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Mercury Source Control & Pollution Prevention Program Evaluation

Final Report

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DISCLAIMER

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Introduction

The effects of mercury exposure on human health and wildlife are driving a number of efforts to significantly reduce the level of this toxic, persistent, and bioaccumulative metal in the environment. Exposure to mercury, a neurotoxin, affects the brain and nervous system. Young children and developing fetuses are most susceptible to its harmful effects. Long-term exposure may cause, among other things, a loss of physical coordination and mental retardation. The consumption of fish from waters contaminated with mercury offers the greatest risk of exposure to this pollutant. [TriTAC, 2001].

Mercury enters waterbodies through several pathways including air deposition (from combustion and incineration processes), urban runoff, wastewater discharges, geothermal discharges, mine site runoff, and contaminated sediments.

Increased monitoring of mercury in the water column and fish tissue and the application of more stringent standards has led to increasingly stringent mercury effluent limits in NPDES permits. Some of the standards that have been used or proposed are listed in Table 1.

Table 1. Mercury Water Quality Criteria

Basis of Criteria	ng/L
California Toxics Rule Saltwater Criterion	25
EPA Fish Tissue Methyl Mercury-based Criterion (Rivers & Streams)	17-18[1]
EPA Fish Tissue Methyl Mercury-based Criterion (Lakes)	7.5-7.8[1]
Great Lakes Initiative Human Health Criterion	3.1
Great Lakes Initiative Wildlife Criterion	1.3
Proposed Maine Freshwater Chronic Criterion	0.2

Currently, approximately 6% (253 of 4307) of the major publicly owned treatment works (POTWs) have NPDES permits with mercury effluent limits and approximately 10% of the major POTWs (423 of 4307) have monitoring requirements (Morris, 2001). As more monitoring for mercury is conducted, the number of agencies with effluent limits is likely to significantly increase. Of the agencies with limits, several (particularly in the Great Lakes region) have limits based on the Great Lakes Initiative (GLI) Wildlife Criterion (i.e., 1.3 ng/L) and have had difficulty meeting these limits (EPA, 2001).

In order to comply with permit requirements, POTWs with effluent limits for mercury have investigated a variety of strategies, including non-regulatory approaches such as pollution

1 These are projected criteria for total mercury that have been calculated from the national fish tissue residue criteria for methylmercury using, as default values, draft bioaccumulation factors, trophic level-specific fish consumption rates, and dissolved methyl-to-total mercury translators.

prevention and source control, in an effort to achieve mercury reductions. National efforts to reduce mercury releases to the environment have already used source control and pollution prevention to target incineration of medical and dental wastes, disposal of consumer products (i.e., fever thermometers, thermostats, switches, fluorescent light bulbs) and dental office wastewater discharges.

In addition to source control and pollution prevention programs, mercury has also been the target of legislation. Legislation to restrict mercury use in consumer products and in certain other applications has been introduced at the federal level as well as in many states throughout the country. Legislation has been proposed that prohibits the sale or supply of mercury fever thermometers (except by prescription), novelty items and automobile switches as well as prohibiting purchases of mercury by schools. Some bills propose the immediate removal of mercury switches from automobiles and provide technical assistance to wrecking yards to remove mercury switches. Yet another bill prohibits improper disposal of mercury containing products and requires POTWs to perform wastewater monitoring, source identification and pollution prevention. There is also a provision requiring that mercury containment traps be installed for facilities that have the potential to discharge trace amounts of mercury to the sewer system. Many states are creating task forces to come up with recommendations on how to regulate mercury as a solid and hazardous waste.

While pollution prevention and source control are effective tools for reducing the amount of a pollutant entering the environment, several factors influence a POTW's ability to achieve mercury reductions and permit compliance using pollution prevention and source control. These factors include:

- Initial influent mercury levels;
- Percentage of the influent loading that can be attributed to specific sources;
- Ability of the POTW to control a particular source;
- Potential effectiveness and cost of the source control strategies employed;
- Form of mercury present in the influent (i.e., particulate vs. dissolved);
- Treatment plant removal efficiencies at varying influent concentrations; and
- Final effluent limit that must be achieved and corresponding reduction needed to achieve this limit.

The purpose of this project was to:

1. Determine the extent to which pollution prevention and source control programs can achieve measurable reductions of mercury in POTW influent, and if these reductions will enable POTWs to comply with new, lower effluent limits based on the criteria listed in Table 1. (Note: The term pollution prevention program, as used in this report, refers to a source control program that uses only voluntary approaches); and

2. Identify the beneficial impacts of wastewater source control on other pathways by which mercury enters the environment.

The following steps were taken to complete this assessment:

- Estimate mercury reduction in influent achievable through source control;
- Assess ability of POTW to comply with effluent limits based on these influent reductions;
- Compare impact of implementing source control programs (cost) with impact of additional POTW treatment costs; and
- Identify benefits of source control programs in addition to impacts on wastewater.

The procedure used and the results of this assessment are described in the following sections.

Procedure. This section describes the process, the assumptions and the data sources used in the analysis.

Results. The results of the analysis are presented with respect to estimated mercury influent loadings for each plant, reductions that may be achievable through pollution prevention, resulting effluent mercury levels and potential for each case study candidate to comply with future effluent limits. The impacts of the various assumptions made are also discussed in this section.

Findings. The implications of the results with respect to the potential effectiveness of mercury pollution prevention programs and regulatory impacts are discussed. The impacts on other media in addition to water are also considered. Limitations of the study are presented.

Conclusions and Recommendations. Overall conclusions are summarized. Recommendations for source control programs are presented. Areas requiring future study are identified.

Procedure

A flow chart of the process used to reach final effluent concentrations based on pollution prevention activities can be found in Figure 1. The basic steps of this process included:

- Selection of Case Studies
- Source Identification
- Source Load Calculation
- Reduction Estimate
- Resulting Influent, Effluent and Biosolids Loads and Concentrations
- Comparison to Effluent Limits
- Cost of Compliance

These process steps are described in detail below.

Selection of Case Studies

Initial outreach to POTWs was based on plant size and geographic location. To encompass a range of possible mercury sources and concentrations, different size plants, spread throughout the country, were contacted. Spreadsheets were e-mailed to each agency asking for information such as the number of households, influent/effluent concentrations and number of dental offices in their service area (See “Plant Data Spreadsheet” in Appendix A). Several agencies provided data and information about their plants and service areas, some of which is shown in Table 2, below. The data entered into the Plant Data Spreadsheet were linked to a second spreadsheet which used source values from previous studies to calculate loadings (grams/day) for each identified source.

Figure 1. Flow Chart of Processes Used

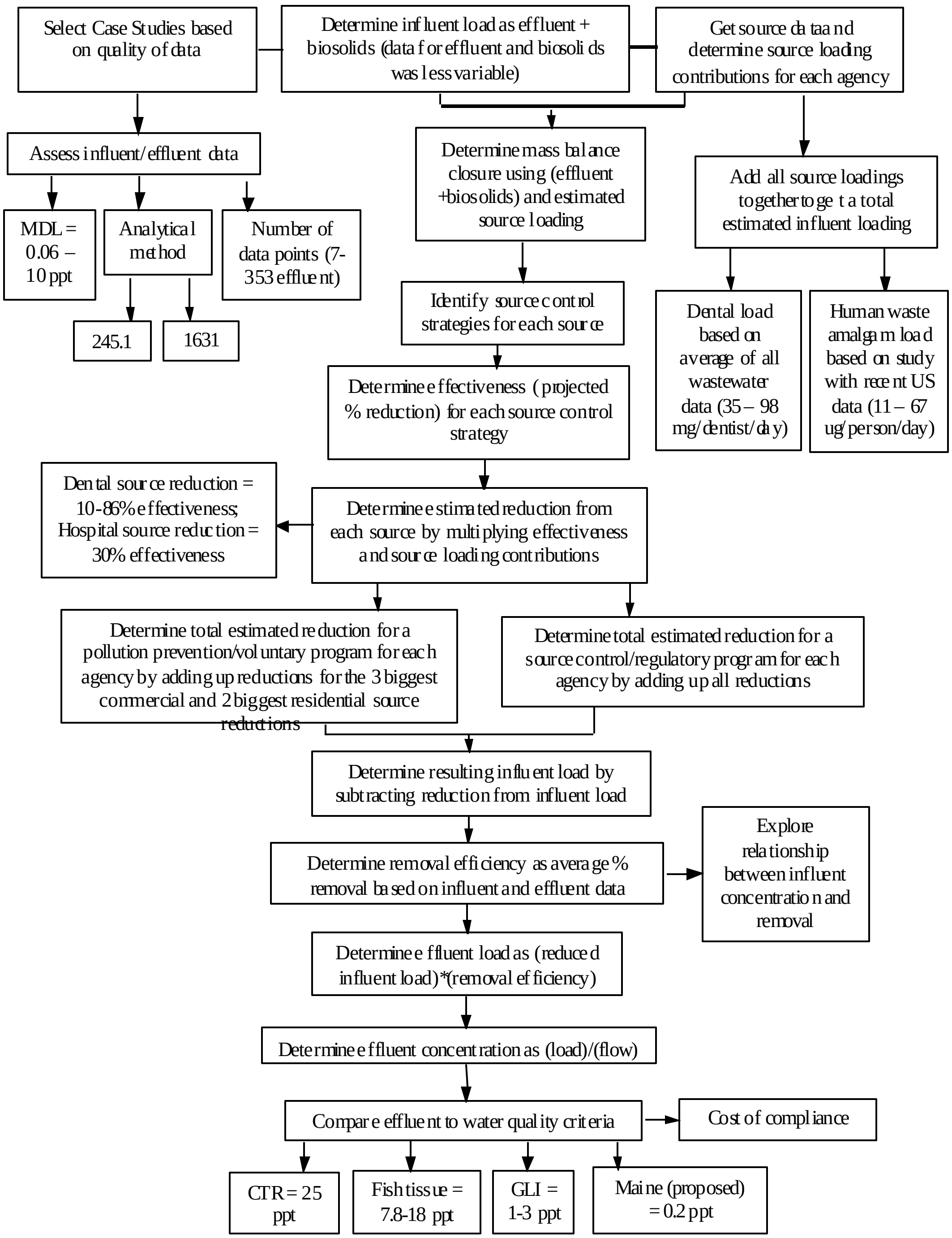


Table 2. POTW Data

POTW		Community Size	Ave. Op. Size (MGD)	Average Inf. (ppt)	# Influent Samples	Average Eff. (ppt)	# Effluent Samples	Average Biosolids (g/day)	# Biosolid Samples	Analytical Method	MDL (ppt)	Time Period	% Non-Detect (effluent)
Massachusetts Water Resource Authority (MWRA)	MA	2.5 M	375	260	12	30	12	340		245.1	10	1999-2000	
Hampton Road Sanitation District (HRSD)*	VA	1.5 M	157	29-292	43	<5-29.5	36	5.7-21.1	133	245.7	5 QL	2000-2001	86%*
Sacramento Regional County Sanitation District (SRCSD)	CA	1.1 M	157	227	105	9	116	113	164	1631	0.06	1998-2000	0%
Northeast Ohio Regional Sewer District - Easterly (NEORSD-e)		401,167	104.1	143	19	3.56	19	55	19				0%
Northeast Ohio Regional Sewer District - Southerly (NEORSD-s)	OH	597,936	109.5	323	10	3.17	11	144	366	1631	0.5	2000	0%
Northeast Ohio Regional Sewer District - Westerly (NEORSD-w)		123,170	31.2	113	7	3.11	11	16	366				0%
San Francisco - Southeast Plant	CA	564,744	65	414	23	21	50	<0.323	2	1631	2.5	2000	0%
San Francisco - Oceanside Plant		224,033	17.6	237	12	51	18	<0.097	2				0%
Western Lake Superior Sanitary District (WLSSD)	MN	95,000	39	106	366	4.7	353	16.3	47	245.1	5	2000	58%
Palo Alto Regional Water Quality Control Plant	CA	226,000	28	219	34	5.5	24	25.2		1631	10	1999-2000	50%
Green Bay Metro Sewerage District (GBMSD)	WI	180,900	28	104	12	<7	12	18.9	40	245.7	7	2000	100%
Portland Water District - Portland Plant	ME	60,000	16.4	101	1	14	8	8.47		1631	0.2	2000	0%
Lewiston-Auburn WPCA	ME	50,000	12.2	70	4	5	11	10.15	39	1631	0.2	1999-2000	0%
Novato Sanitation District (NSD)	CA	34,190	4.4	593	30	22.6	34			1631	10	1998-2000	0%
Portland Water District - Westbrook Plant	ME	15,000	2.51	281	3	6.9	7	1.51		1631	0.2	2000	0%

*The data in Table 2 for the Hampton Roads Sanitation District were changed in July 2002 to more accurately reflect actual monitoring information. Note that the value in the column for Method Detection Level (MDL) is a Quantitation Level (QL) not an MDL. Also, the % Non Detect value is the percent not quantifiable, rather than not detectable. The "effluent" values were obtained at the end of HRSD's chlorine contact tanks, which is not the official effluent sampling site.

To develop reasonable load reduction calculations, it was important to use data that accurately accounted for a majority of the mercury moving through each plant. Therefore, mass balance closures (influent = effluent + biosolids) were determined for each agency to assess the quality of available data. Influent, effluent and biosolids loads were determined based on flow and concentration data provided by each agency. Agencies used for the full calculation were selected based on the following criteria:

- Number of influent and effluent samples reported
- Analytical method and detection limits
- Mass balance closure
- Availability of all requested information.

Source Identification and Data Sources

Many studies have been performed that attempt to identify sources of mercury from commercial, residential and industrial activities. In addition, research has been conducted on the effectiveness of pollution prevention and source control programs. Information on sources of mercury and effectiveness of pollution prevention was collected from various reports and Internet sites. In most cases, data obtained were averaged to obtain representative mercury concentrations and source flow data. A variety of commercial, industrial and residential sources were considered. Stormwater inflow and septage waste were also considered for agencies who provided data on these sources. The mercury data used for source loading calculations, and an explanation of how the final values were calculated can be found in Appendix B. Two of the most significant sources were dental office discharges and human waste associated with amalgam fillings. Literature values for these two sources were highly variable and based on several assumptions. Therefore, a sensitivity analysis (Appendix D) was conducted to assess the impact of varying these two values. By varying the dental and human waste values it was possible to get a sense of how influential the numbers used for these sources were on reduction estimates, mercury concentrations, compliance, and project costs. Dental and human waste loading data were chosen as discussed below.

Dental Loading

Mercury levels measured in dental wastewater were used to estimate loading contributions from dental offices to treatment plant influent. Several studies were available in which wastewater concentrations, water flow and consumption rates, and number of dentists had been measured [Rourke, 2000; SFWPPP, 1993; Barruci *et al*., 1992; NEORSD, 1997]. Because there is no way to conclude that any one of these studies is better then another, the data were treated equally. An unweighted average of the data from these studies resulted in a dental loading value of 56 mg/dentist/day as shown in Table 3. Other studies measuring mercury discharges from dentists that were considered include those by Drummond et al., Cailas et al. and Arenholt-Bindslev and Larsen (Table 4) and Metropolitan Council Environmental Services (MCES). The differences between the values measured in Tables 3 and 4 are discussed below.

Table 3. Data Used for Calculation of Dental Loading Value

Barruci *et al*., 1992	35 mg/dentist/day	24 samples from 3 buildings
SFWPPP, 1993	46 mg/dentist/day	56 samples from 9 buildings

Rourke, 2000	98 mg/dentist/day	114 samples at 6 buildings
NEORSD, 1997	44 mg/dentist/day	37 samples at 5 facilities
AVERAGE	56 mg/dentist/day (0.056 g/dentist/day)	

Table 4. Mercury Loadings in Dental Clinic Vacuum System Wastewater

All data is given as: mg Hg/day	Passing Chairside Trap (per chair) soluble + solids	Passing Chairside Trap (per chair) settled solids(1)	Discharged (per dentist) without amalgam removal equipment	Discharged (per dentist) (2) without amalgam removal equipment
Mean	612	773	250	234
Median	499	522		
N	58	66	10	275 (3)
Maximum		3298	842	1293
Minimum		20	65	8
Std. Dev.	529	733		
Reference:	Cailas, et al. (1994)	Drummond, et al. (1995)	Arenholt-Bindslev and Larsen (1996)	Berglund (2001)

(1) Supernatant passing chair had low mercury amount relative to solids, and also variable amount. Drummond also measured the amount of mercury in solids retained in chairside traps. The median value was 819 mg/chair/day (N = 57, Std. Dev. = 1032).
(2) Data for seven clinics, all operated with a chairside trap. Five operated with a vacuum filter, and two without a vacuum filter.
(3) Some samples of wastewater and waste solids were collected over numerous days. Therefore, the “N”, or number of samples, is less than 275. However, the units for the data is “per day”, and the number of days of sample collection was 275 days.

