Executive Summary

Introduction

The United States Coast Guard (USCG) maintains about 12,000 fixed lighted aids to navigation (AtoN). These AtoNs, or lights, are located in or adjacent to all major waterways. Historically, primary batteries most of these lights were powered by. Primary batteries contained small amounts of mercury, which was used to smooth the oxidation of the zinc anode. By the mid-1980's the vast majority of primary battery powered AtoNs were converted to solar power that utilize lead acid or "secondary" batteries. Spent primary batteries, when replaced, were sometimes disposed of at the AtoN sites. It is estimated that each of these discharged batteries could contain 0.1- 3 grams of mercury, which may pose an environmental or health threat. The USCG initiated an assessment of potential environmental effects to determine what, if any, impact resulted from spent primary batteries.

The assessment was performed between October 1993 and December 1997 by the Volpe National Transportation Systems Center of the U.S. Department of Transportation's Research and Special Programs Administration. Several agencies provided assistance in the form of analyses or program review, including the Massachusetts Institute of Technology, R.M. Parsons Laboratory; the University of Maryland, Chesapeake Bay Biology Laboratory; Environmental Transportation Consultants/CH2M Hill; and the National Oceanographic and Atmospheric Administration (NOAA). During the conduct of the environmental sampling crews and ships were provided by the USCG and diving services were provided by the U.S. Navy and Oceaneering Technologies International.

This work included laboratory studies, and investigations at five prototype sites:

(1) Chesapeake Bay

(2) Tampa Bay

(3) Tennessee River (Chattanooga)

(4) Puget Sound (Budd Inlet)

(5) Midway Island

Demonstration cleanup projects, which involved battery removals and post-removal sediment sampling were also performed at Tampa Bay. In addition, a post-removal, preliminary investigation and ecological impact assessment was conducted at Aton sites on four California Channel Islands. This document reports the results obtained from laboratory studies and site investigations, the conclusions drawn from these results, and their implications for AtoN battery recovery. Specific results from the prototype sites, appear in the appendices.

Objectives

The primary objective of the study was to determine whether the batteries disposed of at the terrestrial and aquatic AtoN sites posed a hazard to the environment and humans. It was concluded from the laboratory analysis of spent batteries that the long-term potential impact on human health or the environment is limited to the uncontrolled release of metals, specifically zinc and mercury. Other battery parts, such as the plastic casing, pose no hazard, and the internal caustic solutions quickly dissipate and neutralize in the aquatic environment. Since 99% of the recovered batteries were primary batteries, and since they were phased out by the mid-1980's, only their long-term effects were of concern. When they were deployed, primary batteries contained a 500g zinc electrode that was coated with about 20g of elemental mercury (Hgo). They did not contain lead therefore lead was not expected to be a metal of concern in the environmental assessment. All of the individual prototype investigations fully evaluated the zinc, lead and mercury concentrations in sediment, however, this overview focuses on mercury because of it's bioaccumulation potential and greater toxicity. The preliminary work refined the objectives:

(1) to describe the fate and transport of mercury from spent primary batteries

(2) to determine the concentration, spatial distribution and form of metals found near AtoN battery sites

(3) to determine whether aquatic biota were contaminated at AtoN due to spent batteries

(4) to determine whether hazardous mercury vapor is released at terrestrial AtoN sites.

Studies and Investigations

Laboratory Studies

The laboratory studies at the Massachusetts Institute of Technology and at the University of Maryland analyzed spent batteries for total mercury and the solubility of mercury under salt water conditions. The form of mercury in spent batteries (elemental, organic, or ionic) was also determined. The laboratories measured the likelihood of release using a standard US Environmental Protection Agency protocol (TCLP, see below). They also postulated and described mercury transport mechanisms. The results of TCLP analyses confirmed that the mercury present in spent primary batteries was at low concentrations and generally undetectable using standard TCLP procedure (Mason, 1995).

AtoN Sites Prototype Investigations

The AtoNs that were investigated within the five prototype locations are listed in Table E-1. The following data are given for each AtoN studied:

(1) batteries found during investigation

(2) estimated maximum number of batteries assuming that all spent batteries were disposed of at the site

(3) type of bottom (e.g., mud, sand, etc.)

(4) the percent of AtoN sites in the corresponding USCG district that have a similar bottom type

(5) the water depth at the time of site investigation

(6) description of the aquatic environment

The investigation addressed the dispersal patterns of mercury and zinc releases by collecting sediments close to discarded batteries, at increasing distances from batteries and AtoNs, and at background locations where batteries had never been used. Ionic and methylmercury levels were also determined because of their increased bioaccumulation potential.

Mercury was also measured in aquatic biota attached to batteries, in nearby sediment, and free swimming animals living in close association with batteries. These measurements were taken because accumulation in these organisms is the most critical exposure pathway for humans and the aquatic ecosystem as a whole.

