrusive and they cause the least disturbance to the ecosystem.

There are two main disadvantages to phytoremediation. The first is that plants grow slowly, and there is a waiting period until the trees or plants mature and extract enough contaminant out to effectively remove mercury. However, since this mercury pollution has been present in the watershed for over one hundred years, the benefits of embracing a low impact and low cost method outweighs the drawback of a short wait for effective and non-destructive remediation. The second disadvantage is that phytoremediation may involve introducing a species of plant to an area, and the risks of invasion and cross-pollination with natives are well documented (US EPA 2000). Research suggests that many of the plants used in remediation processes are genetically engineered to thrive in contaminant rich environments, and when there is no longer contaminant in the ecosystem, the introduced plants are often no longer competitively viable

(Meagher, R.B. et al. 2000). This suggests that phytoremediation plants have a self-limiting quality built in so that once they have served their purpose; they will no longer survive in a non-contaminated environment (US EPA 2000). While engineered accumulator plants tend to wither in a non-contaminated medium in a controlled setting, the reaction of the plant may be different in an actual watershed. So, there are some doubts to the claim that introducing accumulator plants will have no impact on the watershed ecosystem.

It is also important to point out that many phytoremediation methods have been tested in the field or in the laboratory, but their prospects for success in large-scale remediation projects like the Guadalupe River Watershed remediation have not been proven beyond doubt. This uncertainty is a major drawback to recommending a full-scale remediation strategy based solely on phytoremediation. Therefore, although I recommend utilizing phytoremediation in the Guadalupe River Watershed, I also recommend small field trials within select sites in the Guadalupe watershed to verify that a given phytoremediation method will be effective. For example, if some sediment in the shallow section of the Lower River is targeted for clean up, and phytoremediation is the chosen method, a pilot project to see if mercury accumulating plants can actually grow in that site. If not, some watershed parameter manipulation may be required, such as an adjustment of pH, in order to accommodate the accumulator plant.

The point should be made that specific highly polluted sites within the overall total remediation area, or sites that are integral in releasing or re-releasing mercury into the watershed must be dealt with in a timely and tested manner. These individual sites, while all not yet clearly defined, should be addressed first. They should be analyzed with the major influence being quick and effective clean up, and with cost considered secondarily.

The two most general mediums where mercury exists within the Guadalupe River watershed are in the soil or sediment and in the water column. Remediation for atmospheric mercury will not be discussed. Both sediment/soil and water column issues concerning mercury will be discussed for all three sections of the river: Upper, Downtown and Lower.

There are some general recommendations that can be made for all three river sections. (1) Address mercury in the soil/sediment before the water column mercury because reducing the soil/sediment mercury will help reduce the water column mercury. (2) The soils bordering the river should be sampled for mercury levels so that potential erosion or runoff sites that might be adding mercury to the waterway can be identified. In this process, historical depositional and meander patterns should be considered to identify areas that might have more mercury deposited than other areas. These areas along the channel banks can then be remediated by fortifying the banks with the addition of riparian vegetation that included phytoremediating plants. (3) River sediment found to contain large amounts of elemental mercury would likely need to be removed, using either traditional methods or phytremediation in areas with shallow water and low to intermediate mercury concentrations. (4) Areas of methyl mercury production could be addressed using a combination of water quality management practices to limit the water quality parameters that favor methyl mercury production followed by removal or phytoremediation where needed and depending on site parameters such as water depth.

In addressing pollution sites away from the current channel, but concerning areas once part of the river flow pattern, the recommended method for surrounding soils is phytoextraction using a variety of mercury accumulating plants. Removal and disposal or containment is not desirable due to the potentially large total area these types of sites could end up involving, and the associated high cost. Soils closest to the river channels with the highest concentrations of mercury and the highest chance of eroding into the waterways should be addressed as the priority, while areas where the likelihood of erosion is lower, should be addressed if time and budget constraints permit. However, sampling to identify sites of mercury pollution in the historical river pathways that are no longer a part of the current river channel can be helpful, especially if they occur in flood plain areas, and might have the opportunity to re-enter the waterway at some point in time in the future.