The values listed in Table 4 are based on samples taken in the dental office. MCES (WEF, 1999) estimated that half of the mercury passing the chairside traps would be captured in a vacuum filter, commonly used with liquid-ring vacuum pumps. The other half, or 250-261 mg/dentist/day (WEF, 1999) would be discharged from the clinic vacuum system and mixed in with the clinic’s other wastewater. A recent study by MCES estimated a dental loading contribution of 120 mg/dentist/day to the influent of two treatment plants (Anderson, 2001). This was based on a back-calculation from measured reductions in biosolids mercury levels and estimated grit removal rates resulting from installing amalgam removal equipment at all dental clinics in two treatment plant service areas (the result of 120 mg calculated out the same for each of the two service areas). A second study recently completed by MCES found a variable loading rate from dentists, yet with a similar average loading rate of 234 mg/dentist/day (Berglund, 2001), as compared to the other data in Table 4.

The basis for the calculations in this report is 56 mg/dentist/day (0.056 g/dentist/day). In the sensitivity analysis, loading values greater than 56 mg/dentist/day will be used, up to 150 mg/dentist/day (with the understanding that the loadings may be higher than 56 mg/dentist/day based on data from Cailas, et al., Drummond et al., Arenholt-Bindslev & Larsen, and MCES). The measurements leading to the average of 56 mg/dentist/day may be lower than data in Table 4 and lower than the 250-261 mg/dentist/day reported by the 1999 WEF monograph due to issues with:

- Sampling location and amount of solids suspended in liquid fraction; and
- Subsampling prior to analysis and digestion methods of subsample.

Some portion of the amalgam that goes down the drain will settle in the collection system and leach back into the liquid fraction (which will contain particulate and dissolved mercury) over time. While there is a considerable amount of uncertainty regarding the fate and transport of solid amalgam in sewer lines, this settling could explain the difference in concentrations measured in the collection system (Table 3) and the concentrations measured in the dental office (Table 4). Another possible factor contributing to the differences in the values listed in Tables 3 and 4 is the digestion method used as part of the sample analysis. The digestion process used for wastewater in Methods 245 and 1631 is appropriate for samples with low solids (i.e., values listed in Table 3). However, a more aggressive digestion method is used for high solids samples and may account for the higher mercury levels shown in Table 4.

It was assumed that the samples taken in the laterals leaving the dental offices (Table 3) represent the best estimate of the mercury actually leaving the dental office and the mercury leaching back into the liquid fraction at a given snapshot in time that will ultimately reach the treatment plant headworks. Therefore, 56 mg/dentist/day offers the best representation of the mercury that enters the treatment plant. Other viewpoints on this issue are addressed in Appendix C: Response to Comments.

Human Amalgam Waste Loading

In the case of human waste loadings associated with amalgam fillings, wastewater data was not readily available. Instead, the analysis used a calculated loading designed to best represent a typical U.S. population. A number of existing studies were reviewed to formulate the loading for this analysis. A Canadian study compiled data from a variety of sources and attempted to account for the relationship between number of fillings and human waste-amalgam mercury loadings. The resulting number was 11 µg/person/day [O'Conner Associates, 2000]. However, this was based on data averaging the number of fillings per person in Canada in the 1970's. Another study, done by Barron (2001a, 2001b), found that the average number of amalgam surfaces is 16.6 per person (based upon Hyman data for the 1990 United States census). From this, the daily average mercury waste (urine + feces) is in the range of 27-39 µg/day/patient.

‘Patient’ refers only to adults with amalgams. Restated, for all people beyond just those who have amalgams, the overall average number of amalgam surfaces is 10.8 per person. Therefore, the daily average loading is in the range of 17 to 26 µg/person/day. ‘Person’ here means all adults (>20 years), including those with and without amalgam fillings. The estimate based upon the Hyman data for fillings per person gives the high end of the above two ranges. The lower estimate is found by using Skare’s (1995) average and low values (Table 5). Skare’s curve fit was not used because the data included individual(s) with very high amalgam counts.

Table 5. Barron’s Estimates Applied to Skare’s Average and Low Values

	Surfaces	U-Hg	F-Hg	Total Hg	Units
Ave	40	1.7	64	65.7	µg/day/patient
Low	18	1.4	27	28.4	µg/day/patient

These values imply mercury waste loads of 1.64 (65.7÷40) and 1.58 (28.4÷18) µg/day PER AMALGAM SURFACE, respectively. The Barron estimate (2001b) uses 1.60 µg/day for this parameter. Doing so produces a human mercury waste result of 26.5 µg/day/adult ‘patient’, which is equivalent to an overall average of 17.2 µg/day/adult ‘person’. Table 6 summarizes human waste values calculated in the studies cited. Table 7 provides details of how these values were calculated.

Table 6. Human Waste Mercury Studies Cited

Reference	Human Waste (µg/person/day)	Amalgam Surfaces	µg Hg/ surface /day
Skare	49.3	40	1.64
	21.3	18	1.58
Barron	17.2	10.8	1.60
O’Conner	11.4	7.6	1.50

The value calculated by Barron, 17.2 µg/day/person, was used because it appears to be the most representative of the U.S. population. This number accounts for all people; the fact that some people have amalgam fillings and some don’t, has been factored into the 17.2 µg/day/person value.

Table 7. Human Waste Mercury Calculations

	Barron (2001b) [Revised] [1,2]	O'Connor (2000) [Table 4.2] [3]	Skare (1995a) [Table 1 - low]	Skare (1995b) [Table 1 - mid]	AMSA (2000) [Page 11]
Per Adult Person (including just those with amalgam fillings)					
Total Filling Surfaces/person	18.43	• • •	• • •	• • •	• • •
Pct of surfaces that are amalgam	90%	• • •	• • •	• • •	• • •
Average amalgam surfaces / person	16.59	• • •	18.00	40.00	• • •
Hg Waste (u+f) per amalgam surface (µg/d)	1.60	• • •	1.58	1.64	• • •
Human Hg waste (u+f) in µg/d [1]	26.54	• • •	28.40	65.70	67.00
Convert to mg per year (multiply)	0.37	• • •	0.37	0.37	• • •
Human Hg waste (u+f) in mg/yr	9.69	• • •	10.37	23.98	• • •
Per Adult Person (including both those with and w/out amalgams)					
Pct. Of population w/ fillings	65%	• • •	75%	75%	65%
Overall avg. amalgam surfaces / person	10.78	7.60	13.50	30.00	• • •
Hg Waste (u+f) per amalgam surface (µg/d)	1.60	1.50	1.58	1.64	• • •
Overall avg. human waste (u+f) in µg/d/pers	17.25	11.44	21.30	49.28	• • •
Convert to mg per year (multiply)	0.37	0.37	0.37	0.37	• • •
Overall avg. human waste (u+f) in mg/yr/pers	6.30	4.17	7.77	17.99	• • •

Interpretation by Barron (2001b)

Notes.

[1] Equation: Hg (u+f) = c + m * N

c	0.00	(Hg = 0 when Amalgam surfaces = 0)
m	1.60	(Hg Waste per amalgam surface)
N	16.59	(No. of surfaces)
Hg (u+f) µg/d	26.54	u = urine wastes; f = fecal wastes

Skare data and curve fit include a person with 82 surfaces. The lower end of Skare's data seems more applicable to the US & Canada.

[2] Interpretation of Skare ("low" = 18 surfaces, "mid" = 40 surfaces)

[3] Interpretation of O'Connor

Caution: Four digits used to show arithmetic, not to imply accuracy.

Load Calculation

The first step in assessing the contribution of pollution prevention to effluent reduction was to estimate the quantity of mercury in treatment plant influent that is contributed from the identified sources. The following business categories and residential activities were determined to be potentially significant sources and were, therefore, included in the influent load calculation.

Commercial Activities

- Dental offices
- Hospitals
- Laboratories
- Universities
- Secondary schools
- Medical clinics
- Vehicle service facilities
- Industrial activities

Residential Sources

- Human waste (amalgam)
- Human waste (dietary)
- Laundry graywater
- Household products
- Improper disposal of mercury thermometers

Other Sources

- Industrial activity
- Stormwater inflow

To estimate the load from each of the business categories for a given community, the number of businesses in a category (provided by the case study POTW) was multiplied by an average flow and mercury concentration for this business category. The average flow and concentration values were compiled from the literature and from data provided by agencies that have conducted this type of sampling. Loadings from residential activities were estimated on a per person or per household basis also based on literature values and multiplied by the service area population or number of households (provided by the case study POTW). It was assumed that commercial and residential activities do not vary from community to community allowing pooling of available data and application of these data to each of the case studies. Industrial loadings, however, were based on community specific data provided by each case study participant. Equations used to estimate source loadings are shown in Table 11. Total influent loading was then determined as the sum of the loadings calculated for the individual residential, commercial, and industrial sources. Stormwater inflow and septage waste were estimated to be small contributions but were considered if the agency provided specific data.

Reduction Estimate

The next step in the process was to identify source control strategies for the sources listed above and to assign an effectiveness rating to each strategy. The predicted effectiveness of a control strategy was then multiplied by the estimated load for each applicable source to estimate a potential reduction achievable in the source's loading through pollution prevention. The procedure for predicting effectiveness and estimating reductions is described below. The effectiveness of a source control strategy can be estimated on the basis of the level of participation expected and the maximum load reduction that may be achieved by the strategy. This is determined as the product of a participation factor and a load factor.

The participation factor is an estimate of the portion of the targeted audience that will make the desired behavior change and implement the recommended practice. Ideally, implementation of a control strategy would result in the elimination of the source it was designed to address. In reality, only a certain percentage of the people and procedures addressed by the strategy will change. Pollution prevention programs typically rely on voluntary actions. In the case of residential sources, agencies do not have the legal authority to regulate residents so, in general, voluntary approaches are the only strategies available. There are other strategies that may seem useful for residential sources such as product bans or changing building codes. These strategies are often outside the jurisdiction of the local POTW. To pursue these strategies, efforts must be coordinated regionally or at the state level. In some cases, agencies have worked together and with state legislators to achieve product bans or restrictions (e.g., San Francisco Bay Area restrictions on the use of copper sulfate root control products, California ban on lindane-containing head lice remedies, statewide bans on mercury fever thermometers). In other situations, the agency that the POTW must work with that has the authority to achieve the desired change is less cooperative. For example, in California, there is an ongoing and, so far, unsuccessful effort to change the state plumbing codes to allow the use of non-copper plumbing materials. Therefore, available approaches for residential sources are primarily voluntary and outreach-based. Product bans and other approaches requiring support by other groups are more difficult to accomplish and require longer time periods and greater resources than public education. Therefore, participation rates used in this study for strategies requiring cooperation with other agencies are typically lower than public education.

For commercial sources, voluntary programs can be effective and may be more cost effective for the agency than working with the general public. Regulatory approaches are also available for commercial sources and will have higher participation rates than voluntary approaches during the initial stages of a program. Over time, an effective voluntary program can achieve participation rates comparable to regulatory programs. Specific participation rates used for this study are listed below. The participation rate used for dentists with respect to implementing BMPs on a voluntary basis is based on the results of surveys conducted regarding dental office waste management practices in San Francisco. San Francisco and other Bay Area agencies have worked with the dentists in its service area for a number of years educating them regarding the environmental impacts of mercury and recommended amalgam management practices. San Francisco Bay area dentists have been responding reasonably to data that is presented to them indicating that they are a major source of mercury in wastewater. The California Dental Association has been cooperating in recommending non-treatment related BMPs. However, their acceptance of separators remains to be seen. Surveys (231 responses from a possible 843 dentists) and site visits (34 offices) conducted for San Francisco dentists both indicate that approximately 65% of the dentists are implementing the recommended BMPs (WERF, 2001). WLSSD has also worked closely with the dental community and, after 10 years, reports high rates of cooperation from the dentists (Tuominem, 2001). However, participation rates can vary. King County reported a lower BMP implementation rate of 38% (King County, 2000).

The loading factor is the expected amount of pollutant load reduction from a source if there was 100% participation. The loading factor varies depending on the sources that the strategy addresses. Loading factors are determined by estimating the amount of mercury coming from individual sources within a category and determining what portion of the loading is addressed. For example, sources of mercury from hospitals include mercury-containing equipment, mercury solutions and mercury present in the sewer lines. Each control strategy is then examined to determine the individual sources that it addresses.

Business outreach and public education strategies are assumed to address all individual sources. For example, all programs related to thermometers and contact lens solutions have a loading factor of 100% because control strategies aimed at these sources would effectively eliminate the source. In the case of dentists, it was determined that approximately 80% of the dental amalgam wastes would be kept out of the drain because that is the approximate amount of material captured in standard traps. The load factor for amalgam separators is 95% because they are able to capture smaller particles and, therefore, a larger percentage of the amalgam wastes discharged. The load factor for stopping use of amalgam is 50% because it is estimated that about half the amalgam discharges in a practice come from placing fillings. The other half comes from removal of old amalgam fillings. This division between fillings placed and fillings removed is based on the responses of dentists surveyed in the San Francisco Bay Area (WERF, 2001).

The strategies available for addressing the identified sources and their predicted effectiveness are shown in Table 8. The participation and load factors are based on the results observed from various pollution prevention efforts. Some specifics include:

- The participation rate of 65% for the strategy targeting dental offices of voluntary implementation of BMPs is based on the results of surveys conducted in 2000 by Palo Alto, San Francisco, and Central Contra Costa Sanitary District (WERF, 2001; Brandenburg, 2000; Hughes, 2000).

- The load factor is based on the percent capture of amalgam particles through chair-side traps and vacuum filters estimated by MWRA and MCES studies (MWRA, 1997; WEF, 1999).

- The load factor for amalgam separators is based on the results of performance tests on separators. The participation factor associated with persuading dentists to stop using amalgam is based on the dental survey results mentioned above (WERF, 2001).

- The participation factor for the other business categories is based on percent of businesses complying with BMPs seen by Palo Alto and West County in the first year of voluntary programs conducted by these agencies for vehicle service facilities and is approximately 50% (WERF, 2000).

- The load factor for all the businesses that had BMP/modified purchasing are based on reductions measured by Detroit [Williams, 1997] and MWRA [MWRA/MASCO, 1995] for hospitals implementing these practices. For hospitals going to 'Mercury-Free' operation, the reductions may be greater than those observed in Detroit and Massachusetts. However, the reduction may not be 100% if there is residual mercury deposits in the laterals. In the absence of other data, the load factor is based on the results measured in these two studies (i.e., 60%).

- The vehicle service load factor is based on West County monitoring results for its vehicle service program (WERF, 2000).

- The thermometer exchange program participation rate is based on results of programs conducted by San Francisco, Palo Alto, and Connecticut. For each of these programs approximately 1% of the service area population turned in thermometers.

- A review of several surveys assessing increased awareness or behavior change resulting from public education programs was used to set participation rates for residential source control strategies. Residential participation rates (i.e., reported behavior change) are typically 5-10% with much lower participation seen for a more complicated strategy (like removing amalgam fillings or installing a graywater system).

- Research regarding graywater systems has indicated that this is a complicated strategy for homeowners to implement. In some cases, it is not even possible due to space limitations. Graywater systems divert the water to landscaping and in densely populated areas not enough landscaping is available to accommodate the graywater discharges. Therefore, a lower participation rate is used (i.e., 2%).