Demonstration Battery Removals

In addition to the investigations at the prototype sites, batteries were removed at 35 AtoNs. This report summarized the results of the demonstration removal effort completed within Tampa Bay. Areas previously covered by battery piles were sampled to assess the residual mercury levels in sediments after removal.

California Channel Islands

Additional investigations were conducted at four of the California Channel Islands due to potentially elevated concentrations of mercury and lead remaining in the soil after battery removal. Human health and ecological impact assessments were completed.

Measures and Criteria

The data obtained during the prototype site investigations were compared against the following criteria: 1) differences from site specific background levels or background levels established by local or state authorities, or 2) levels above local or nationally established levels that could indicate adverse effects.

The specific measures used were:

Air

The applicable criteria for inhalation exposure are the Occupational Health and Safety Administration criteria for permissable exposure limits (PELs). The PEL for mercury is 0.05 mg/m3.

Substrate (sediment, soil) Background and comparison levels:

Collected at unlighted AtoNs,

the perimeter of the AtoN sampling field (20 meters from the base of the AtoN),

regional background levels established by states or other local investigations,

NOAA National Screening Guidelines: low (ER-L), median (ER-M).

States of Florida and Washington Criteria: No effects (NOEL) and Probable Effects Levels (PEL).

Methylmercury

Comparisons to percent methylmercury of total mercury based upon the literature and variation among local comparison stations.

Table E-1: AtoNs and Environments

AtoN Name/Location	Batteries Found	Maximum Est. Batts	Substrate	%Bot District	Depth	Habitat
Chesapeake Bay						
Greenbury Point Lt	80	64	Silty, mud	52	5 meters	Estuarine
Bodkin Point	2	49	Silty sand	52	5 meters	Estuarine
South River	9	36	Silty sand	52	3 meters	Estuarine
Rocky Creek (Unlighted AtoN)	None	None	Clay/silt	0.55	5 meters	Estuarine
Tampa Bay						
Gadsen Point #8	21	238	Sand	80	4 meters	Estuarine
Gadsen Point #10	37	328	Sand	80	5 meters	Estuarine
G Channel FRL	23	173	Sand	80	3 meters	Estuarine
G Channel RRL	12	238	Sand	80	4 meters	Estuarine
Alafia River FRL	33	47	Silty Sand	5	3 meters	Freshwater Inflow/Estuarine
Alafia River RRL	66	161	Silty Sand	5	3 meters	Freshwater Inflow/Estuarine
E Channel FRL	35	173	Sand	80	7 meters	Estuarine
E Channel RRL	68	238	Sand	80	7 meters	Estuarine
C Channel FRL	20	328	Sand	80	7 meters	Estuarine
C Channel RRL	6	622	Sand	80	7 meters	Estuarine
Tennessee River- Chattanooga						
Moon Light	16	55	Silty sand	80	3 meters	Fresh Water
Patton Island Upper	0	55	Silty sand	80	10 meters	Fresh Water
Patton Island Lower	0	55	Sandy silt	90	5 meters	Fresh Water
Selcer Lt	17	75	Sandy silt	90	5 meters	Fresh Water
Williams Island Lt	15	55	Silty sand	90	8 meters	Fresh Water
Chickamauga Unlighted	None	None	Sandy silt	90	5 meters	Fresh Water
Lake Nickajack Area	None	None	Silty sand	90	8 meters	Fresh Water
Puget Sound- Budd Inlet						
Olympia Range Lt	33	82	Silty mud	90	3 meters	Estuarine
Olympia Channel Lt	44	118	Silty mud	90	4 meters	Estuarine
Olympia Channel Unlighted	None	None	Silty mud	90	5 meters	Estuarine
Midway Island						
Front Range Light	143	NA (1)	Sand	NA	5-8 meters	Marine

Table E-1: AtoNs and Environments Characterized During Prototype Investigations (continued)						
AtoN Name/Location	**Batteries Found**	**Maximum Est. Batts**	**Substrate**	**%Bot District**	**Depth**	**Habitat**
Reference Station	0	NA	Sand	NA	5-8 meters	Marine atoll
Channel Islands Preliminary Investigation (2)						
San Clemente – China Point	21 55-gallon drums	NA	Soil	NA	Surface	Terrestrial
Pyramid Head	15 55-gallon drums	NA	Soil	NA	Surface	Terrestrial
San Nicolas Island – N. Side	780 lbs.	NA	Soil	NA	Surface	Terrestrial
East Side	930 lbs.	NA	Soil	NA	Surface	Terrestrial
South Side	600 lbs.	NA	Soil	NA	Surface	Terrestrial
Santa Barbara Island AtoN	200 lbs.	NA	Soil	NA	Surface	Terrestrial
Santa Catalina Island – East End	200 lbs.	NA	Soil	NA	Surface	Terrestrial

(1) Not Available
(2) Battery Removal was not part of Channel Islands Validation investigation
(3) Not Relevant

Biota

Background and comparison levels:

- biota taken at comparison stations (unlighted AtoNs),
- Local criteria: established in literature, by states, etc,
- NOAA National Status and Trends studies of biota in selected environments,
- Food and Drug Administration (FDA) Action Level for methylmercury in tissue.