Sites with high mercury levels in channel bottom sediments need to be identified through more comprehensive sampling. Once identified, the locations where sediments produce methyl mercury should be addressed first using water quality management practices and both phytoremediation and removal as deemed necessary because these are the sites that present the highest health risk. Sediment sites can be remediated by phytoremediation because even though there are many more terrestrial accumulator plants than aquatic ones, and aquatic ones are not well tested, aquatic plants like duckweed and water hyacinth have shown promise with accumulating mercury in wetlands (Horne 2000). For areas where sediment type is not conducive to growing aquatic accumulator plants, removal should be considered.

Mercury in the water column will be found in low flow areas. It should be noted that surface water remediation should be taken on only after the source of the mercury has been addressed, or else the remediation will only be temporary. The most highly contaminated areas concerning the water column are found just below the Almaden and Guadalupe Reservoirs. Areas like these could be cleaned by using a combination of water quality management and rhizofiltration with aquatic accumulator plants, which can be grown on the water surface, allowing roots to extend into the water column and immobilize the mercury.

The plant of choice to remove metals from water is Indian mustard (*Brassica juncea*), but water hyacinth and water milfoil (*Miriophyllum spicatum*) also may prove promising (US EPA 2000), even though they are two of the best-known aquatic plant invaders in the western united States. Advantages include low cost, \$2-\$6 per thousand gallons of water treated, and low negative impact on the ecosystem. *In situ* applications in water bodies are not likely to represent a disturbance or limitation to the use of a site because site activities generally do not occur in water (US EPA 2000). The amount of precipitation of the area usually has little effect on the effectiveness of this technology. Some pretreatment to manipulate pH, particulate matter or flow rate may be required to ensure efficient remediation. Other remediation methods are either too invasive and/or too costly to apply to an area whose mercury content is likely to be reduced by remediation measures performed on soils/sediments as well.

**Upper River Section** Located in the mining area, at the farthest upstream point of the Upper section, the calcine rock waste should be one of the first areas addressed since it is the farthest upstream, and has the potential to continue releasing more mercury into the downstream areas. As this site has a large potential to release mercury into the watershed, the slow-working phytoremediation methods may not remove the mercury at a pace acceptable for the risk of further pollution involved at this site. Also, in general, treatments of the medium on site are not well tested due to concerns about unintended consequences of such a manipulation. Therefore, the possible options for remediation are removal to a safe and secure location or immobilization of contaminated soil at the site. The less expensive of the two methods would be containment of waste piles on site. However, containment would be a challenging operation and maintenance costly and require long-term monitoring. Despite the high cost, the recommendation for the mine waste site is removal and burial in a secure landfill. A substantial remediation of a mercury pollution site in Oak Ridge, Tennessee relied on this method (Turner, R.R. et al. 2000). It may be feasible to remove only the rocks, and soils of the locations on the mine site that are extremely hot, while attempting phytoextraction on soil contamination sites within the mine area that have lower mercury concentrations.

An important consideration for the Upper River is addressing potential mercury accumulation within the reservoirs and learning more about how this affects mercury levels in the water column downstream. First, the contamination causing these extremely high levels of mercury in the water downstream of reservoirs needs to be remediated. Then the water column mercury needs to be addressed with an exception to the previous recommendation of phytoremediation for water column pollution. Noting that the remediation of sites with extremely high levels of mercury, like just downstream from the Guadalupe and Almaden reservoirs (150 ug/l), cannot be effectively cleaned with phytoremediation, perhaps chemical treatment or filtration of the reservoir water to remove the mercury should be performed before discharging the water into the river, or pumping highly contaminated waters out of the waterway would be an option (Turner, R.R. et al. 1999).

The presence of high levels of mercury downstream from the reservoirs is not fully understood and before remediation can be planned, studies into how these high levels are produced are required. Recent studies have been inconclusive but do show raised levels of mercury, even though they are not as high as would be expected. The difficulty here lies in the fact that high levels of water column mercury do not always mean that the sediment in that same location will have high levels of mercury. This reactivity of mercury within the watershed is not fully understood, and needs more study.

Important to consider in any development of a remediation plan for the Upper River is that the Upper Guadalupe River Flood Control Project has been proposed by the Santa Clara Valley Water District to reduce the potential for flood damage. This project will involve extensive modifications to the river, and is planned to start in 2002 and be completed in 2025. Mercury remediation planning would be most effective if planned in conjunction with the efforts of this project as it is likely to involve sediment removal or erosion control as well.