- All participation rates used are the participation observed in the initial stages of a program, typically the first year. In this sort of time frame, regulatory approaches will have higher participation rates than voluntary programs. However, over time, participation rates for well-implemented voluntary programs will approach the participation rates for regulatory programs. After ten years, WLSSD has a high level of cooperation with the dentists in its service area (i.e., close to 100%). Palo Alto's vehicle service program had a 50% participation rate in its first year. After 5 years, participation and BMP implementation was over 90% (WERF 2000).

Table 8. Source Control Strategies and Their Respective Effectiveness

Source	Control Strategy	Participation Factor	Load Factor	Effectiveness
COMMERCIAL				
Dentists	**Voluntary programs**			
	BMPs - Recycle all amalgam wastes	65%	80%	52%
	Amalgam separators	10%	95%	10%
	Stop using amalgam	25%	50%	13%
	Permits/regulatory			
	BMPs - Recycle all amalgam wastes	95%	80%	76%
	Amalgam separators	90%	95%	86%
	Stop using amalgam	90%	50%	45%
Hospitals Laboratories Universities Secondary Schools Medical Clinics	BMPs -Modify purchasing/ disposal practices (voluntary)	50%	60%	30%
Vehicle Service	BMPs / Zero discharge	50%	80%	40%
Pottery Ceramics	BMPs -Modify purchasing/ disposal practices (voluntary)	50%	60%	30%
RESIDENTIAL				
Human Waste-amalgam	Remove amalgam fillings – public outreach	2%	100%	2%
Human Waste-dietary	Uncontrollable			
Laundry Graywater	Graywater systems– public outreach	2%	100%	2%
Household products	Substitute alternatives– public outreach	10%	100%	10%
Thermometers	Turn in Hg thermometers - public outreach	1%	100%	1%
	Work w/ pharmacies to not sell	50%	100%	50%
	Local sales ban	90%	100%	90%
Contact Lens Solution	Work w/ pharmacies to not sell	50%	100%	50%
	Local sales ban	90%	100%	90%
INDUSTRIAL	BMPs	90%	90%	81%

Resulting Influent, Effluent and Biosolids Loads and Concentrations

Source reduction estimates were made for each identified source of mercury. These reduction estimates were then added together to estimate an overall influent reduction. Reductions were calculated based on two types of programs, pollution prevention/voluntary and source control/regulatory. A pollution prevention program was an all voluntary program and was based on implementation of the top three commercial and top two residential voluntary strategies with respect to estimated achievable reduction. A source control program included regulatory elements for the largest sources (i.e., dentists) and was calculated by assuming implementation of all reduction strategies. These estimates were tailored to each plant based on existing pollution prevention efforts as some plants had already implemented many of the strategies listed in Table 8 and other plants were just beginning their source control and pollution prevention programs.

Once a reduced influent concentration was established for each plant, reduced effluent concentrations could be calculated. Effluent reduction was determined using average removal efficiency calculated from influent and effluent data provided by each plant [(average influent – average effluent)/ average influent]. The range of removal efficiencies from plant to plant was 96% - 99%. Another approach to determining removal efficiencies was to consider any correlation between influent concentration and removal efficiency. It has been found that there may not be a linear correlation between influent and effluent concentration. Data provided by Western Lake Superior Sanitary District (WLSSD) and Sacramento Regional County Sanitation District (SRCSD) is shown in Figures 2 and 3. These figures indicate that as influent mercury concentration decreases, removal efficiency might also decrease. However, because of the variability of the data, no systematic approach for determining how much the removal efficiency decreases with decreasing influent could be established. Therefore, the average removal efficiency for each treatment plant was used as a best estimate.

Figure 2. SRCSD % Removal in Effluent vs. Influent Concentration

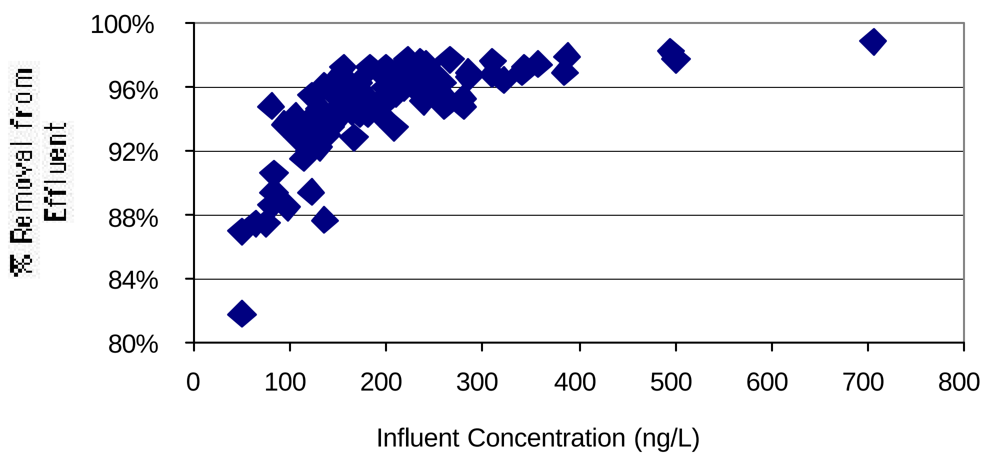
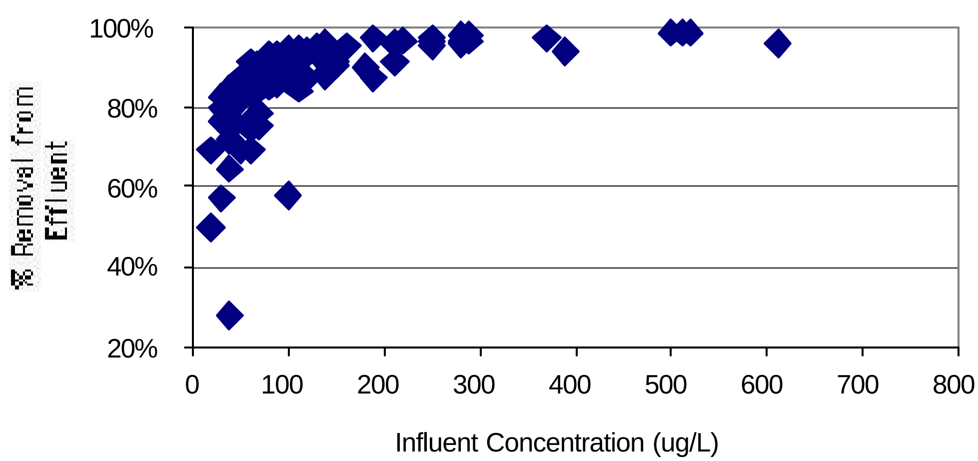


Figure 3. WLSSD % Removal in Effluent vs. Influent Concentration



Biosolids reductions were determined based on the mass balance equation (influent – effluent = biosolids). Reduced influent and effluent values were used to calculate the reduction that plants would see in their biosolids concentrations. Reduced biosolids concentration is another beneficial effect of pollution prevention efforts.

Comparison to Effluent Limits

Mercury effluent levels, resulting from implementation of pollution prevention programs with the predicted effectiveness, were first determined using the process described above. The levels were then compared to water quality-based effluent limits. Table 9 lists criteria representing the range of limits that POTWs are facing.

Table 9. Range of Mercury Criteria

Basis of Criteria	ng/L
Fish Tissue-based Criterion (Rivers/Streams)	17-18
Fish Tissue-based Criterion (Lakes)	7.5-7.8
Great Lakes Human Health Criterion	3.1
Great Lakes Initiative Wildlife Criterion	1.3
Proposed Maine Criterion	0.2

Permits in the San Francisco Bay area have effluent limits based on the National Recommended Water Quality Criteria (12 ng/L). However, as these permits are reissued, the CTR criteria of 25 ng/L will be used. Agencies in the Great Lakes area have permit limits based on the Great Lakes Water Quality Initiative Criterion (1.3 ng/L) and, in Maine, 0.2 ng/L was under consideration.

In January 2001, EPA issued a water quality criterion for methyl-mercury defined as a level in fish tissue. Implementation of this criterion will be complicated as states struggle to use the fish tissue concentration in a regulatory context by attempting to convert the value into a water column number. EPA has set up a workgroup to develop implementation guidance for the criterion and water-quality standards based on it. This guidance could result in changes in the way POTW compliance is defined. For the purposes of this study, water quality criteria calculated from the fish tissue criterion were considered by using default values to translate the fish tissue criterion to a water quality criterion. The calculated values are shown in Table 9. The actual values of water quality criteria developed from the fish tissue criterion will depend on the specific water body and its properties.

The calculated effluent concentrations (based on applying estimated reductions to maximum observed and average effluent concentrations reported by the POTWs) were then compared to the range of criteria in Table 9. Compliance with criteria was determined 'end-of-pipe' (i.e., no dilution). Permits containing mercury effluent limits are often applied with no credit for dilution. This is either because the receiving water is impaired for mercury (303(d) listed) or because the receiving water is an effluent dominated water body.

Cost of Compliance

The cost to comply with the criteria in Table 9 was determined based on the costs to implement the proposed pollution prevention programs and, as necessary, to construct additional treatment facilities where reductions through pollution prevention were inadequate. The costs to businesses targeted by pollution prevention programs was not considered. However, if treatment is required of dentists there would be a cost to install amalgam separators ($100 to $3000 installed) and to maintain the system ($35 - $200/month) [Barron, 2001; Boyd, 2001].

Pollution prevention costs were estimated based on a review of the cost of effective pollution prevention programs and the cost to develop demonstration pollution prevention projects [LWA, 2001; WERF, 2000]. The costs of several pollution prevention program elements are shown in Table 12. In general it was assumed that a pollution prevention/voluntary program would address dentists, two other business categories and a public education campaign. The program would be conducted on a voluntary basis and would roughly cost the following (based on the costs of pollution prevention programs shown in the Table 12):

- Program for dentists, voluntary - $100,000
- Voluntary BMP based program for other businesses - $50,000
- Public education program - $50,000 for agencies <20 MGD; $100,000 for agencies between 20 and 100 MGD; $150,000 for agencies >100 MGD

The cost associated with a source control/regulatory program factors in costs of each strategy listed. In addition, costs for implementing a program with regulatory elements were considered. Implementing a regulatory or permit-based program is more costly than a voluntary program in that it requires more tracking and paperwork to assess compliance. However, permit based programs for small dischargers (e.g., dentists) do not have to be as resource intensive as standard pretreatment permits. Agencies have implemented general or group permits for small dischargers (e.g., photoprocessors) or have developed permits that have fewer requirements or are BMP-based. It was assumed that a regulatory program for dentists would be twice as costly as a voluntary program and, therefore, would have an annual cost of $200,000.

Treatment costs were determined based on a study conducted by the Sanitation Districts of Los Angeles County (LACSD) for the unit operations directly associated with mercury removal (i.e., reverse osmosis and ion exchange). Waste removal costs were estimated by ADVENT. This results in an annual treatment cost of $1,922,000/ MGD as shown in Table 10.

Table 10. Annual Treatment Costs for Removing Mercury[2]

Unit Process	Total Cost ($ 10^3/MGD)	Reference Source
Reverse Osmosis	876	National Research Council
Ion Exchange	900	Bureau of Reclamation[3]
Brine treatment	146	ADVENT
Total	1922	

These costs were applied to a portion of the total plant flow based on the reduction needed to meet proposed limits after the reductions achieved through pollution prevention were considered. The amount of flow treated was estimated as shown in Table 11.

Table 11. Cost Based on Reduction Needed

Reduction needed	Portion of flow treated	Annual cost multiplied by
>75%	100%	100%
50%-75%	75%	75%
25%-50%	50%	50%
0%-25%	25%	25%

[2] Includes amortized capital and operation and maintenance costs.

[3] *Mercury and Cadmium Fact Sheet*, Bureau of Reclamation, Technical Service Center, Denver, CO, September 1999.

Table 12. Costs of Pollution Prevention Programs

Source	P2 Item	Number in Target Audience	Annual/ Start-up Cost	Source
Dentists	Brochure/ Fact Sheets + distribution	900	$60,000	SFWPPP
	Brochure/ Fact Sheets + distribution	500	$12,000	Palo Alto RWQCP
	Outreach/advisory group	500 dentists	$10,000	Palo Alto RWQCP
	Outreach	100	$30,000	WLSSD
	Site visits	35 visits	$12,000	SFWPPP
Consumer Products	Thermometer exchange program	3.3 million people, 38,000 thermometers	$144,816	Connecticut DEP
	Thermometer exchange program	790,000 people, 5000 thermometers collected	$70,000	SFWPPP
	Thermometer exchange program	227,000 people, 1000 thermometers	$15,000	Palo Alto RWQCP (KM)
	Thermometer Sales ban/ legislation		$15,000	Palo Alto RWQCP
	Root killer sales ban legislation		$30,000	Palo Alto RWQCP (KM)
	HHW Collection facility/event	76 collection events	$ 2,660	Connecticut DEP
Vehicle Service	Site visits/inspections	330 facilities	$20,000	Palo Alto RWQCP (KM)
	Develop permits	330 facilities	$50,000	Palo Alto RWQCP (KM)
	Inspections/BMPs	46 facilities	$50,000	West County
Secondary Schools	Clean-out/ collection of chemicals	8 high schools	$40,000	Connecticut DEP
Non-Hg Sources	Brochure development & printing	50,000 people, 6000 guides	$12,000	Davis healthy gardens
	General public outreach	50,000 people	$40,000	Davis healthy gardens
	Residential outreach	20,000 residents, 1000 packets	$12,000	Woodland O&G
	Business outreach/ recognition program	200 businesses	$20,000	Davis Partners Program
	8 fact sheets/ BMPs, regulatory info	500 businesses	$20,000	Davis Partners Program
	Business workshops (2)	1000 businesses	$27,000	Santa Monica New Development Program
	Brochure/ fact sheets -general		$15-20,000	General depending on size, number, etc.
	Clean Bay Hardware program		$20,000	Palo Alto RWQCP (KM)

Results and Discussion

The results of the analysis are discussed below in the following sections:

- Select Case Studies
- Calculate Load Estimates
- Identify Most Significant Sources
- Estimate Influent Reductions
- Determine Resulting Effluent Concentrations
- Assess Potential Compliance
- Estimate Changes in Biosolids Levels

- Determine Costs Associated with Compliance
- Assess Impact of Assumptions

Select Case Studies

A large quantity of quality information was received from a number POTWs throughout the mercury source control study. However, for the final report, only a few of these agencies were examined more closely. The selection of these final plants was based on four criteria as listed in the Procedure section. First, the quantity of data available for each plant's influent, effluent and biosolids was evaluated. As shown in Table 2, Portland Water District's Portland plant had only one influent sample and with the variability of influent mercury sampling, it was decided not to use Portland for the final calculations. Second, the analytical method used and subsequent detection limit were investigated. As shown in Table 2, Green Bay Municipal Sanitation District (GBMSD), the Massachusetts Water Resources Authority (MWRA) and Western Lake Superior Sanitation District (WLSSD) presently use EPA Method 245.1 for mercury analysis. This method has a higher detection limit than EPA Method 1631 and, due to the variance this causes in influent and effluent concentrations, it is not appropriate to compare plants that use Method 245.1 to those using Method 1631. Only plants using EPA Method 1631 were included in the final calculations with the exception of WLSSD because they use an improved method of 245.1 that has a lower detection limit of 5 ng/L. The third criterion involved a comparison of influent to effluent plus biosolids. Calculating this mass balance was useful for evaluating the consistency of the collected data. Comparisons between influent and effluent plus biosolids were used to identify plants with acceptable mass balance closure. The measured influent load is the product of average flow and average concentration. In addition, "Effluent + Biosolids" was calculated to provide another measure of influent load. The measured influent and effluent plus biosolids loads for each plant are compared in Table 13.