Results

Laboratory Studies

Spent batteries from Tampa Bay, Florida and Chattanooga, Tennessee were analyzed to determine their total mercury content and concentration in various components, and the form of mercury in each (elemental, ionic or methyl). The total mercury content in spent batteries averaged to about three grams each, and most of it was concentrated in individual battery components. The component concentrations varied from 0.006 mg/kg in the plastic casing to 4040 mg/kg in the carbon electrodes. Only elemental mercury was found in aged batteries (over 1 year in the environment). Newly spent batteries and batteries that were disposed on land contained traces of ionic mercury.

Mercury dispersal from spent batteries was measured using the EPA protocol Toxicity Characteristic Leaching Procedure (TCLP) 7471 with whole batteries and their components.

Batteries analyzed using TLCP 7471 yielded concentrations of mercury no greater than 109 g/L. The TCLP maximum allowable concentration is 200 g/L.

Prototype Site Investigations

Analysis of Air Samples

The mercury remaining in spent primary batteries that are exposed to air can be released as vapor. Mercury vapor concentrations near batteries were measured at two terrestrial sites in the Tampa Bay area. At both of these locations, mercury vapor levels were measured over battery piles on the ground, which consisted of both intact and broken batteries. Mercury vapor levels were measured using two devices: (1) a photo ionization detector (PID) meter and (2) a mercury vapor analyzer (MVA) , both capable of detecting concentrations as low as the OSHA PEL level (0.05 mg/m3). No measurable mercury concentrations were found in air samples measured at Anclotte Key Light and Egmont Light in Tampa Bay.

Analysis of substrate (sediment , soil)

The results of substrate analyses are summarized in Table E-2. The average of the mean samples values are grouped by proximity to the AtoN are reported for each location investigated during the prototype studies. The near field average is for samples taken within 10 meters of the base of the AtoN. Samples taken at distances greater than 10 meters are reported in the far field rows, and samples taken directly at batteries are reported separately. Reference values were measured at unlighted AtoNs near the sample locations. These AtoNs which do not require batteries, were chosen due to their similarities to the prototype locations chosen for study. Additional comparative background levels are included in Table E-2; these have been established by state agencies or other research. The States of Florida and Washington each have sediment "criteria" relevant to these studies. NOAA publishes a set of screening "guidelines" which may also be used for comparison.

Analysis of Biota

In Chesapeake Bay, seven biological samples were collected from batteries and five were taken from structures near the AtoNs. The average mercury concentrations in the samples from batteries was 0.02 mg/kg (wet weight). No values above 0.05 mg/kg (wet weight) were reported. All of these values are well below the FDA action limit of 1 mg/kg (wet weight).

In Tampa Bay the biological samples showed a pattern similar to that seen in Chesapeake Bay. The average concentration was 0.03 mg/kg (wet weight) with a maximum value of 0.09 mg/kg (wet weight). These samples were taken near the Alafia River. In these cases, samples on pilings were less than the levels taken on batteries. These levels were six times higher than those found in the mid-bay areas. The majority of AtoNs sampled in Tampa Bay exhibited levels less than 0.5 mg/kg.

In the Tennessee River all biological results were less than 0.13 mg/kg in tissue. In the Puget Sound, all sampled organisms tissue concentrations were less than 0.1 mg/kg. Near and far field averages for each station are provided in Appendix A (Table A-1).

At Midway Island, the concentrations were evaluated in the deposit feeding detritivore, sea cucumber and the territorial, herbivorous damsel fish. Although the tissue levels were extremely low, concentrations of mercury were slightly higher in one species of fish

associated with the AtoN than those at the Reference station. This was not observed in the sea cucumber nor in the other species of herbivorous fish studied, and in fact the converse was true for the sea cucumber. These observations of higher tissue concentrations were for fish collected at the largest battery pile. However concentrations were less than 0.2 percent of the FDA advisory limit of 1 mg/kg wet weight.