**Downtown River Section** The Downtown River section is considered an erosion and transport zone with lower energy flows than the Upper River. There is an increase in washload, or finer sediments at this point in the river. The flow in this portion of the river varies from medium to low energy. The Downtown River is sediment starved due to manipulations of the water flow upstream (US Army Corps of Engineers 2001).

The downtown section of the river is currently the focus of several different projects including the Downtown Flood Control Project and others, summarized in Appendix A. As a result, some remediation measures are already planned, and will include strengthening channel banks to prevent erosion as well as the removal of mercury-contaminated sediment. Due to these on-going projects, and the unknown consequences of their implementation, additional remediation planning should begin after completion of or within the context of these projects. It may be beneficial to try and incorporate more remediation methods into current projects. For example, riparian vegetation mitigation could be re-evaluated to include mercury accumulating plants along the channel, such as Poplar trees, Indian mustard, etc.

The Downtown section of the river needs to be monitored to determine sites with mercury contamination during and after current projects. After sites that need further remediation are identified, both in sediments/soil and the water column, further remediation recommendations can be made. However at this time, the general recommendations for mercury remediation made above for all river sections may be applicable.

**Lower River Section** The Lower River is a sedimentation zone of the watershed and has accumulated contaminated sediments for decades. The flow is much slower here, the slope lessens greatly for the Upper and Downtown portion, and the meander path widens creating shallower sloughs and marsh conditions as the watershed reaches San Francisco Bay. The lower section of the river involves both tidal and nontidal areas, and this is the major difference between this section of the river and others. Also, the sediment here tends to be more washload (finer) with less movement, and this means that a lot of mercury contamination can be deposited in certain areas. As with the Upper River, mercury contamination is not well documented and more comprehensive sampling needs to be performed to help identify potential remediation sites.

Soil/sediment remediation of mercury will focus less on erosion and runoff and more on clean up of highly contaminated sediment that has accumulated downstream. Using phytoremediation methods appears plausible due to the lower flow and shallower depths. Both rhizofiltration and phytoextraction can be considered as options. However, it is not clear from the literature whether phytoremediation accumulator plants would thrive in tidal marine environments. Where phytoremediation methods cannot function, or the mercury in the sediments is of high level, a recommendation for removal and burial at a secure landfill is made.

For water column remediation of mercury, the recommendations follow the general recommendations made above; however, the same lack of clarity as to whether accumulator plants will survive in marine influenced environments exists. Summarizing, the first line of defense should be to see if gentle remediation methods such as water quality management or phytoremediation could work to reduce mercury levels in the water, and then rely on removal or treatment of the contaminated water if it does not.

In planning remediation for the Lower River section of the Guadalupe River Watershed, awareness of the on-going Lower Guadalupe River Project is essential. The project involves dredging, construction of levees, and other modifications that could affect mercury transport and/or re-release within the lower river section. The main effort in the project is to remove sediment that has accumulated in the Lower River for the past decades in order to make more available area to accommodate a 100-year flood. This removal is likely to address mercury issues and could potentially remove huge amount of mercury from this portion of the river.

**Discussion**

There are significant gaps in essential data for the Guadalupe River watershed. These data are required before a more definitive recommendation for remediation can be made. Currently, a major research information gathering process is underway in the watershed as part of the TMDL (Total Maximum Daily Load) determination project headed by the Santa Clara Valley Water District. In drafts of this TMDL report, researchers have noted that measurements of general spatial distribution of overall mercury have been achieved. They also noted however that the following specific information is lacking: 1) Spatial distribution of methyl mercury in the watershed; 2) Spatial distribution of factors potentially important to mercury methylation and demethylation processes (Dissolved Oxygen Content, POC, pH, alkalinity, sulfate/sulfide); 3) Concentrations of bioavailable mercury in sediments; 4) Sediment load from subwatersheds; and 5) Concentrations in stream sediments subject to scour (EOA, Inc 2000).