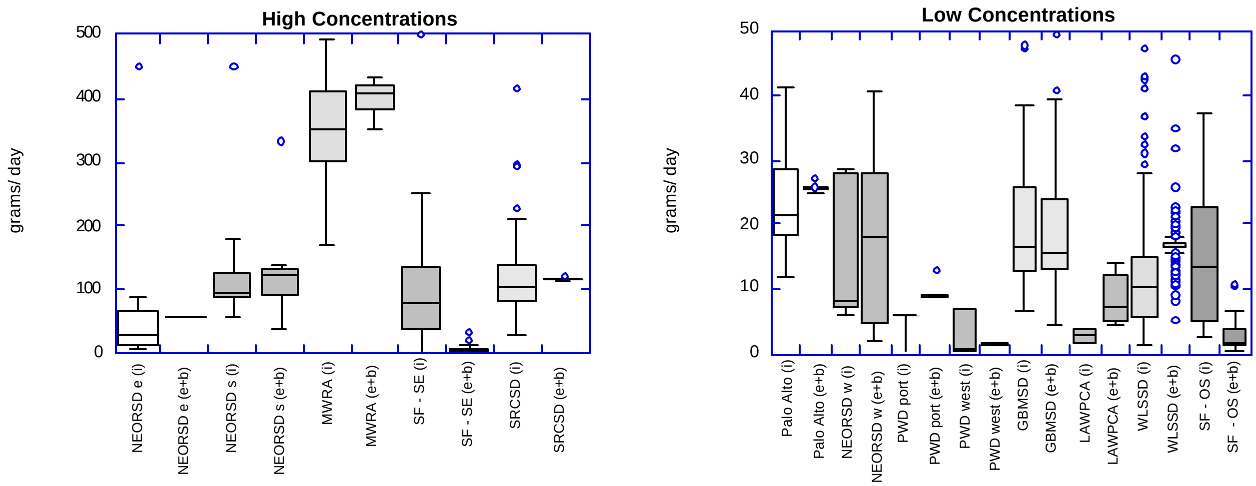
Table 13. POTW Mass Balances

POTW		Community Size	grams Hg / day			
			Effluent	Biosolids	Effluent + Biosolids	Influent
MWRA	MA	2.5 M	42.6	340	383	369
HRSD	VA	1.5 M	0.7	1.37	2.07	110
SRCSD	CA	1.1 M	5.44	113	118	135
NEORSD - Easterly	OH	401,167	1.4	55	56.4	56.3
NEORSD - Southerly	OH	597,936	1.3	124	125.3	134
NEORSD - Westerly	OH	123,170	0.36	16	16.4	13.3
San Francisco - SE	CA	564,744	5.2	<0.323*	5.4	101
San Francisco - OS	CA	224,033	3.4	<0.097*	3.4	15.8
WLSSD	MN	95,000	0.69	16.3	17	15
Palo Alto	CA	226,000	0.555	25.2	26.1	23.2
GBMSD	WI	180,900	0.73	18.9	19.6	10.8
Portland	ME	60,000	0.869	8.47	9.34	6.27
LAWPCA	ME	50,000	0.23	10.15	10.38	3.23
Novato	CA	34,190	0.38	?	?	8.61
Westbrook	ME	15,000	0.066	1.51	1.58	2.67

* 1/2 MDL was used in effluent + biosolids calculation

Box plots were created to show the distribution of influent data as well as effluent plus biosolids data. If the influent (i) and effluent + biosolids (e+b) boxes overlapped, the range of influent values was considered statistically equivalent to the effluent plus biosolids values. Based on the comparison shown in Figure 4, Portland Water District's Portland plant was removed from the list, as well as Lewiston-Auburn Water Pollution Control Agency (LAWPCA) and GBMSD. San Francisco's biosolids data was non-detect for 2000 and therefore did meet the mass balance criteria.

Figure 4. Box Plots of Influent and Effluent + Biosolids



The final criterion evaluated to select the case studies was the availability of all requested information. It was not possible to obtain enough data from Hampton Roads Sanitation District (HRSD) or Novato Sanitation District to make key calculations, therefore they were not included in the final assessment.

Therefore, the plants used as case studies were:

- Northeast Ohio Regional Sewer District, Ohio – Easterly Plant (NEORSD-e)
- Northeast Ohio Regional Sewer District, Ohio – Southerly Plant (NEORSD-s)
- Northeast Ohio Regional Sewer District, Ohio – Westerly Plant (NEORSD-w)
- Palo Alto Regional Water Quality Control Plant, California (Palo Alto)
- Sacramento Regional County Sanitation District, California (SRCSD)
- Portland Water District, Maine – Westbrook Plant (Westbrook)
- Western Lake Superior Sanitary District, Minnesota (WLSSD)

Calculate Load Estimates

Once the case study plants were selected, the next step was to calculate an influent load from the individual source loading contributions. Source loading contributions were determined using the procedure discussed above and the values listed in Appendix B. The estimated influent load for each plant was computed as the sum of the estimated mercury loads from each source. Percent closure estimates were obtained by using the estimated influent concentration as well as the measured effluent and biosolids concentrations and are presented in Table 14. The calculated influent load accounts for a large percentage of the measured influent load, the worst case being SRCSD, where 30% of its influent mercury is unaccounted for. A sample load calculation for one agency is shown in Table 15.

Table 14. Closure of Measured and Estimated Influent Loads

POTW	Flow (mgd)	Estimated Influent Load (g/d)	Measured Influent Load (g/d)	Effluent + Biosolids (g/d)	% closure (Estimated/ Measured)	% closure (Effluent+Biosolids/ Measured)
NEORSD - e	104.1	40.9	56.3	56.4	73%	100%
NEORSD - s	109.5	117.5	133	125	88%	94%
NEORSD - w	31.1	13.1	13.3	16.4	98%	123%
Palo Alto	28	20.1	23.2	25.8	87%	111%
SRCSD	157	88.2	135	118	65%	88%
Westbrook	2.51	2.4	2.7	1.58	90%	58%
WLSSD	39	11.7	15.6	17.0	75%	109%

The estimated mercury loadings were grouped into residential, commercial and industrial contributions as shown in Figure 5. Commercial sources represent the largest percentage of the influent loading, due largely to dental wastewater discharges. As shown in Figure 5, industrial mercury loads represent a relatively small portion of the total influent load.

Figure 5. Estimated Load Closure

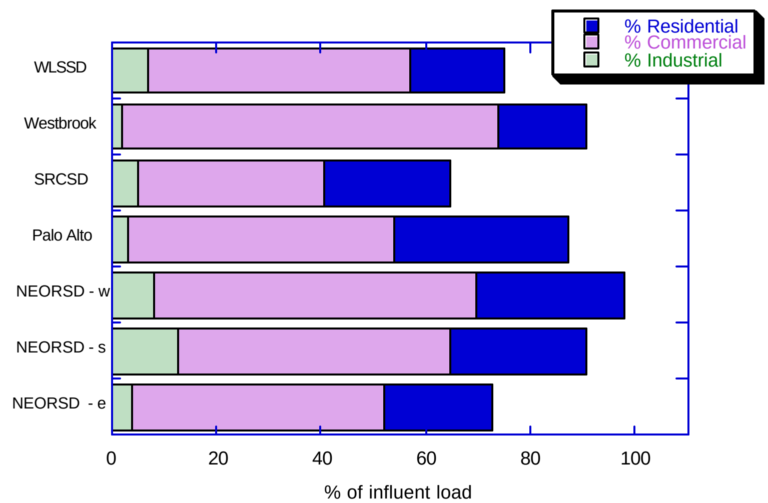


Table 15. Example of Load Estimation from Identified Sources

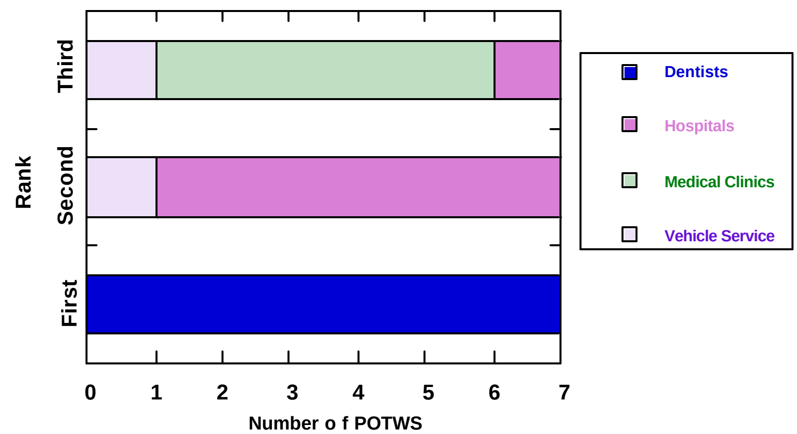
Source	#	Conc	Units	Flow/ Facility	Units	Load	Units	Calculation
Commercial								
Dentists	500	0.056	g/dentist/day			28.00	gm/day	Number of dentists x concentration
Medical Clinics	80	4.3	µg/l	2800	gal/day	3.65	gm/day	Number of medical clinics x flowx concentration
Hospitals	39	4.39	µg/l	120000	gal/day	77.76	gm/day	Number of hospitals x flow x concentration
Laboratories	77	0.37	µg/l	11000	gal/day	1.19	gm/day	flow x concentration x number
Universities		0.17	µg/l	48500	gal/day	0.00	gm/day	flow x concentration x number
Secondary Schools		0.3	µg/l	7000	gal/day	0.00	gm/day	flow x concentration x number
Vehicle Service	1284	1.2	µg/l	500	gal/day	2.92	gm/day	flow x concentration x number
Pottery/ Ceramics Studios	200	0.31	µg/l	168	gal/day	0.04	gm/day	number x flow x concentration
Estimated Commercial Load						113.55	gm/day	
Residential								
Population	1100000			100	gal/person/da y			
Number of Households	326000			168	gal/house/ day			
Human Waste (amalgam)		17.2	µg/person/day			12.30	gm/day	population x concentration x 65% population w/ fillings
Human Waste (dietary)		1.4	µg/person/day			1.54	gm/day	population x concentration
Laundry Graywater		8.4	µg/person/day			9.24	gm/day	population x concentraiton (1 load per person per week)
Household Products		0.021	µg/house/day	1.10E+08	gal/day	8.74	gm/day	residential flow x concentration
Thermometers		2.3	µg/house/day			0.75	gm/day	number of households x 22µg/house/day x 52% of households own hg therm.
Contact Lens Solution		0.044	µg/person/day			0.05	gm/day	popluation x concentration
Estimated Residential Load						32.62	gm/day	
Industrial		0.21	µg/l	8570000	gal/day	6.81	gm/day	
Estimated Influent						152.98	gm/day	
Measured Influent		0.199	µg/l	1.57E+08	gal/day	118.25	gm/day	

Identify Most Significant Sources

The next step was to determine the sources that accounted for the greatest contributions to the influent loading. For the seven plants examined in this study, dentists, hospitals, medical clinics and vehicle service facilities represented the largest commercial mercury sources for each agency. Figure 6 shows the rankings for these top four commercial mercury sources. As the “First” rank exhibits, in all seven plants, dentists are the greatest contributors to the mercury load. The next greatest loading, or “Second” rank, comes from mainly hospitals (6 of 7 plants).

Finally, the third greatest contribution to mercury loading comes from medical clinics for most of the plants, with vehicle service facilities and hospitals also contributing.

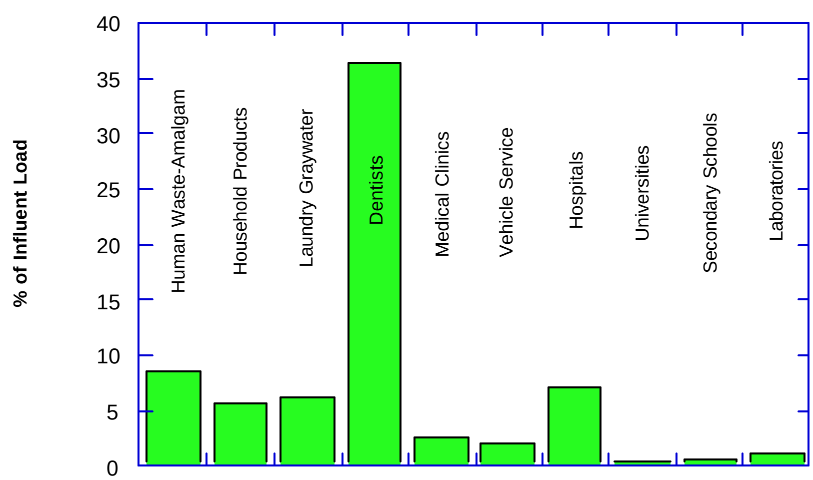
Figure 6. Top Three Commercial Sources



Based on average source contributions identified for each POTW, the largest residential source was human waste due to amalgam fillings for all seven plants. Laundry graywater and household products were the second and third largest sources respectively for all seven plants.

The relative contributions of each of the identified mercury sources are shown in Figure 7. The values shown in Figure 7 are the average percent contributions for the source for all seven plants. Dentists are the largest source by far when compared to average contributions from the other sources. Human waste amalgam and hospitals are the next most significant sources.

Figure 7. Average Source Contributions to Influent Mercury Load



Estimate Influent Reduction

The estimated reduction achievable through pollution prevention was then determined for each plant. Load reductions were calculated using a participation factor, load factor and effectiveness for each identified control strategy as described in the Procedure section above. An example of the reduction estimate calculated for one plant is shown in Table 16.

Table 16. Source Reduction Estimation Example

Source	Estimated Load (gm/day)	Control strategy	Participation Factor	Load Factor	Effective-ness	Load Reduction
Commercial						
Dentists		Voluntary programs				
	1.4	BMPs - Recycle all amalgam wastes	65%	80%	52%	0.7280
	1.4	Amalgam separators	10%	95%	10%	0.1330
	1.4	Stop using amalgam	25%	50%	13%	0.1750
		Permits/regulatory				
	1.4	BMPs - Recycle all amalgam wastes	95%	80%	76%	1.0640
	1.4	Amalgam separators	90%	95%	86%	1.1970
	1.4	Stop using amalgam	90%	50%	45%	0.6300
Hospitals	0.3323	BMPs -Modify purchasing/ disposal practices (voluntary)	50%	60%	30%	0.0997
Laboratories	0.0154	BMPs -Modify purchasing/ disposal practices (voluntary)	50%	60%	30%	0.0046
Universities	0.0000	BMPs -Modify purchasing/ disposal practices (voluntary)	50%	60%	30%	0.0000
Secondary Schools	0.0477	BMPs -Modify purchasing/ disposal practices (voluntary)	50%	60%	30%	0.0143
Medical Clinics	0.0911	BMPs -Modify purchasing/ disposal practices (voluntary)	50%	60%	30%	0.0273
Vehicle Service	0.0545	BMPs / Zero discharge	50%	80%	40%	0.0218
Pottery Ceramics	0.0004	BMPs -Modify purchasing/ disposal practices (voluntary)	50%	60%	30%	0.0001
Commercial Total	1.9414					
Residential						
Human Waste-amalgam	0.1677	Remove amalgam fillings	2%	100%	2%	0.0034
Human Waste-dietary	0.0210	uncontrollable				0.0000
Laundry Graywater	0.1260	graywater systems	2%	100%	2%	0.0025
Household products	0.1192	Substitute alternatatives	10%	100%	10%	0.0119
	0.1192	HHW collection	13%	100%	13%	0.0155
Thermometers	0.0112	Turn in Hg thermometers - low	1%	100%	1%	0.0001
	0.0112	Work w/ pharmacies to not sell	50%	100%	50%	0.0056
	0.0112	local sales ban	90%	100%	90%	0.0100
Contact Lens Solution	0.0007	Work w/ pharmacies to not sell	50%	100%	50%	0.0003
	0.0007	local sales ban	90%	100%	90%	0.0006
Residential Total	0.4457					
Industrial	0.0480	BMPs	90%	90%	81%	0.0389
Total Estimated Load	2.4352				Max Reduction	1.4203
Average Influent Load	1.5771				Realistic Reduction	0.9065

Using this table it was possible to develop two reduction estimates, one for pollution prevention/ voluntary programs and another for source control (semi-regulatory) programs, as discussed previously. The pollution prevention (voluntary) reduction estimates included reduction strategies for the top three residential sources, top two commercial sources, and industrial sources. Human waste is considered uncontrollable, except to the extent that less amalgam filling are placed by dentists. For commercial sources, dentists were the major commercial contributors to the influent load for every agency. The pollution prevention (voluntary) reduction strategy used for dentists was to encourage BMPs or require amalgam separators for agencies that had tried BMPs. The source control method of estimating mercury reduction assumes that control strategies are implemented for all commercial, residential and industrial sources and that dentists have a regulatory program. The subsequent pollution prevention and source control percent reductions for each agency can be found in Table 17. The average pollution prevention reduction is 26% while the average source control reduction is 37%.