Demonstration Battery Removals

Several important findings were derived from the demonstration battery removal programs conducted in Tampa Bay, Tennessee, and Puget Sound. First, the number of batteries likely to be found at aquatic locations is about one-half the maximum number used during the 20 years of primary battery service at AtoNs. Few secondary batteries (two of thirteen - hundred) were found in these locations. Most (62%) batteries were within 5 meters of the base of the AtoN, and almost all (95%) batteries ever found at any AtoN were within 20 meters of its base. About one-half of the batteries found in salt water environments are broken and decaying. Conversely, batteries found in fresh water, or where sediments are soft and muddy (for instance in Puget Sound), were generally found intact.

Sediments under battery piles were sampled after the batteries were removed. The measured mercury levels in these sediments were usually at or below the background levels, and were within the range established by NOAA (ER-M of 0.71 mg/kg). In two locations in Tampa Bay, where a large number of broken batteries were removed, sediment levels exceeded 5 mg/kg (total mercury). It is believed that these sediments contained some residue from the outside of the batteries that accumulated during removal, rather than mercury released directly from the batteries.

These levels indicate that care must be taken when batteries are removed to collect attached sediments and biota so that the contaminants will not be returned to the environment.

Southern California Channel Islands

Mercury soil concentrations immediately following battery removal at the Channel Islands varied between islands and in some cases between AtoN on islands (CH2M HILL, 1996). The mercury concentrations recorded at that time were below the levels considered protective of human health.

The concentrations of lead, zinc, copper and mercury in samples collected a year later from soil, plants, invertebrates, and small mammals indicated no elevated risk from AtoN batteries. Mercury was below background levels for all samples collected as posed no ecological risk (Table E-3). Although some isolated samples had concentrations of lead, zinc, or copper above background or conservative benchmarks, calculations of average exposures indicate no ecological risk from these metals. Since two AtoNs sampled (San Nicolas East End AtoN or Santa Catalina East End AtoN) showed the highest levels of metals and the greatest potential for exposure, no unacceptable risk is anticipated at any other Channel Island AtoNs. Furthermore, methylmercury was also not detected and was less than 0.01% of total mercury, well below the threshold of 1.0%. Biological samples from specimens of plants invertebrates, and small mammals demonstrated that the metals were not bioaccumulating to concentrations harmful to their respective trophic level, nor to the top trophic level represented by the Island fox.

Table E-2: Average Measured Mercury Levels and Comparison Values -

Area	Average Mean Values	Background [1]	FLORIDA (NOEL) [2]	NOAA (ERL) [3]	NOAA (ERM) [4]	FLORIDA (PEL) [5]
Chesapeake Bay		0.25	<.15	0.15	0.71	1.41
Near Field (i)	0.216					
Far Field (ii)	0.045					
Battery(iii)	0.13					
Unlighted Reference AtoN (iv)	0.27					
Tampa Open Bay		0.05	<.15	0.15	0.71	1.41
Near Field	0.19					
Far Field	0.06					
Battery	0.25					
Unlighted Reference AtoN (iv)	0.05					
Tampa Alafia River		0.35	<.15	0.15	0.71	1.41
Near Field	0.23					
Far Field	0.07					
Battery	2.83					
Unlighted Reference AtoN (iv)	not available					
Tennessee Chicamauga		0.5	<.15	0.15	0.71	1.41
Near Field	0.176					
Far Field	0.243					
Battery	0.11					
Unlighted Reference AtoN (iv)	0.09					
Puget Sound (Budd Inlet)		0.16	<.15	0.15	0.71	1.41
Near Field	0.24					
Far Field	0.20					
Battery	0.12					
Unlighted Reference AtoN (iv)	0.18					
Midway		0.003 - .02	<.15	0.15	0.71	1.41
Plot A	.04					
Plot B	.04					
Plot C	.03					
Plot R	.03					

Total Mercury (ppm) in Substrate (sediment, soil)

(1): Values from literature   (i): Sample < 10 meters from base of AtoN

(2): Florida: No effects level   (ii): Sample 10-20 meters from base of AtoN

(3): NOAA Effects range low   (iii): Sample at battery

(4): NOAA Effects range median   (iv): Samples at unlighted reference AtoN
(5):Florida:Probable effects limit

Table E-3 - Mean Soil Concentrations (mg/kg) at Channel Island AtoNs

Metal	San Nicolas	Santa Catalina	San Nicolas Background	Santa Catalina Background	Pooled Background
Mercury	BDL*	BDL	BDL	BDL	BDL
Zinc	32.92	234.2	31.73	51.5	41.62
Lead	14.2	16.3	6.3	BDL	4.22
Copper	8.32	58.5	11.58	33.3	NA*

Notes: * BDL = Below Detection Limit. Detection limit for mercury = 0.1 mg/kg.
           NA = Not Applicable, backgrounds were significantly different at the alpha = 0.05 level

Conclusions

Mercury in spent AtoN batteries is primarily in elemental form. Although a small portion of the mercury originally in spent batteries (not submerged in an aquatic environment) was in ionic form; it was released to the environment and dissolved immediately at the time the battery was discarded. Thus, the contents of the batteries themselves are relatively harmless.