The shortcomings of the available data are in the process of being addressed, but until these gaps can be understood, a more focused effort at eradicating the highly toxic methyl mercury “hotspots,” and potential factors that contribute to these forming these “hotspots,” is impossible. Therefore, while a most effective remediation plan would first address those sites that have high levels of methyl mercury, or those that contribute to the production of methyl mercury, at this time remediation can only address sites that have elemental mercury in general.

The recommendations for phytoremediation as the remediation method of choice should only be performed in large scale after the plant chosen as accumulator can be determined, and the wildlife that might potential feed on it identified. This is due to the fact that mercury is accumulated in these plants, and if they are eaten aggressively by any species within the remediation area, the accumulated mercury could then be collected inside of the wildlife (Horne 2000). If it is shown that the phytoremediation plant will be eaten and the mercury concentrated in the wildlife will have a negative effect, then alternate methods of remediation should be considered.

Few mercury-contaminated sites in North America have actually undergone deliberate comprehensive remediation, nor have the consequences of specific corrective actions always been determined, and thus information on the effectiveness of remediation strategies is rather limited (Turner, R.R. et al. 1999). This makes is difficult to sort through the possible remediation methods and chose the best one. It should be noted that the emphasis on phytoremediation is an emphasis on an experimental technology that may or may not be successful in large-scale projects. This recommendation to attempt phytoremediation is also a recommendation to set-up small-scale pilot projects to determine the effectiveness in various situations prior to full implementation.

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**APPENDIX A – Maps of the Guadalupe River Watershed**