Table 17. Pollution Prevention and Source Control Reduction

POTW	Flow (mgd)	Measured Influent Load (g/d)	% Reduction **Pollution Prevention**	% Reduction **Source Control**
NEORSD - e	104.1	56.3	24%	39%
NEORSD - s	109.5	133	20%	29%
NEORSD - w	31.1	13.3	29%	44%
Palo Alto	28	23.2	14%	14%
SRCSD	157	135	23%	32%
Westbrook	2.51	2.7	58%	90%
WLSSD	39	15.6	12%	12%

The estimated reductions for Palo Alto and WLSSD are low because these agencies have mature pollution prevention programs and have implemented many of the strategies listed in Table 12. Therefore, few additional reduction opportunities exist in their service areas.

Estimate Resulting Effluent Concentrations

After estimating the reduction of mercury in each plant's influent, resulting effluent concentrations were calculated using each plant's average reported removal efficiency. As mentioned previously, this is an optimistic assumption because as influent concentrations get lower it is likely that removal efficiencies decrease as well. Tables 18 and 19 report the reduced influent and effluent concentrations for the pollution prevention and source control programs, respectively. They also provide a comparison of the reduced effluent concentrations ("*Pollution Prevention/Source Control Reduced Ave. Effluent*") to the effluent concentrations prior to source control ("*Ave. Unreduced Effluent*").

Table 18. Resulting Concentrations Using Pollution Prevention/Voluntary Estimates

POTW	Flow (mgd)	Ave. Measured Effluent + Biosolids (ppt)	Pollution Prevention Reduced Influent (ppt)	Ave. Plant Removal Efficiency	Pollution Prevention Reduced Ave. Effluent (ppt)	Ave. Unreduced Effluent (ppt)
NEORSD - e	104.1	143	108	97%	3.25	3.56
NEORSD - s	109.5	302	209	99%	2.09	3.17
NEORSD - w	31.1	139	98.1	97%	2.94	3.11
Palo Alto	28	246	212	97%	5.32	5.50
SRCSD	157	199	154	96%	6.17	9.00
Westbrook	2.51	166	70.4	98%	1.41	6.90
WLSSD	39	115	102	96%	4.07	4.70

Table 19. Resulting Concentrations Using Source Control/Regulatory Estimates

POTW	Flow (mgd)	Ave. Measured Effluent + Biosolids (ppt)	Source Control Reduced Influent (ppt)	Ave. Plant Removal Efficiency	Source Control Reduced Ave. Effluent (ppt)	Ave. Unreduced Effluent (ppt)
NEORSD - e	104.1	143	87.8	97%	2.63	3.56
NEORSD - s	109.5	302	162	99%	1.62	3.17
NEORSD - w	31.1	139	78.5	97%	2.35	3.11
Palo Alto	28	246	211	97%	5.29	5.50
SRCSD	157	199	135	96%	5.39	9.00
Westbrook	2.51	166	16.3	98%	0.33	6.90
WLSSD	39	115	102	96%	4.06	4.70

Assess Potential Compliance

Using the reduced effluent concentrations it was possible to compare the new, reduced concentrations to the range of mercury criteria. Tables 20 and 21 list the number of plants (out of 7) that meet the mercury criteria based on no pollution prevention, pollution prevention/voluntary and source control/regulatory. Using average effluent concentrations, all agencies meet the 18 ppt criteria (and the 50% margin of error value, 9 ppt; see below for discussion) before any pollution prevention or source control is implemented. Pollution prevention and source control help one agency meet the 7.8 ppt criteria. Source control/regulatory also helps one agency meet the 1.3 ppt effluent criteria. None of the agencies are able to meet the 0.2 ppt criteria with pollution prevention or source control alone. Basing compliance on reductions achieved compared to maximum effluent concentrations for each plant, only 4 plants have maximum effluent levels prior to source control or pollution prevention that meet the 18 ppt criteria. Pollution prevention helps one agency and source control helps two agencies comply with the 18 ppt criteria. Both programs help two agencies comply with the 7.8 ppt criteria. No agencies are able to meet the 1.3 ppt or 0.2 ppt criteria when maximum effluent concentrations are considered.

Some of the reduced effluent concentrations are very close to the criteria used for evaluation as shown in Tables 20 and 21. It is important to recognize that plants do not operate to *just* meet criteria, there must be a safety factor. Effluent mercury levels resulting from reductions achieved through source control and pollution prevention are based on average values. Plants would be more likely to operate within a margin of safety to assure compliance. In some parts of the country, NPDES permit effluent limits are implemented as values never to be exceeded. Even one violation may result in stiff fines and other penalties. Therefore, plants designed to comply with these regulations are designed with margins of safety that will assure compliance at least 99.9% of the time (corresponding to an exceedance once in three years)(Tschobanoglous, 2001). A less extreme approximation of the need to operate with a margin of safety to assure compliance is to assume that a plant would operate with a 50% margin of safety. Therefore, in addition to the number of plants meeting a criteria by comparing effluent values directly to water quality criteria in Tables 20 and 21, effluent levels are compared to values set at half the criteria. The second column of each set shows the number of agencies meeting a mercury level set at half the criteria to account for a 50% margin of safety.

Table 20. Number of Agencies Meeting Criteria and 50% Factor of Safety Based on Average Effluent Concentrations (Out of 7)

Criteria	18 ppt	9 ppt	7.8 ppt	3.9 ppt	1.3 ppt	0.65 ppt	0.2 ppt	0.1 ppt
No Program	7	7	6	3	0	0	0	0
Pollution Prevention	7	7	7	4	0	0	0	0
Source Control	7	7	7	4	1	1	0	0

Table 21. Number of Agencies Meeting Criteria and 50% Factor of Safety Based on Maximum Effluent Concentrations (Out of 7)

Criteria	18 ppt	9 ppt	7.8 ppt	3.9 ppt	1.3 ppt	0.65 ppt	0.2 ppt	0.1 ppt
No Program	4	2	2	0	0	0	0	0
Pollution Prevention	5	4	4	1	0	0	0	0
Source Control	6	4	4	2	0	0	0	0

Estimate Changes in Biosolids Mercury Levels

The biosolids concentrations after pollution prevention or source control were calculated using the resulting influent and effluent concentrations (influent – effluent = biosolids). Table 22 shows the change in biosolids mercury levels from no pollution prevention to pollution prevention to source control. Pollution prevention and source control are able to reduce concentrations of mercury in biosolids by 11 – 90 %. It is possible that even more biosolids mercury reduction may be achieved as a result of pollution prevention and source control if the implemented practices reduce substantially the amount of particulate and solid materials discharged. Since particulate mercury that reaches the plant influent is more likely to end up in the biosolids than in the effluent.

Table 22. Estimated Biosolids Mercury Levels

POTW	Biosolids Concentration (grams/day)		
	No P2	Pollution Prevention	Source Control
NEORSD - e	55.0	41.4	33.5
NEORSD - s	124	85.6	66.5
NEORSD - w	16.0	11.2	8.97
Palo Alto	25.2	21.9	21.8
SRCSD	113	87.9	76.8
Westbrook	1.51	0.66	0.15
WLSSD	16.3	14.4	14.4

Determine Costs Associated with Compliance

The potential cost associated with compliance for each plant was determined as follows. The reduction needed to achieve an effluent level of 1.3 ppt was determined based on the maximum observed effluent concentration for each plant. The cost to achieve the estimated reduction was determined using the cost estimates for pollution prevention and source control programs described in the Procedure section. Any additional reduction needed to meet 1.3 ppt was assumed to be accomplished through additional treatment, the cost of which was estimated as described in the Procedure section. The resulting cost calculations are shown in Tables 23 and 24.

Table 23. Pollution Prevention Using Maximum Effluent Concentrations for Cost Calculations

POTW	Ave. Op. Size (MGD)	Max Eff. (ppt)	Reduction to achieve 1.3 ppt	Reduction thru Pollution Prevention	Reduction thru Treatment after Pollution Prevention	Annual Pollution Prevention Cost ($1000)	Annual Treatment Cost ($1000) – With Pollution Prevention	Annual Treatment Cost ($1000) – No Pollution Prevention
NEORSD-E	104.07	9.54	86%	24.3%	62.1%	$350	$ 150,017	$ 200,023
NEORSD-S	109.49	5.84	78%	19.6%	58.1%	$350	$ 157,830	$ 210,440
NEORSD-W	31.07	5.03	74%	29.4%	44.7%	$300	$ 29,858	$ 44,787
Palo Alto	28	18.3	93%	13.8%	79.1%	$250	$ 53,816	$ 53,816
SRCSD	157	24.9	95%	22.5%	72.2%	$350	$ 226,316	$ 301,754
Westbrook	2.51	16.9	92%	57.5%	34.8%	$250	$ 2,412	$ 4,824
WLSSD	39	29	96%	11.5%	84.0%	$300	$ 74,958	$ 74,958

Table 24. Source Control Using Maximum Effluent Concentrations for Cost Calculations

POTW	Ave. Op. Size (MGD)	Max Eff. (ppt)	Reduction to achieve 1.3 ppt	Reduction thru Source Control	Reduction thru Treatment after Source Control	Annual Source Control Cost ($1000)	Annual Treatment Cost ($1000) - with Source Control	Annual Treatment Cost ($1000) - No P2
NEORSD-E	104.07	9.54	86%	38.6%	47.8%	$700	$ 100,011	$ 200,023
NEORSD-S	109.49	5.84	78%	28.9%	48.9%	$700	$ 105,220	$ 210,440
NEORSD-W	31.07	5.03	74%	43.5%	30.6%	$600	$ 29,858	$ 44,787
Palo Alto	28	18.3	93%	14.3%	78.6%	$300	$ 53,816	$ 53,816
SRCSD	157	24.9	95%	32.3%	62.4%	$600	$ 226,316	$ 301,754
Westbrook	2.51	16.9	92%	90.1%	2.2%	$550	$ 1,206	$ 4,824
WLSSD	39	29	96%	11.7%	83.9%	$450	$ 74,958	$ 74,958

Sensitivity Analysis

The impacts of the assumptions made in the above analysis were assessed in several ways. One approach was to vary the load values used for human waste and dental discharges to evaluate the impact of these numbers on the results. Subsequent sections provide details on the impacts of varying the school loading contribution and how a probability-based model was used to assess the impacts of the assumptions.

Variation of Dental Discharge and Human Waste Values

The impact of the load values used for dental and human waste estimates was assessed as follows. Dental values were varied from 0.035 – 0.15 g/dentist/day to encompass the range of dental values found in the literature. Similarly, human waste values were varied from 11 – 43.6 µg/person/day. The cases examined are shown in Table 25.

Table 25. Scenarios used to test dental and human waste assumptions

Dental Discharge Estimate (g/dentist/day)	Human Waste Amalgam Estimate (µg /person/day)
0.056*	17.2*
0.035	11
0.035	43.6
0.15	11
0.15	43.6

*Base case

These values were carried through the reduction calculations to see the impact of using each of these scenarios on mass balance closure, influent reduction, effluent concentration, compliance and cost. Except for the mass balance closures, the values for human waste did not affect the calculation. Trends associated with varying these values were the same for the pollution prevention scenario and the source control scenario. Table 26 shows selected results for the pollution prevention scenario. More detailed results can be found in Appendix D.

Mass balance closures ranged from 96% to 192% when the high dental discharge number was used (i.e., 0.15 g/dentist/day). Using the 0.035/11 scenario resulted in low mass balance closures ranging from 56.5% to 77%. The mass balances that stayed closest to 100% closure were for the base case and the 0.035/43.6 scenario.

Estimated influent reductions ranged from a low of 7% to greater than 100% reduction. Reductions corresponded to the dental value used with much higher reductions seen when the 0.15 value was used. Reductions exceeding 100% were only seen when the high dental value was used. Similarly, variation in resulting influent and effluent concentrations also corresponded to the dental value used. In some cases, the use of the 0.15 g/dentist/day resulted in negative influent and effluent concentrations.

Compliance assessments were not impacted significantly by the scenarios. However, compliance did result slightly more often in the cases where 0.15 g/dentist/day was used as the assumed dental loading.

Treatment costs varied only slightly from case to case. The assumptions only had significant impact in those situations where no treatment was needed to achieve compliance. It should be noted that for 4 of the 6 situations where no treatment was necessary, the estimated effluent concentration was less than zero.

Figure 8 compares the average relative loadings from different sources for the different scenarios. Dentists were the largest source in every case, regardless of the loading values used. However, the percent of influent load attributed to dentists varied from approximately 25% to over 100%, depending on the value used for dentists. The final value used for this study resulted in dentists contributing on average 35% of the influent load. This seems plausible in that dentists are determined to be the main contributor to influent loading of mercury without the estimate being greater than 100% of influent mercury. Human waste contribution did not vary greatly between scenarios. Average contribution to influent loading ranged from 8 – 18%, depending on the value used for human waste loading. The final value used accounted for on average 13% of influent loading.

Table 26. Results of Varying the Dental and Human Waste Values (g/dentist/day, µg /person/day)

Percent Closure (Estimated / Measured)

POTW	0.056, 17.2	0.035, 11	0.035, 43.6	0.15, 11	0.15, 43.6
NEORSD-e	73%	56.5%	71.6%	129%	145%
NEORSD-s	88%	70.3%	88.5%	158%	177%
NEORSD-w	98%	77.2%	97.0%	172%	192%
Palo Alto	87%	66.1%	93.0%	150%	177%
SRCSD	65%	54.2%	71.5%	96.8%	114%
Westbrook	90%	68.5%	80.3%	175%	187%
WLSSD	75%	58.8%	71.7%	132%	145%

Table 26. (cont'd.)