Human exposure through inhalation of mercury vapor or ingestion of contaminated water is not a concern.   Contamination of drinking water is unlikely because elemental mercury does not easily dissolve. Neither is exposure through inhalation a concern because the mercury in spent terrestrial batteries is tightly bonded to the carbon and zinc components, and no vapor was detected.

Given its low solubility, the most likely release pathway for elemental mercury is to surrounding sediments through battery casing decay. Evidence from prototype investigations indicate that battery casings tend to remain intact in freshwater environments but decay in open marine environments (CH2M HILL, 1993(b), 1994(a), 1994(b), 1996). When these casings decay, the components of the battery containing elemental mercury may be exposed. However, due to the properties of the open marine environment, methylation is not a pathway of primary concern at open marine sites. While the elemental mercury is still potentially toxic, its relative toxicity is significantly less than methylmercury (EPA 1985). Therefore, its direct threat to human health is negligible.

Elevated sediment concentrations near batteries may result in very small - localized environmental hazards. The potential for environmental impact will probably be limited to organisms that attach to batteries or reside in nearby sediments. Evidence from the prototype investigations indicate that some of these organisms have higher measured levels of mercury in their tissue than other biota at the same AtoN.

Implications for Battery Removal

The evidence from the investigations, which indicates that the contents of batteries themselves are relatively harmless, suggests that the presence of batteries in most environments is not a hazard. Because of the potential effect on local organisms, removal of batteries and attached biota is prudent. Measured levels of mercury in surrounding sediments do not indicate that substrate (sediment or soil) removal along with batteries is warranted.

Results - Demonstration Battery Removals" (Section 3.3) states that at locations in Tampa Bay, where a large number of broken batteries were removed, sediment levels exceeded 5 mg/kg (total mercury).Furthermore, it is believed that the sediments contained matter previously attached to the outside of the batteries and lost during battery removal. Similarly, immediately after battery removal at some Channel Island location there were elevated soil concentrations of mercury. However, sampling at the Channel Islands, approximately one year later revealed mercury values that were below detectable concentrations. This suggests that battery removal should be undertaken in a manner that will minimize the loss of attached sediment and biota during removal.

Although it is prudent to remove the subject batteries from the AtoN sites, a phased removal, subject to the availability of funds, is consistent with the low contaminant levels observed.

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1. Introduction

1.1 Background

The U.S. Coast Guard is responsible for the maintenance of over 12,000 fixed lighted aids to navigation (AtoNs) in the major rivers and coastal waters of the United States. From the 1960's to the mid-1980s, many of these AtoNs were powered by disposable primary batteries that contained small amounts of mercury. These batteries have a service life of one to three years depending on the power requirement of the AtoN. During their twenty years of use, some service crews disposed of spent batteries at the AtoN. In the mid-1980's, the Coast Guard's environmental concern and the development of reliable solar technology resulted in a primary battery replacement program, which has succeeded in upgrading the AtoN's power source to solar powered rechargeable batteries at almost all locations. In addition, the Coast Guard initiated a research program, conducted by the Volpe Center, to determine the environmental effect of spent batteries. The Volpe Center research program included: 1) a contaminant fate and transport assessment, by laboratory analyses of batteries, conducted at the Ralph Parsons Laboratory - Massachusetts Institute of Technology, 2) environmental assessments for prototypical AtoN disposal sites in the Chesapeake Bay, Tampa Bay, Tennessee River, Puget Sound, and Midway Island, 3) a demonstration cleanup project at Tampa Bay; and 4) ecological and human health assessments for four Southern California Channel Islands (Channel Islands).

The Channel Islands assessments were completed after battery removal and were subsequent to the completion of the five prototype investigations.   The Channel Island investigations were conducted in response to potentially elevated contaminant concentrations in accordance with the National Plan for AtoN Battery Recovery and Disposal (USCG, 1995).   Human health and ecological impact assessments were conducted.

1.2 Laboratory Contaminant Fate and Transport Studies

Contaminant fate and transport was initially investigated through laboratory studies. The studies were conducted to analyze the composition and magnitude of potential releases from spent batteries and to develop preliminary conclusions concerning health and environmental hazards associated with the batteries.
A laboratory study was conducted to estimate health and environmental hazards posed by discarded AtoN batteries, based on an understanding of the harmful effects of the contaminant, mercury. The principal objective was to determine the ways that humans can encounter mercury released from primary AtoN batteries (which are referred to as primary batteries by the major battery industries, the Coast Guard, and the railroad industry), the volume of mercury released, and its potential effects.
The volume of mercury likely to be released from individual batteries was estimated by analyzing spent batteries in varying states of "decay". These states included batteries recently removed from an AtoN, those found intact in an aquatic environment, and those found in an aquatic environment with broken casings and missing internal contents. The total mercury released from all batteries was estimated based on the results of the laboratory analyses.