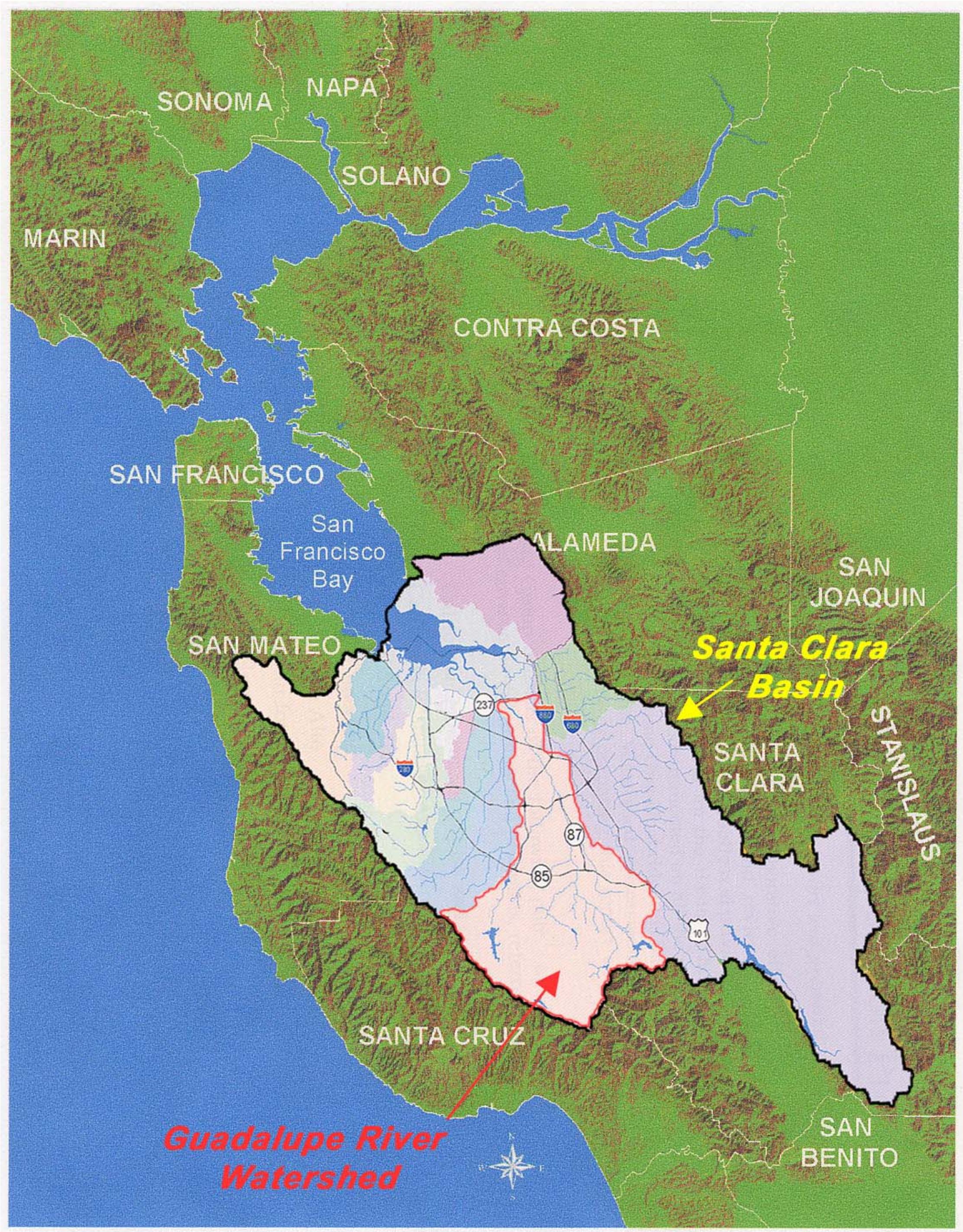


Figure 1. Map of Guadalupe Watershed in Context of Bay Area.

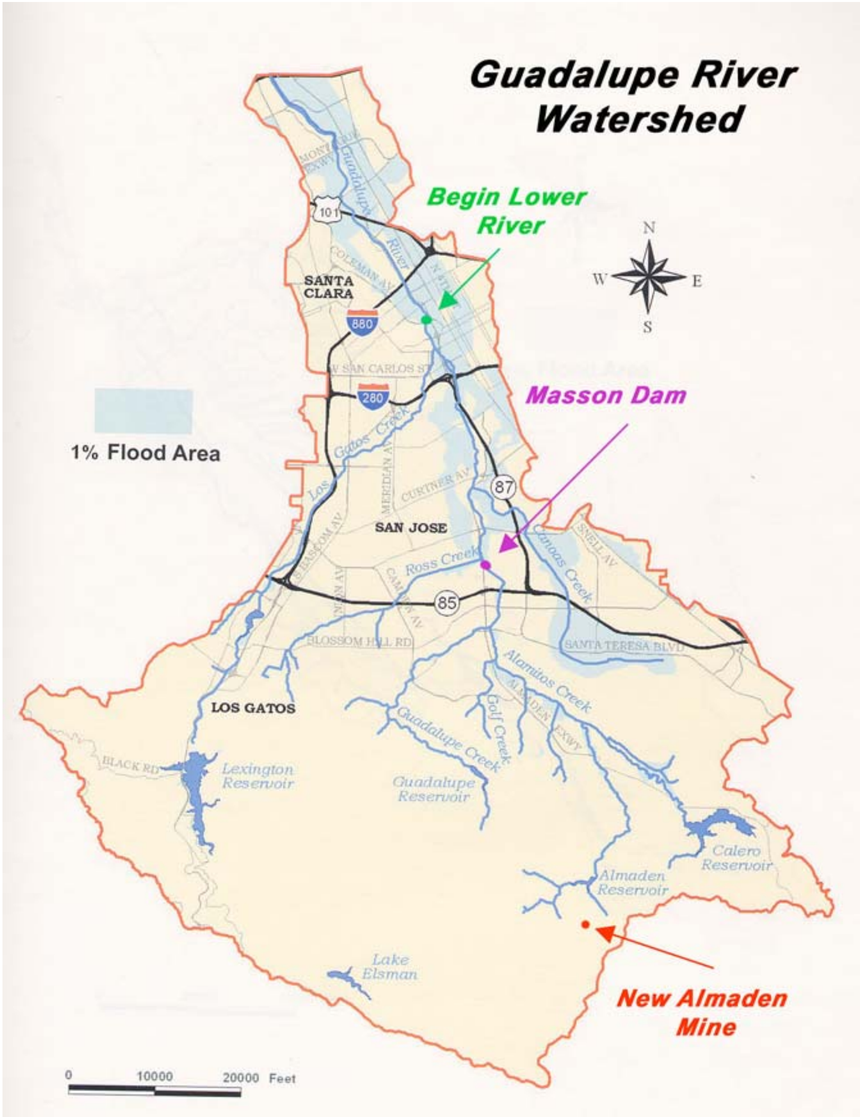


Figure 2. Guadalupe River Watershed divided into three remediation areas.