Percent Reduction due to Pollution Prevention/Voluntary

POTW	0.056, 17.2	0.035, 11/43.6	0.15, 11/43.6
NEORSD-e	24%	17%	55%
NEORSD-s	20%	15%	41%
NEORSD-w	29%	22%	62%
Palo Alto	14%	9%	34%
SRCSD	23%	18%	43%
Westbrook	58%	40%	135%
WLSSD	12%	7%	30%

Reduced Effluent Concentration due to Pollution Prevention/Voluntary (ppt)

POTW	0.056, 17.2	0.035, 11/43.6	0.15, 11/43.6
NEORSD-e	3.25	3.54	1.92
NEORSD-s	2.09	2.32	1.05
NEORSD-w	2.94	3.25	1.57
Palo Alto	5.32	5.61	4.06
SRCSD	6.17	6.53	4.52
Westbrook	1.41	1.98	-1.16
WLSSD	4.07	4.26	3.22

Number of Agencies Meeting 6 ppt Criteria Based on Average Effluent

POTW	0.056, 17.2	0.035, 11/43.6	0.15, 11/43.6
Nothing	5	5	5
Pollution Prevention	6	6	7
Source Control	7	7	7

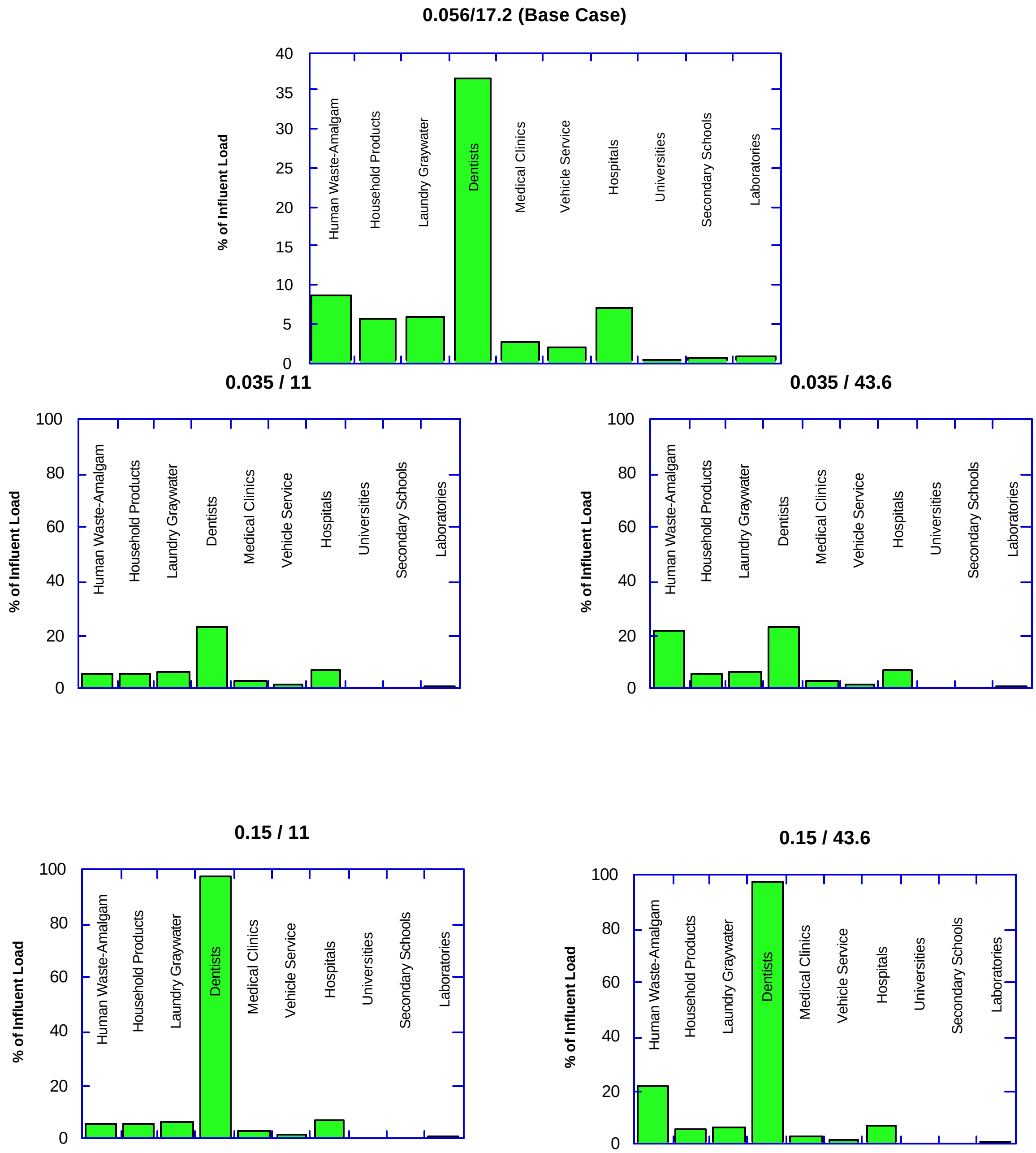
Number of Agencies Meeting 1.3 ppt Criteria Based on Average Effluent

POTW	0.056, 17.2	0.035, 11/43.6	0.15, 11/43.6
Nothing	0	0	0
Pollution Prevention	0	0	2
Source Control	1	1	4

Annual Treatment Costs With Pollution Prevention/Voluntary Maximum Effluent ($1000)

POTW	0.056, 17.2	0.035, 11/43.6	0.15, 11/43.6
NEORSD-e	$ 150,017	$ 150,017	$ 100,011
NEORSD-s	$ 157,830	$ 157,830	$ 105,220
NEORSD-w	$ 29,858	$ 44,787	$ 14,929
Palo Alto	$ 53,816	$ 53,816	$ 40,362
SRCSD	$ 226,316	$ 226,316	$ 0
Westbrook	$ 2,412	$ 4,824	$ 3,618
WLSSD	$ 74,958	$ 74,958	$ 56,219

Figure 8. Average Relative Contributions of Mercury Sources (g/dentist/day, µg /person/day)



Influence of Secondary School Values

It has been suggested that secondary schools may release as much mercury as hospitals, even though the limited data available for this study showed schools to release approximately 0.3 g/day to the sewers. Increasing the value used for schools in the loading calculations to be the same as the hospital value (4.39 g/day) produced an average change in secondary school contribution to influent loading from 0.48% to 7.00%. The percent contribution to influent loading from commercial sources did not change drastically with the increased loading from schools (Table 27). However, when examining the top three sources of mercury for each plant, secondary schools changed the distribution significantly (Figure 9). In the original calculations, secondary schools were not in the top three commercial sources of mercury, only dentists, hospitals, medical clinics and vehicle service stations contributed. When the increased loading from secondary schools was introduced, the hospital and medical clinic influence decreased as secondary schools were the second biggest source in 3 of 7 plants and the third biggest source in 2 of 7 plants. The change in maximum reduction possible (source control reduction) upon using the higher number for schools was not significant enough to change the number of plants able to meet water quality criteria using source control and pollution prevention except at Westbrook (Table 28). The change in criteria met at Westbrook is not necessarily a true representation due to the fact that source control reduction (with schools at 4.39 g/day) is 103%. This produces a less than zero grams/day influent concentration.

Table 27. Estimated Percent Contribution to Influent Loading from Commercial Sources

POTW	Schools = 0.3 g/day	Schools = 4.39 g/day
NEORSD-e	48%	52%
NEORSD-s	27%	29%
NEORSD-w	62%	65%
Palo Alto	51%	57%
SRCSD	36%	36%
Westbrook	72%	96%
WLSSD	50%	57%

Figure 9. Change in Top Three Commercial Sources

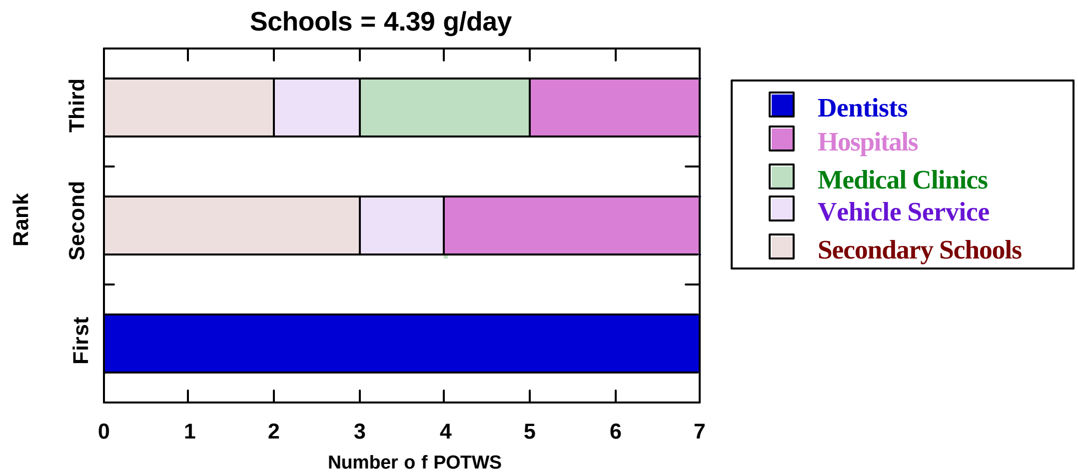
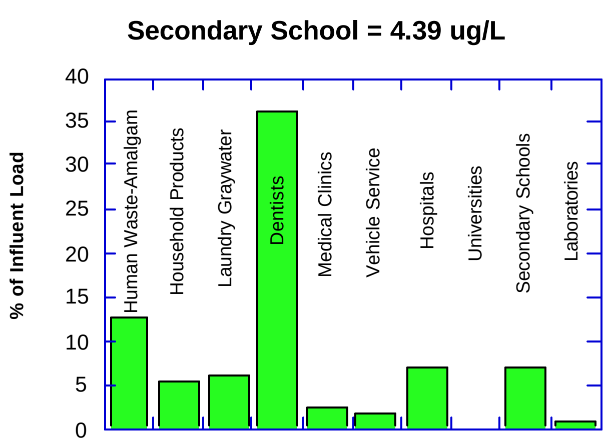


Table 28. Change in Source Control/Regulatory Reduction (g/day) Based on Varying Secondary School Influent Mercury Concentrations

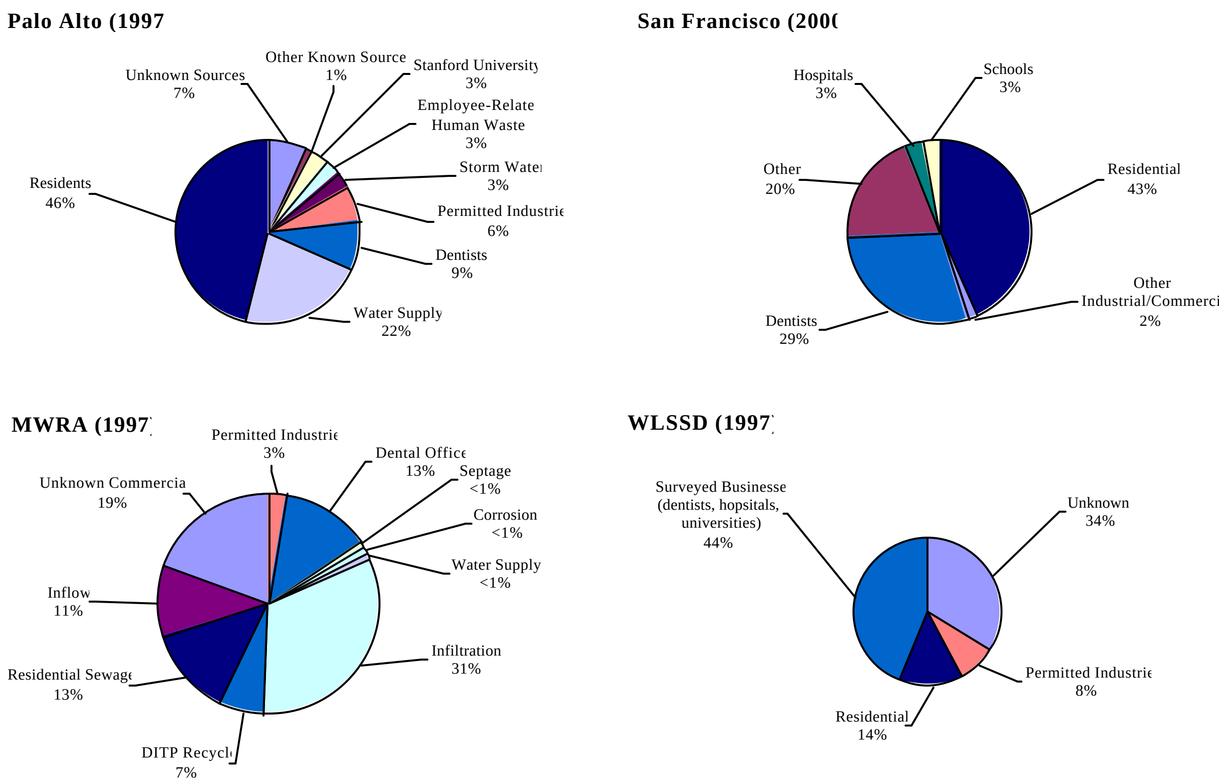
POTW	Schools = 0.3 g/day	Lowest Effluent Criteria Met	Schools = 4.39 g/day	Lowest Effluent Criteria Met
NEORSD-e	21.8	7.8	22.5	7.8
NEORSD-s	36.0	7.8	36.8	7.8
NEORSD-w	7.1	7.8	7.2	7.8
Palo Alto	3.7	7.8	3.7	7.8
SRCSD	38.4	7.8	39.4	7.8
Westbrook	1.4	1.3	1.6	0.2
WLSSD	2.0	7.8	2.3	7.8

Figure 10. Elevated Secondary School Value



A few wastewater treatment authorities have attempted to identify their most significant sources of mercury in treatment plant influent separately from this study. Their estimated source loading breakdowns are shown in Figure 11 for comparison. Please note that these source loading estimates are just a few examples of the potential variation from plant to plant.

Figure 11. Influent Mercury Source Pies



Probability-Based Model

The impact of the assumptions made for the analysis were also assessed by estimating uncertainty and confidence limits for mercury reductions in influent and effluent through implementation of different mercury reduction strategies.

Probability-based modeling procedures were applied to the reduction estimates previously developed. The basic calculation of loads, load reductions, and influent and effluent concentrations were performed as described previously in this report. Loading values for specific mercury sources were the same as described previously, unless noted. Confidence limits for mercury concentrations and percent reductions in influent and effluent were estimated by incorporating variability for the following values in the reduction model:

- Dental loads. Variance in mean mercury concentrations from dentists is estimated by resampling (i.e., using randomly selected values from the entire data set for each iteration of the calculation) the distribution of mean mercury loads (g/dentist/day) for all dentists sampled in the SF 1992, SF 1993, NEORSD 1997, and SF 2000 studies.

- Participation factors. Variance in participation for each control strategy (e.g., BMP implementation) is estimated based on survey results where available (e.g., dental practices survey) and the number of sources in each agency. The variable participation for a control strategy is combined with the fixed estimate of mercury load reduction associated with implementing each specific control strategy to provide the total reduction in mercury loads.
- Average influent and effluent concentrations. Variance of 12-month average influent and effluent mercury concentrations is estimated by resampling the available monitoring data for each agency. A comparison between the monitoring data and the model values for influent and effluent concentrations is shown in Figures 12 and 13.
- Treatment plant removal efficiency. The probability based model accounted for the relationship between influent concentration and removal efficiency. This relationship is shown in Figure 14. Variance in mercury removal efficiency for each agency is based on an analysis of covariance (ANCOVA) model of influent and effluent data for all 7 agencies. The variance is estimated as the standard deviation of the residuals of the ANCOVA model. The data used to model these parameters is summarized in Table 29.

The mercury reduction model was run for 500 iterations for each agency and mercury reduction scenario (i.e., pollution prevention and source control program implementation). The influent and effluent mercury concentrations and percent reductions are recorded for each iteration, and the resulting data represent the distribution of mean estimates for each result. Confidence limits (95% CL) for each estimate are calculated as the 0.025th and 0.975th percentiles of the set of estimates. The accuracy of the model and adequacy of the input data are assessed by comparing the effluent and influent concentrations from the model to the distribution of 12-month averages estimated from monitoring data for each agency. A summary of the model is provided in Table 29.

Results

The following results are provided in Appendix E for each agency and mercury reduction strategy. An example is shown in Table 30.

- Estimates of mean mercury concentrations in influent and effluent, based on the source load model and monitoring data, with 95% CL; and
- Estimates of mean reductions in mercury concentrations (and loads) in influent and effluent with 95% CL, based on the source load model.

A comparison of influent mercury levels predicted by the model before and after pollution prevention program implementation is shown in Figure 15. A comparison of effluent mercury levels predicted by the model before and after pollution prevention program implementation is shown in Figure 16. Results for the source control program showed similar variations. Mean values predicted by the model for each agency are summarized in Table 31. Average effluent reductions predicted by the model are lower than reductions calculated as part of the analysis because the model accounted for the relationship between influent concentration and plant removal efficiency. As can be seen in the figures, the results predicted by the model give a wide range of values for resulting effluent concentrations because of the variability of the data used to develop the model.

Table 29. Summary of Probability-Based Modeling of Mercury Reductions Achievable Through Pollution Prevention and Source Control Strategies

	Pre-Pollution Prevention/Source Control Implementation		Post-Pollution Prevention Implementation		Post-Source Control Implementation	
SOURCE LOADS	Fixed Estimate	Resample Estimate	Fixed Estimate	Resample Estimate (3)	Fixed Estimate	Resample Estimate (3)
Dentists		X		X		X
Medical Clinics	X		(2)	(2)		X
Vehicle Service		X	(2)	(2)		X
Hospitals		X	(2)	(2)		X
Universities	X		(2)	(2)		X
Human Waste, Amalgam	X		X			X
Human Waste, Dietary	X		X			X
Laundry Graywater	X		X			X
Household Products	X		X			X
Thermometers	X		X			X
Contact Lens Solution	X		X			X
Industrial	(4)		(4)		(4)	

(1) Can be calculated as resampled estimate based on monitoring data.