The Volpe Center contracted with Dr. Françios Morel and Dr. Robert Mason of the Massachusetts Institute of Technology for this effort, which is being continued by Dr. Mason at the University of Maryland, Chesapeake Bay Biological Laboratory. They chemically analyzed new, spent, and recovered primary batteries from trial cleanup operations, and they reviewed the Volpe Center's design of the environmental impact studies.

1.2.1 Battery Composition

The batteries examined were manufactured by Edison, McGraw-Edison, and Saft, and consist principally of a zinc anode and alkaline electrolyte. The electrolyte was found to be the largest component by weight in the samples taken, and it consisted of either nearly pure sodium hydroxide (NaOH) or potassium hydroxide (KOH). These materials are very corrosive. Electrolyte is classified as hazardous waste, but NaOH and KOH are non-toxic in low concentrations. The researchers concluded that electrolyte would be harmless when diluted by the water at an aquatic disposal site. However, elemental mercury (Hg 0) was found in all the samples taken from the zinc anodes. About 20g of Hg0 is applied to the zinc plates (anodes) during manufacture. This mercury coating helps catalyze the electricity producing reaction, and it keeps the zinc plate from corroding. No other hazardous battery materials were identified.

The potential threat of mercury is complex to assess because it may be found in many forms in the environment. Mercury exists in the environment in three principal forms: elemental (Hg^0),ionic (Hg^{2+}), and organometallic ($(CH_3)H^+$, $(CH_3)_2Hg$). Elemental mercury, because of it's low solubility, is considered the least potentially hazardous of the three forms, but the adverse effects of inhaling elemental mercury vapor are well documented (Heast, 1993), and vapor exposure standards have been established. Highly soluble ionic (oxidized) mercury is the dominant form of natural and anthropic mercury pollution. It is a precursor to formation of highly toxic organometallic mercury by bacteria in stagnant water. Organometallic mercury (methylmercury) is water soluble, it is readily absorbed and retained by tissue, which results in its bioaccumulation in biota, fish, and eventually humans. Therefore, the researchers were interested not only in the total amount of mercury at the disposal sites, but also in the potential for the mercury to be converted into this more bioavailable and toxic form.

Methylmercury has long been considered a potent neurotoxin that can accumulate in the food chain, and recent studies have prompted the EPA to re-examine its standards for safe human exposure (Stern, 1993). The current EPA reference dose (0.3 µg/kg/day) may be revised to 0.07 µg/kg/day to limit the developmental effects, in utero, due to mercury exposure (USEPA, 1990).

1.2.2 Analytical Techniques

Morel and Mason examined spent primary batteries taken directly from an AtoN, they found that less than 20 percent (3 g) of the original mercury remained. They also found that in these batteries (which were never submerged), nearly all of the original mercury remained in elemental form. The mercury was shown to be tightly bonded to the zinc plate and carbon electrode, thus unlikely to dissolve or volatilize. They conjectured that the missing mercury had vaporized by the chemical reactions that produce electricity. A

small amount of ionic mercury was also present in the spent battery. If any of the ionic mercury were released in the water, it would quickly dissipate due to its high solubility, and be undetectable. No organometallic mercury was found.

Analysis of submerged discarded batteries confirmed the earlier results. These batteries contained less than 5 percent of their original mercury content, nearly all in elemental form. Some mercury was also found in broken batteries, apparently surviving for at least 25 years of exposure in an open marine environment (Morel and Mason, 1994). This was confirmed by Mason (Mason, 1995).

To evaluate the possible effects of the released mercury on water quality, Morel and Mason also studied the rate of mercury dissolution in the laboratory. They immersed new and decaying battery cells in salt water tanks and measured the increase of mercury concentration in the water. Very low levels of mercury were released. The researchers concluded that the elemental mercury bonds tightly to the zinc plates (especially when the battery is spent) and to the carbon in the electrodes (Morel and Mason, 1994). At most, only microgram quantities of Hg0 were released per day. Mercury concentrations were measured before and after battery submersion in a plastic drum containing 10L of a 0.5M solution of salt water. For a completely intact battery cell (containing approximately 0.8g of mercury), with stirring, the increase in mercury concentration in water over 36 hours was less than 0.02 µg/L (reactive Hg was measured), and the dissolution rate was <10-7 µg/L per day. Analysis of an intact battery with the top removed revealed a dissolution rate of 17 µg/L per day – higher than a completely intact battery.