## APPENDIX B – Ongoing Projects in the Guadalupe River Watershed

The district conducts activities that store and release local runoff in five water conservation reservoirs: Calero, Almaden, Guadalupe, Lexington and Vasona, recharge the groundwater basin, and delivered imported and local water to the SCVWD's three water drinking plants (EOA, Inc. 2000). Reservoirs control or regulate runoff from an area 63 square miles in the Upper Guadalupe River watershed (US Army Corps of Engineers 2000). Approximately 72 square miles of the basin downstream of the reservoirs are largely urbanized, with the river and its tributaries having been extensively chanelized and levied for flood conveyance.

There are others operations and special projects that have either been completed or are still occurring within the watershed. SCVWD facility maintenance includes sediment removal, stream bank protection by repairing erosion, and hazardous materials investigations. The Guadalupe River Flood Protection Projects are joint projects between the U.S. Army Corps of Engineers and the SCVWD. The flood control projects involve improving flood protection along the Guadalupe River and are separated in to three categories: 1) Lower River Flood Control Project; 2) Downtown Flood Control Project; and 3) Upper River Flood Control Project. The Guadalupe Creek Restoration Project is designed to improve aquatic habitat and establish shaded riverine aquatic cover vegetation in the lower creek area between Almaden Expressway and Masson Dam. The Guadalupe Fish Ladder Project in 1999 was to install a bypass of the 13-foot Alamitos drop structure for fish migration (EAO, Inc. 2000). All of these projects involved disturbance of the some portion of the watershed and therefore required intense soil and sediment sampling to determine mercury concentrations for various sites within the watershed because these projects have the potential to release more mercury into the watershed.

## APPENDIX C – Elemental Mercury Levels in the Guadalupe

Soil sampling in the Upper Guadalupe River shows sporadic pockets of sediment with high mercury content with the highest level being 52 mg/kg (Kleinfelder 1995), which far exceeds the allowable level of 20 mg/kg. The heavy siltation of the watershed reservoirs led to sediment testing to see if mercury was accumulating in these accumulating sediments. The samples that were discrete enough to be verified accurate averaged 9 mg/kg, but researchers still feel that more accurate testing will show higher levels of mercury in these sediments (EOA, Inc. 2000). The Upper Guadalupe between San Jose and highway 85 show 2-25 ug/l of mercury (WCC

1992). Also, directly below both the Almaden and Guadalupe Reservoirs, the levels of mercury reached 150 ug/l (WCC 1992).

In the Downtown River area between Almaden Expressway and Masson Dam, sampling in six sites resulted in 16 of 40 samples having concentrations that exceeded 20 mg/kg, ranging from 21-69 mg/kg (EOA, Inc 2000).

The Lower Guadalupe between Alviso and downtown San Jose shows average levels of 1 ug/l mercury (WCC 1992). Testing of groundwater sites in the watershed showed that mercury was not present above allowable limits (Kleinfelder 95).

**APPENDIX C – Parameters Affecting Potential Remediation**

Precipitation affects the potential for runoff and erosion, can cause flooding, and increase or decrease flow rates in the watershed. These processes influenced by precipitation can affect changes in the amount of mercury loaded into the watershed and the potential for the production of methyl mercury. The precipitation within the Guadalupe River watershed averages 20 inches per year. Normal annual precipitation in the Upper River section of the watershed ranges from 16 to 44 inches per year with an average of 30 inches per year. The Downtown River section normal annual precipitation averages 15 inches per year. The Lower River portion's normal annual precipitation averages 14 inches per year. Ninety percent of the rainfall occurs in the late fall and winter months; January is usually the wettest month (US Army Corps of Engineers 2001).