(2) BMP reductions implemented only for 3 largest commercial sources for each agency.

(3) Post-BMP loads based on fixed percent reduction and variable participation in BMPs.

(4) Assumed that BMPs for Industrial Hg reduction already implemented for all scenarios.

INFLUENT DATA	Model Estimate	Monitoring Data
Influent Load	Calculation: • Hg Source Loads	Not Estimated
Avg. Hg Concentration	Calculation: • Hg Loads ÷ Mean Plant Discharge	Resampled 12-month avg. for compariso to modeled estimates
Percent Hg Reduction	Calculation with Model estimates: 100% x ($Hg_{Post-BMP}$ - $Hg_{Pre-BMP}$) ÷ $Hg_{Pre-BMP}$	

Treatment Efficiency (% Removal)	Regression Model with random error; adjusted for each agency: $Ln(1\text{-}\%Removal) = b_{Intercept} + Ln[Hg_{Inf}] \bullet m + b_{plant} + Error_{St.Dev,}$

EFFLUENT DATA	Model Estimate	Monitoring Data
Avg. Hg Concentration	Calculation: Influent Hg x (1 - % removal)	Resampled 12-month avg. for compariso to modeled estimates
Avg. Percent Hg Reduction	Calculation with Model estimates: (Post-BMP [Hg} - Pre-BMP [Hg]) ÷ Pre-BMP [Hg]	

Table 30. Results of Probability-Based Modeling of Mercury Reductions Achievable Through Pollution Prevention and Source Control BMP Implementation Strategies: SRCSD.

	12-Sample Mean Influent Hg, ng/L				%Reduction		12-Sample Mean Effluent Hg, ng/L				%Reduction	
	Monitoring Data (1)	Load Model, Pre-P2/SC	Load Model, P2	Load Model, SC	P2 Program	SC Program	Monitoring Data (1)	Load Model, Pre-P2/SC	Load Model, P2	Load Model, SC	P2 Program	SC Program
Count	500	500	500	500	500	500	500	500	500	500	500	500
Average	198	245	180	174	26.4%	32.6%	8.7	9.7	9.4	9.0	2.4%	3.1%
SE	28.4	30.5	23.5	23.3	4.2%	4.2%	0.6	5.2	5.1	4.4	0.4%	0.5%
LL95	149.7	189.2	138.2	134.3	18.4%	24.6%	7.5	3.2	3.1	3.2	1.6%	2.2%
Median	193.5	243.9	178.5	170.5	26.5%	32.7%	8.6	8.5	8.3	8.0	2.4%	3.1%
UL95	263.8	305.7	227.4	225.6	34.1%	40.3%	10.0	22.4	21.9	19.5	3.3%	4.0%
Min	117.9	156.9	123.1	112.4	15.2%	21.7%	7.1	2.4	2.4	1.7	1.3%	1.9%
Max	303.8	331.4	259.0	250.2	36.3%	44.1%	11.1	40.3	39.5	31.7	3.5%	4.6%

(1) Estimated from resampled monitoring data distribution.
P2 = Pollution Prevention
SC = Source Control

Figure 12. Influent Levels Based on Monitoring Data and Load Model

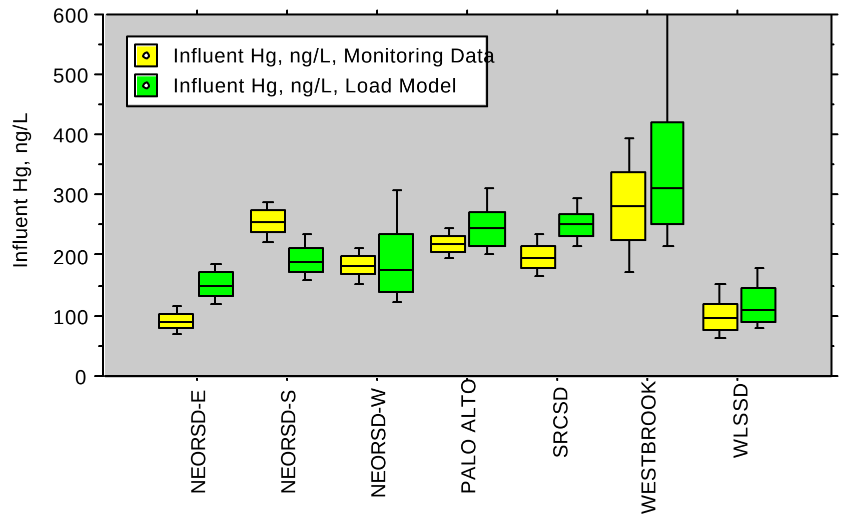


Figure 13. Effluent Levels Based on Monitoring Data and Load Model

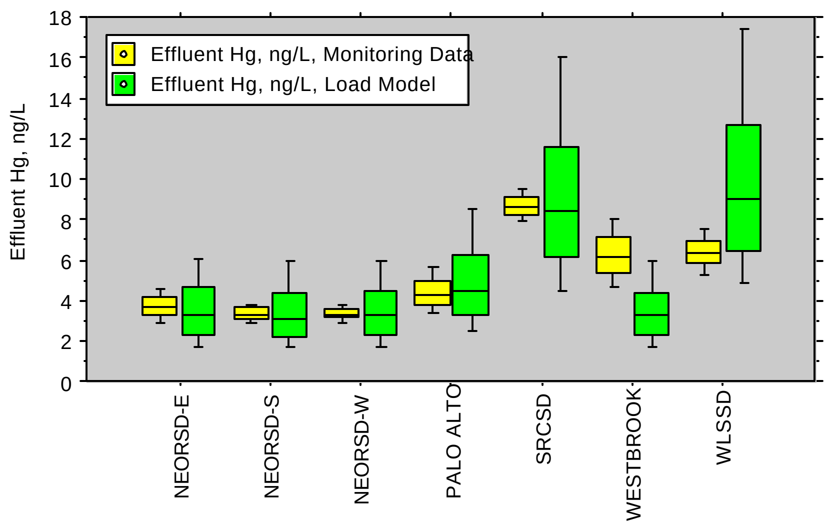


Figure 14. Influent Concentration and Removal Efficiency

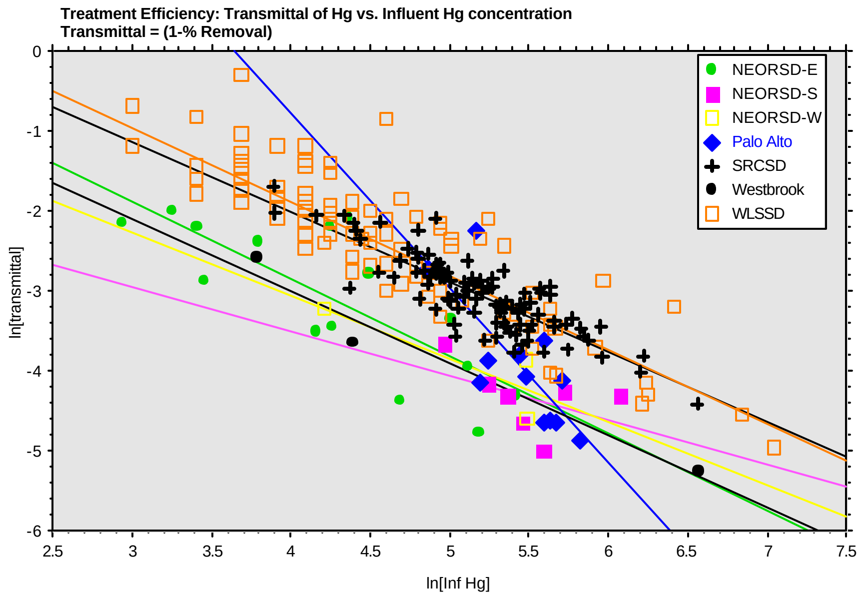


Figure 15. Influent Reduction Resulting from Pollution Prevention Implementation

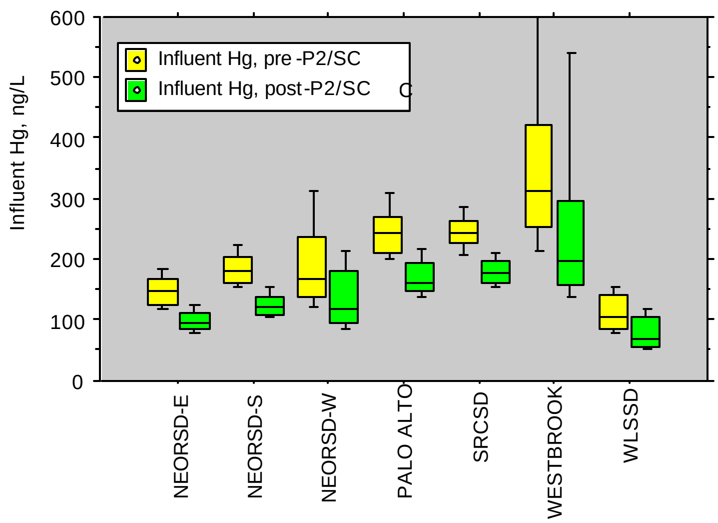


Figure 16. Effluent Reduction Resulting from Pollution Prevention Implementation

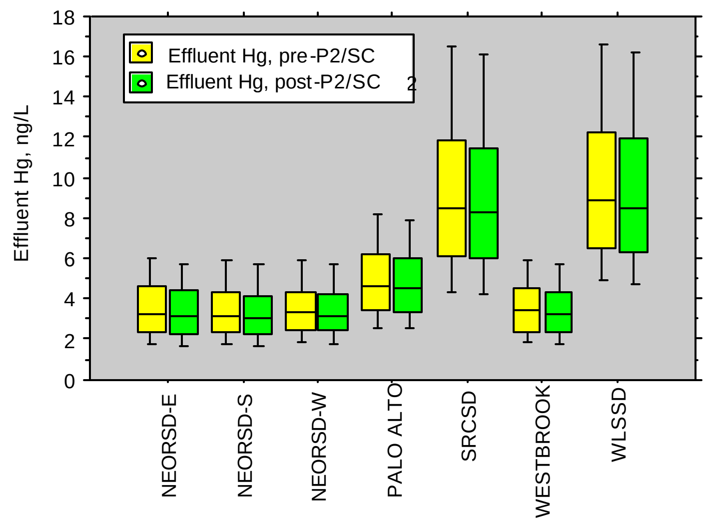


Table 31. Average Concentrations and Reductions Predicted by Model

Post-Pollution Prevention(voluntary) Influent and Effluent Qualit

	Mean Influent, ng/L	Percent Reduction	Mean Effluent, ng/L	Percent Reduction
NEORSD-E	145.9	33.0%	3.1	3.2%
NEORSD-S	181.3	31.5%	3.0	3.0%
NEORSD-W	167.7	28.9%	3.2	2.7%
Palo Alto	244.1	30.3%	4.5	2.8%
SRCSD	243.9	26.5%	8.3	2.4%
Westbrook	313.8	35.9%	3.3	3.5%
WLSSD	101.5	32.6%	8.5	3.1%

Post-Source Control (regulatory) Influent and Effluent Quality

	Mean Influent, ng/L	Percent Reduction	Mean Effluent, ng/L	Percent Reduction
NEORSD-E	92.7	41.3%	3.2	4.2%
NEORSD-S	117.5	41.3%	3.0	4.2%
NEORSD-W	104.2	43.2%	3.0	4.4%
Palo Alto	136.1	43.1%	4.2	4.4%
SRCSD	170.5	32.7%	8.0	3.1%
Westbrook	131.1	54.5%	2.9	6.1%
WLSSD	68.9	39.4%	8.8	3.9%

Findings

The purpose of this project was to determine if pollution prevention and/or source control programs have the potential to achieve the reductions necessary to enable POTWs to comply with current and proposed NPDES permit effluent limits for mercury. The analysis conducted was based on the use of existing data. However, a variety of assumptions were necessary to apply the collected data to the POTWs used as case studies. As a result, this analysis has certain limitations. The findings regarding the effectiveness of mercury pollution prevention programs, assessment of potential compliance, the impact of the assumptions made, and limitations of the analysis are discussed below.

Effectiveness of Mercury Pollution Prevention and Source Control Programs

The effectiveness of mercury pollution prevention and source control programs may be considered with respect to the direct benefit of achieving reductions in wastewater influent. Mercury pollution prevention and source control programs may also achieve significant reductions to other waste streams resulting in overall reductions of mercury entering the environment. The benefits to other environmental media were not evaluated quantitatively in this study but several reduction opportunities were identified. Effectiveness with respect to wastewater reductions and benefits to other media are discussed below.

Potential for Wastewater Reductions

Using the basic scenario described in this report (i.e., setting dental discharges at 0.056 g/dentist/day and human waste from amalgam at 17 µg/person day), the results of the analysis described above indicate the following about wastewater mercury pollution prevention programs.

Influent load reductions for mercury achievable through pollution prevention activities for the POTW case studies on average ranged from 12% to 90% depending on the agency's existing pollution prevention efforts and the extent of additional pollution prevention conducted (i.e., pollution prevention or source control programs). For agencies like the Palo Alto Regional Water Quality Control Plant, Palo Alto, California and the Western Lake Superior Sanitary District (WLSSD), Duluth, Minnesota with mature pollution prevention programs, there is not much additional reduction available because most strategies have already been implemented. For example, both agencies have worked extensively with dentists and have high rates of participation/cooperation from the dental community with respect to implementation of recommended amalgam management practices. WLSSD has close to 100% cooperation from the dental community, so their influent and effluent concentrations used in the analysis reflect this level of participation. To project any further mercury reduction, source control strategies other than voluntary implementation of best management practices (BMPs) would have to be considered (i.e., regulation, and use of amalgam separators).

Average influent mercury concentrations for the POTW case studies prior to the pollution prevention considered in this analysis ranged from 106 ng/L to 323 ng/L. Average effluent concentrations prior to the pollution prevention considered in this analysis ranged from 3.1 ng/L to 9 ng/L. Maximum effluent concentrations ranged from 5 to 29 ng/L. Influent load reductions from pollution prevention resulted not only in effluent reductions but also in biosolids reductions, which may also have positive implications for POTW operations.

The largest source of mercury in wastewater influent is discharges from dental offices. The next largest sources are domestic sources (human waste, household products, and laundry graywater) and hospitals. Of the domestic sources, human waste is considered uncontrollable and laundry graywater is considered very difficult to effectively control. Household products are controllable to the extent that residents can be persuaded to stop using them or to the extent that their availability can be restricted through product bans. Legislative efforts to restrict the availability of certain mercury containing products may prove effective in reducing discharges from household products. The sources with the greatest potential for achieving measurable reductions in wastewater influent are dental offices and hospitals.

Benefits to Other Media

Another important benefit of pollution prevention programs, although not quantified in this report, is their beneficial impact on other media. Restriction or elimination of mercury-containing products (e.g., thermometers, thermostats, blood pressure cuffs) will also reduce the amount of mercury released to the environment through improper disposal as solid waste or medical waste (and then to landfills, incinerators, or steam autoclaves). Similarly, educating the dental community regarding proper disposal of amalgam wastes will reduce the amount of these wastes that are transferred to solid waste or infectious waste (which gets incinerated or autoclaved). One finding of the San Francisco dental surveys and site inspections was that dentists believed that they were properly disposing of scrap amalgam as hazardous waste (WERF, 2001). However, the site inspections revealed that many of them were disposing of amalgam wastes as biohazardous/medical waste. The result of this was that, while disposal to the sewer was prevented, the ultimate release of the mercury would be through incineration to the air. As a result of this finding, education of dentists has included the message to dispose of amalgam through certified recyclers and not as medical waste. While no additional reductions in wastewater are likely to be achieved by this action, the overall release of mercury to the environment will be reduced. This reduction depends on the proper recycling mechanism being available. Local agencies can help accomplish this by identifying recyclers and providing this information to the appropriate businesses.

Other indirect benefits of wastewater source control and pollution prevention programs include increasing public awareness of mercury pollution issues and the potential to create partnerships with other agencies that have more direct control over certain waste streams and established communication vehicles. Increased public awareness may result in more successful legislative activity at both the state and federal level. Working with other agencies and businesses (i.e., health departments, solid waste programs, air programs, recycling companies, environmental organizations, etc.) may result in more widespread communication to both the general public and the business community that may result in behavior changes that achieve reductions in environmental releases.