Based on these results, the researchers concluded that batteries disposed of in sea water should retain half of their remaining mercury for at least 300 years. Because the analysis of salvaged batteries suggests a 20-year half life, an additional mercury release mechanism is involved. Drs. Morel and Mason did not speculate on this mechanism, but suggested further research.

1.2.3 Magnitude of Release

Morel and Mason also offer an environmental impact assessment of mercury from spent batteries. A generous estimate of all the mercury contained in all the primary AtoN batteries ever disposed of by the Coast Guard would be:

(5 g per battery) x (200 batteries per AtoN) x (12000 AtoNs) = 13.25 tons

A conservative assumption is that all of this mercury is released into the environment in one year. To enter the food chain, the mercury must first be converted to Hg+ 2. It may also be conservatively assumed that all of this mercury is somehow oxidized to Hg+ 2. The earth itself, through volcanoes and along continental subduction zones, releases about 1,600 tons of mercury into the atmosphere each year. All of this mercury is Hg+ 2. This material falls to earth constantly as acid rain. Morel and Mason estimated that as much mercury falls as acid rain on a 40-meter diameter circle around each AtoN as is released from the complete disintegration of ten batteries in one year.

In addition to the mercury released by natural sources, humans release 1,300 tons of mercury per year through waste incineration and 2,600 tons per year through burning of fossil fuels. Relative to these inputs, the mercury released from a spent primary AtoN battery into the rivers or the oceans is minuscule. The only significant measurable

mercury pathway to humans from AtoNs would start with acute methylation and ingestion of mercury by biota living near the AtoN.

1.2.4 Site Characterizations

Drs. Morel and Mason suggested site characterizations for this potential pathway. They conjectured that any Hgo released might stay in the surrounding sediment and migrate into deeper layers over time, forming "hot spots". Mercury hot spots may also be formed by elemental mercury (Hgo) that is bonded to fragments of broken batteries. Benthic organisms living in these hot spots may accumulate mercury and pass it up the food chain. Based on the conclusions of this study, the Volpe center designed in-situ characterizations in battery fields to determine (1) whether elemental mercury indeed remained at the location after battery disposal and (2) whether any organic forms of mercury were evident.

Some environmental factors are likely to affect the behavior of elemental mercury, in turn affecting the conclusions drawn from the Morel and Mason study. These are factors that influence (1) whether batteries break, (2) whether elemental mercury is exposed to an organic material that promotes methylation, and (3) whether elemental mercury is exposed to a fresh water environment also promoting methylation. These factors were all considered in the development of a field sampling plan to confirm the results of the Morel and Mason study.

1.2.5 Conclusions

The general conclusions from the laboratory analysis were:
- The mercury in AtoN batteries is a minute fraction of the total mercury in the environment.
- A significant portion of the mercury in batteries is volatilized (emitted to the air) during use.
- The ionic mercury left in the battery at disposal poses some potential risk to human health, but has a high dissolution rate and has probably already disappeared from the environment.
- The remaining elemental mercury dissolves so slowly that its impact is likely to be minimal.

2. Sampling Design and Methodology

Representative sites and standardized methods for sampling and analysis were used to the greatest extent possible in the prototype investigations, the demonstration cleanup project and the Channel Islands assessments to maximize the comparability of results. In some cases, due to site specific conditions, some deviation from the standard methods was necessary. The standard methods, as well as site-specific deviations are described below.

2.1 Site Investigation Studies

The results of the Morel-Mason study suggest that the presence of discarded AtoN batteries have little environmental or biological impact. However, the conclusions were based on laboratory analysis of a small number of batteries retrieved from only two locations: the Columbia River Gorge in Washington and Tampa Bay in Florida. Because the results are critically important with far-reaching implications for treatment of AtoN battery disposal sites, some method of validating the results was needed.

The hypothesis that mercury released from AtoN primary batteries into surrounding sediments would leave small traces (hot spots) of elemental mercury could be tested by field sampling. These traces would be difficult to detect through a sampling program, but if found and analyzed, Morel and Mason expected them to consist of elemental mercury. They expected that only a tiny fraction of the mercury in batteries to be scavenged by local bacteria and undergo a process that would convert it to a form (methylmercury) that could accumulate in biota. Thus, little, if any, biological contamination would result from battery disposal at AtoNs.

Several unanswered questions remained at the conclusion of Morel's and Mason's work. Were enough batteries analyzed to provide an accurate, reliable basis for the conclusions? Were there environmental factors that would negate them?   If so, in what kinds of environments were battery effects most likely to diverge from those demonstrated by Morel and Mason (i.e.Tampa Bay).

The Volpe Center addressed each of these questions by designing and conducting field sampling and analysis. The design of that field investigation program is described in this section.