Historically, the Guadalupe River has experienced significant flow fluctuations in response to the distinct wet and dry seasons (US Army Corps of Engineers 2001). Flow is important to a consideration of mercury pollution because an increase in flow rate can increase the amount of mercury being transported downstream, especially if this flow increase is caused by an increase in precipitation which means an increase in the potential for mercury loading due to runoff and erosion. Increased flow can also mean flooding, which can dislodge mercury held in the soils along riverbanks, and make the mobile, transporting them downstream (EOA, Inc 2000). The monthly natural average runoff of 19.7 inches per month for the Guadalupe basin is based on the months of December through April. During the remaining months there is virtually no runoff. Flows within the Guadalupe are heavily controlled and altered due to agricultural development, regulation of reservoirs, recharging of groundwater and urbanization. The Downtown section of the river has an average flow of 1 cfs (cubic foot per second) from May to November and 9 cfs from December to April. While Downtown sections have been evaluated for flow rates, the Upper and Lower River has inconclusive data concerning flow rates. However, certain qualities of these flows can be discussed. The Upper River section generally has a greater flow because less has been extracted for agriculture, industry and other water needs, and has more high-energy conditions (US Army Corps of Engineers 2001). The Lower River, especially the tidal section, has a much slower flow and lower energy conditions due a decrease in slope and larger meander patterns (US Army Corps of Engineers 2001). The data on flow has serious gaps.

Sediment type and load are also parameters to consider when evaluating mercury pollution for remediation. Sediment load is the total quantity of sediment derived from the land surface that reaches a river. Sediment load plays an important role in channel erosion and deposition, and ultimately, the morphology of the river. Sediment load is divided into two distinct components: bedload and wash load. Bedload is made up of sediment greater than 0.0625 in diameter, which includes all materials coarser than fine sands. Wash load is made up of sediments less than 0.0625 in diameter, which includes silts, clays and organic materials (US Army Corps of Engineers 2001). Since methyl mercury is more likely to be produced in washload, understanding sediment load patterns throughout the watershed is essential (Turner, R.R. 1999, US EPA 2000, D'Itri 1972). Sediment types vary throughout the different sections of the river, but in general, the farther downstream traveled, the more likely to have accumulations of washload types sediments including silts and clays. Information on sediment load in the Guadalupe watershed is incomplete, and it is important to note that delivery of wash load and bedload sediments to the downstream sections of the river and beyond may vary considerably from year to year (US Army Corps of Engineers 2001).

Channel erosion and deposition patterns have been extensively studied for the Downtown portions of the Guadalupe River, but information about the Upper and Lower River sections is incomplete. Understanding the potential for and the history of channel erosion and depositional patterns is important because places of erosion are potential remediation sites where mercury is entering the waterways, and depositional patterns can identify where mercury may have been deposited. Sediment transport studies have shown that the Downtown area is sediment-starved under existing conditions and has the potential to erode, the bed and bank materials are resistant to erosion. The Downtown area is underlain by estuarine bay muds that are stiff clay and silt deposits that are much more resistant to erosion than the few inches of sands and gravels that lie on the surface of the riverbed (US Army Corps of Engineers 2001). Information concerning erosion potential of the Upper and Lower sections of the river is hardly documented, but it is known that the Upper section is more prone to erosion than the Lower section, and that the Upper River banks may have large amount of mercury that could potentially be added to the waterways.

Temperature of the air and water is important to consider because it can affect the interactions of mercury with the environment, and tracking temperature may help identify methyl mercury hotspots or pathways (US EPA 2000). Also, temperature can affect the potential of remediation methods to be successful, especially phytoremediation, which requires that certain plants are able to grow. Average air temperatures are as follows: 1) Upper: 58-78 degrees Fahrenheit; 2) Downtown: 68-70 degrees Fahrenheit; and 3) Lower: 68-76 degrees Fahrenheit. Average water temperatures are as follows: 1) Upper: not conclusively evaluated, but expected to be cooler than both the downtown and lower sections of the river; 2) Downtown: July through August is 70 degrees Fahrenheit, September through February is 50-60 degrees Fahrenheit, and March through May is 55-70 degrees Fahrenheit; and 3) Lower: not conclusively evaluated, but expected to be warmer than the upper section and pretty consistent with downtown section temperatures (US Army Corps of Engineers 2001). Determination of water and air temperature patterns should be made in order to be able to evaluate how this could affect mercury interaction with the environment as well as mercury remediation success.

Additionally, other information that will help identify potential methyl mercury hotspots should be compiled. This includes data on dissolved oxygen content, pH, alkalinity, and sulfate/sulfide concentrations. This is essential to learning how to counteract pathways once they are identified/located (Verta, M. et al. 1994, US EPA 2000).