The Wisconsin Department of Natural Resources (WDNR) has been working with municipalities and is developing a Municipal Mercury Pollutant Minimization Program to help agencies comply with the GLI mercury effluent requirements (Case, 2001). The program's goals include reducing mercury use through promotion of alternative products and reducing mercury releases through recycling and improved waste management. Program elements include establishing partnerships and working with a variety of mercury sources including medical facilities, dental clinics, secondary schools, colleges, industry and the general public. Effectiveness measurement is an important element of the program.

The program is based on over 4 years of pilot work with municipal agencies. The pilot work has already shown that municipal mercury reduction activities will have benefits beyond wastewater reductions. As a result, WDNR is exploring approaches to provide POTWs with credit for benefits to other media as an offset against final effluent discharge compliance. Another added benefit recognized by WDNR is that outreach activities often reach audiences outside of a POTW's service area. WDNR is exploring approaches to provide some type of credit for this benefit as well.

Compliance Assessment

While measurable reductions are expected as a result of mercury pollution prevention programs, these reductions do not appear to have a significant impact on a POTW's ability to comply with the more stringent effluent limits evaluated in this study. However, pollution prevention or source control may result in adequate reductions to achieve permit limits under certain circumstances (i.e., reduction needed is reasonable, as in the case of achieving the 7.8 ng/L limit developed from the fish tissue criterion using default values). For limits based on the CTR (i.e., 25 ng/L), or other less stringent criteria (i.e., based on fish tissue criterion for rivers and streams, 17-18 ng/L), the case study POTWs could generally comply prior to implementing pollution prevention. For the Great Lakes Criteria (i.e., 1.3 ng/L), none of the POTWs were able to comply even after the estimated reductions based on pollution prevention (all voluntary) efforts were calculated. One agency was able to comply on the basis of a source control/semi-regulatory program. For the intermediate standard of 7.8 ng/L, the two POTWs that could not comply prior to pollution prevention were projected to be able to achieve that level after the implementation of a source control/semi-regulatory program.

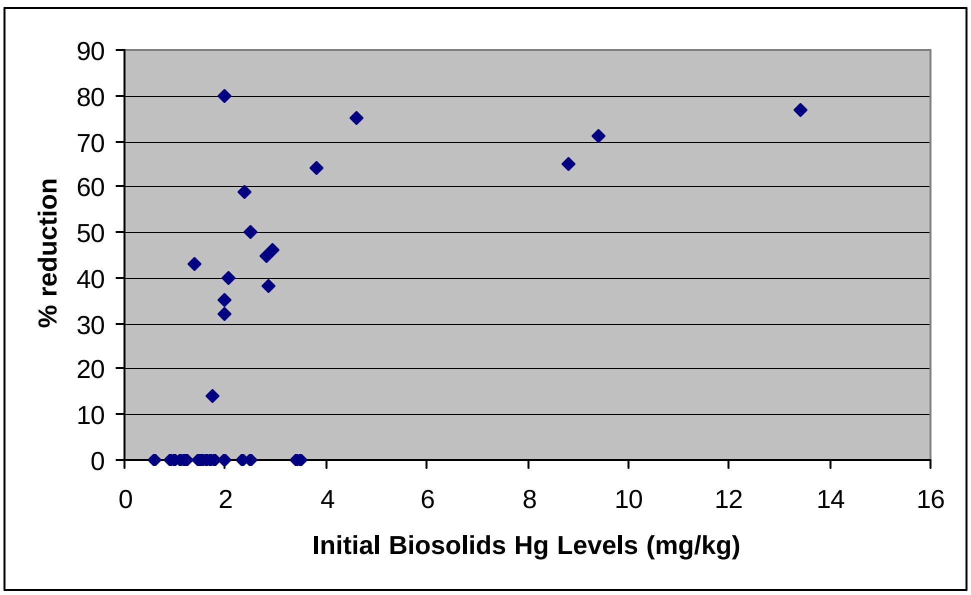
One of the limitations of this study is that it is theoretical in nature. There are very few examples of mercury source control programs that have been in place long enough to yield measurable results. However, some examples that may give an indication of the potential effectiveness of mercury pollution prevention and source control programs include the programs implemented by the Palo Alto Regional Water Quality Control Plant, Palo Alto, California, the Western Lake Superior Sanitary District (WLSSD), Duluth, Minnesota, and Metropolitan Council Environmental Services (MCES), St. Paul, Minnesota, and experiences in Denmark.

As noted previously, WLSSD and Palo Alto have both implemented most, if not all, of the recommended pollution prevention strategies described in this analysis. Source control strategies that have not been implemented include regulating dentists and requiring amalgam separators. Neither of these POTWs is able to consistently achieve effluent concentrations below 3.1 ng/L. Palo Alto's reported maximum and average effluent concentrations were 18.3 ng/L and 5.5 ng/L respectively and WLSSD reported maximum and average effluent concentrations of 29 ng/L and 4.7 ng/L respectively. Therefore, in these two communities pollution prevention has not been able to achieve very low mercury effluent levels.

MCES conducted a study, in cooperation with the Minnesota Dental Association, to assess the reduction of mercury levels in biosolids resulting from the installation and operation of amalgam removal equipment in dental clinics (Anderson, 2001). MCES obtained baseline data for mercury loadings in biosolids for two treatment plants (Hastings and Cottage Grove). Amalgam removal equipment was then installed in all the dental clinics in the Hastings service area and all but one dental clinic in the Cottage Grove service area. Mercury biosolids levels dropped 44% and 29% for the Hastings and Cottage Grove treatment plants respectively during the period when the removal equipment was in operation at the dental clinics. Because influent and effluent monitoring were not conducted for this study, no information is presented regarding the impact of amalgam removal equipment on treatment plant effluent levels of mercury. However, operation of amalgam removal equipment by dentists appears to have the potential to reduce biosolids mercury levels.

In Denmark, several POTWs have required that dentists in their service area to install amalgam separators (Arenholt-Bindslev, 1999). Agencies were surveyed in 1999 to assess the effectiveness of this strategy with respect to mercury reductions. Out of 273 counties surveyed, 174 indicated that amalgam separators had been installed in all dental offices in the service area. Of these counties, 45 provided adequate data to calculate reductions in mercury levels in treatment plant biosolids after the separators had been installed. Reductions for 33 of the plants providing data are compared to initial mercury biosolids levels in Figure 17. Approximately half of the agencies observed no statistically significant change in biosolids concentrations after the installation of amalgam separators. Reductions ranged from 14% to 80% for those agencies experiencing measurable reductions (other than the one value at 14%, the range of the data was 32% to 80%). There appears to be some correlation between initial biosolids levels (i.e., prior to installation of amalgam separators) and reduction achieved. Many of the Danish areas observing no significant changes in biosolids concentrations had relatively low initial levels. No data was reported regarding effluent levels. However, because of the particulate nature of amalgam, it is likely that reductions in effluent were no greater than reductions seen in the biosolids. An 80% reduction would not be adequate for most of the agencies in this study to achieve the most stringent effluent limits (i.e., 1.3 ng/L or lower). The Danish results indicate that the effectiveness of regulation and amalgam separators is highly variable. While significant measurable reductions were achieved in some cases, other cases resulted in no significant change.

Figure 17. Biosolids Mercury Reductions for 33 Danish Counties After Amalgam Separator Installation



The controllability of influent sources and the effectiveness of voluntary programs ultimately impact a POTW's ability to meet the more stringent effluent limits. As noted previously, pollution prevention is based on voluntary actions. While regulatory approaches may be available for commercial sources, they are labor intensive and therefore only cost effective for the largest sources (i.e., dentists). Regulatory approaches are not available for residential activities because POTWs lack the legal authority to regulate domestic users. In addition, some domestic sources are essentially uncontrollable (i.e., human waste). Product bans are one approach being explored in several states, but their impact on wastewater levels of mercury remains to be seen. Overall there is a limit to the potential effectiveness of pollution prevention. On average, residential sources accounted for approximately 25% of the influent loading. Therefore, even if commercial and industrial mercury discharges could be completely eliminated, the maximum reduction achievable is about 75%. As noted above, for the more stringent effluent limits, reductions greater than 75% are needed for most agencies to consistently meet these levels.

The estimated annual cost of the pollution prevention program ranged from $250,000 to $350,000 depending on the size of the service area. The estimated annual cost of the source control program ranged from $300,000 to $700,000. Because pollution prevention was not adequate to achieve consistent compliance with 1.3 ng/L, additional POTW treatment would also be necessary. The annual total cost of this additional treatment ranged from $1.2 to $226 million per POTW depending on the size of the POTW and the reduction needed. Interestingly, the cost of treatment without pollution prevention was not significantly different, ranging from $4.8 to $300 million annually.

Impact of Assumptions

The assumptions that impacted the results most heavily were the values assumed for dental discharges and human waste associated with amalgam and the assumptions regarding percentage removals through POTWs. While the values assumed for the first two parameters had a significant impact on the estimated load reductions and resulting effluent concentrations, they did not have a significant impact on the ability of POTWs to comply with effluent limits or the estimated cost to comply with these limits. Regardless of the values chosen, dental discharges accounted for the largest portion of influent loadings and, therefore, represent the source for which pollution prevention and source control efforts would be expected to be most effective with respect to measurable reductions. The percent removals of mercury at each plant need to be studied in more depth. It is difficult to predict the concentration of mercury in the effluent based on the concentration in the influent. As noted in the discussion regarding the probability-based model, there is some indication that as influent concentrations decrease, the percent removal in the effluent also decreases. The method for determining effluent from influent in this study was the most reasonable available method.

Limitations of Analysis

As noted previously, several assumptions were incorporated into the estimate of effluent mercury reductions achievable through pollution prevention. These limitations are listed below:

- Dental discharge data is primarily the liquid fraction of mercury measured in the lateral leaving the dental facility. While these values were measured as total mercury, they may underestimate the amount of mercury that leaves the dental facility each day, because some of the mercury (as amalgam) will settle out and may leach back into the water at a later date. Other studies, as noted previously, have estimated that larger amounts of mercury may be discharged from dental offices. However, for the purposes of this calculation, a conservative estimate of the amount of mercury that reaches the treatment plant is used. It is assumed that this is best represented by the mercury in the liquid fraction (both smaller amalgam particulates and dissolved) leaving the dental facility but this would need to be confirmed by further monitoring and research.

- The mercury levels from human waste are based on measurements of the human waste itself rather than the amount in the wastewater stream. These measurements are for total mercury, which may overestimate the amount that reaches the treatment plant influent.
- There is some uncertainty regarding total and dissolved mercury measurements and analytical techniques used for the measurements made both by the case study POTWs and by the agencies conducting analysis of sources that were used in this report. These uncertainties may decrease the confidence level associated with the mass balances. For instance, the 7470 digestion method, typically used for wastewater analysis, does not dissolve larger particles of amalgam and, therefore, would not generate an accurate measure of the mercury content. This is a concern for samples that are high in amalgam solids. However, the digestions used for wastewater dental samples (if they have relatively low solids content) are aggressive enough to dissolve the amalgam in the particles in these samples.
- The uncertainties regarding the form of mercury (i.e., particulate vs. dissolved) may also impact the levels of mercury estimated in the POTW influent and effluent and may, therefore, affect the mass balance determinations. It may also impact the effectiveness of source control programs and other efforts seeking to reduce mercury effluent levels. If mercury is reaching the plant as larger particulates, it is likely to be removed in the grit chambers or it will enter the biosolids, not the effluent. Source control efforts that remove larger solids will not necessarily have much impact on influent and effluent levels. However, removal of larger particles still meets the goal of reducing release of mercury into the environment. Overall, the form of mercury and how this affects its movement through the treatment plant requires further study to accurately predict the relationship between source control and effluent reductions.

Regardless of these limitations, discharges from dentists appear to represent the largest contributor to mercury influent levels. Human waste, while a significant source, represents a small contribution relative to dentists.

Another limitation of this analysis is the use of average removal efficiencies when calculating effluent concentrations based on influent reductions. As noted, there is some indication that POTW removal efficiencies will decrease as influent concentration decreases. The probability-based model, for example, predicts much lower effluent reductions than influent reductions. A better correlation between removal efficiency and influent concentrations could increase the accuracy of this analysis.

This report only attempts to quantify mercury reductions in effluent and, to some extent, in biosolids. Other reductions in environmental releases of mercury were only evaluated qualitatively. It is possible that the reductions in releases to other media are equally significant and may merit further evaluation.

It must be recognized that this study was geared towards creating an ‘average’ community, in terms of size and potential sources of mercury. Some communities, especially smaller ones, may be more heavily influenced by sources such as schools and laboratories that were considered to be a small influence in the 'average' community approach.

This report is a theoretical study on the impacts of mercury source control efforts on POTW effluents. As noted above, there is very little experimental verification of predicted results because few POTWs have conducted extensive mercury source control programs over a long enough time period to determine the level of reduction that is achievable. For other pollutants, POTWs have found that, over a period of years, pollution prevention and source control can achieve significant reduction under the right circumstances (WERF, 2000).

Conclusions

The results of this study indicate that mercury source control and pollution prevention programs have the potential to achieve measurable reductions in POTW influent and to have positive impacts with respect to reducing other environmental releases of mercury. Source control and pollution prevention may also be effective in helping POTWs achieve effluent limits assuming the required reduction falls within a specific range. The results of this study indicated that, based on the assumptions made, pollution prevention or source control are potentially effective in achieving sufficient reductions to enable POTWs to meet effluent limits that are 7.8 ng/L or greater. However, if more stringent effluent limits are in effect such as the 3.1 or 1.3 ng/L limits that have been imposed on POTWs in the Great Lakes Region, pollution prevention or source control with no treatment process modifications will not be effective in achieving these limits.

Regardless of the potential for meeting effluent limits through pollution prevention and source control alone, these efforts have many benefits as described in this report and should be considered as an essential tool in any mercury reduction effort. Reduction of mercury at its sources will have positive impacts for wastewater influent and biosolids and for other media.

Pollution prevention efforts targeting sources of mercury should focus on dental offices and medical facilities (hospitals) to have the greatest potential for achieving measurable reductions. With respect to dental offices, implementation of BMPs, such as good housekeeping and proper management of existing filters, should be required as the initial approach. However, if additional reductions are needed, regulatory approaches and the required installation of treatment should be considered. For hospitals and medical facilities, implementation of BMPs and purchasing policies promoting non-mercury containing items has proven effective with respect to reducing mercury wastewater discharges from these facilities.

Recommendations

Areas requiring further study to obtain a better understanding of mercury sources and the potential for reductions were identified in this report and include:

- Additional study of the relationship between influent mercury concentrations and removal efficiencies through the treatment plant would help clarify the relationship between influent reductions and resulting effluent concentrations. Present data shows that the relationship is not linear. Additional study also is needed with respect to the portion of mercury present in wastewater in solid form and in liquid form. The form of mercury present in wastewater will have a significant impact on its travel through the treatment process and the reductions that are ultimately achievable as a result of source control and pollution prevention efforts.

- To gain a more complete understanding of mercury sources in wastewater treatment plant influent, a more comprehensive effort to assess total mercury discharges from dental offices should be conducted. In addition, research that more directly measures mercury in wastewater resulting from human wastes should be conducted.

- To further assess the feasibility of reducing mercury levels in laundry graywater, research could be conducted to ascertain the origin of mercury in the graywater (i.e., does it come from dirt or clothing dyes).

- Recommended practices for larger sources such as dentists may have a significant impact on the magnitudes of reductions achievable by these sources. Certain practices will have greater impacts than others will. For example, attention should be given to screenings disposal/handling at dental offices. It would be helpful to have a standard protocol for disposal/handling and to get cooperation from state agencies to aid in disposal to facilitate implementation of BMPs by dentists and other sources.

- Additional monitoring and evaluation of discharges from schools should be conducted to determine if this is a significant mercury source. There is some indication that schools with laboratories have the potential to discharge significant quantities of mercury.

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