The sampling program was designed to assess the effect of environmental variability on the behavior of mercury released from primary batteries. For instance, had the environments studied by Morel and Mason been freshwater systems, with less current, the effects might have been different. Thus, the environmental assessment program selected for study exhibited a wide range of environments to identify any unanticipated effects of battery disposal.

The assessment program had several additional purposes. Standardized operational protocols for site mapping and documentation prior to battery removal were developed. These protocols provided critical input into assessing the reliability of the results and verifying that batteries had been removed from the AtoN. A least-impact removal protocol was also developed. Site closure after battery removal was addressed by post-removal sediment sampling. These techniques are documented in the site investigation

program results (CH2M Hill (Maughan) 1993, 1994a, 1994b, 1995, 1996, 1997). However, the primary purpose of the sampling program was to assess the effect of spent primary batteries on human health and the environment.

Fixed aquatic AtoNs were examined in the Chesapeake Bay, Tampa Bay, Tennessee River, Puget Sound, and Midway Island. Terrestrial AtoNs were also examined on two keys in Tampa Bay area and on four Channel Islands.

The Chesapeake Bay study included two visits to AtoNs. During the first visit, a group of AtoNs was selected for survey, based on the high estimated battery use at the AtoN, maximizing the likelihood that batteries were present. These lights were surveyed using a remotely operated vehicle (ROV) to document AtoN characteristics and locate batteries. Very useful data were collected, allowing the Volpe Center to describe the dispersal of batteries at typical AtoNs, and to identify the area where most batteries were found. AtoNs where batteries were found were revisited to collect sediment and biological samples. During the second visit, only AtoNs known to have discarded batteries nearby were chosen for characterization. The Coast Guard had conducted independent surveys of the bottoms near AtoNs in these areas, and provided data identifying the number of batteries at each location. A subset of this group of surveyed AtoNs was characterized in the same manner as the AtoNs in the Chesapeake Bay; selection was based on representation of various AtoN characteristics, including salinity, bottom type, and depths.

Research scientists designing the aquatic characterization supposed that battery movement might result in casing deterioration with resulting low, but detectable mercury releases around the disposal field. During the many years following battery disposal, events such as storms and dredging have, in all likelihood, moved the batteries from their original resting place. The researchers hypothesized that battery movement could result in a dispersed mercury release rather than the " concentration spots" expected by Mason and Morel. Alternatively, some batteries remain at or near their original position, as indicated by biological overgrowth or burial in sediment. These batteries were more likely to have " concentration spots" of mercury near them. Location and variation in disposition of the batteries were studied by sampling near batteries and at random locations in varying distances around the AtoN base. Sediments were collected at randomly selected locations representing 5-meter strata up to the field perimeter around the AtoN (CH2M HILL, 1993). The field perimeter was set at 20 meters, based on the results of the reconnaissance of battery locations in the Chesapeake Bay and the results of the demonstration battery removal program in Tampa Bay, Florida. (Borener, 1994)

Other phenomena, in addition to battery movement, might affect the measured levels of mercury in sediments and biota. J ust as some batteries become buried in sediments due to sedimentation, mercury migrates deeper into sediments. Mercury migration past the active benthic layer into less biologically active zones reduces the overall exposure risk. Samples were collected from these zones, using 30-cm-core tubes, to describe this migratory path. An intact cross-section of the field sediments was retrieved. The samples were separated into top (10 cm) and bottom (10 cm) samples for independent laboratory analysis. Attached biota and species of opportunity were also collected at AtoNs. These biota were analyzed for total mercury content in tissue. Sediment samples

were analyzed for total mercury, lead, zinc, and total organic carbon. In addition, some sediment samples were analyzed for methylmercury.

Mercury concentrations and estimated risk to benthic invertebrates were evaluated in local sediment and biological tissue samples. Sediments were evaluated because elemental mercury concentrates in that medium due to low solubility and affinity for particles. No water column samples were taken because elemental mercury is insoluble and nearly impossible to detect by standard measuring techniques in the water column, and any ionic mercury (potentially released when a primary battery was first broken open) would have quickly dissipated after disposal (Morel and Mason, 1993).

Environmental Transportation Consultants, (ETC), working under direction of the Volpe Center, designed and implemented an investigation program to evaluate the fate of mercury at battery disposal sites in a variety of environments. The initial program design reflected recommendations from NOAA (Hoff and Beckvar, 1993) and later was modified to include a general conceptual model of exposure also provided by NOAA. Scientists from the Massachusetts Institute of Technology, and the U.S. Environmental Protection Agency (EPA) provided comments on the initial program design. Throughout the study, presentations on the program design and results of the prototype investigations were provided to scientists at NOAA. Their suggestions and comments are reflected in the final study design.

2.2 Locations Studied

Due to the time constraints and cost considerations involved, only a few locations could be characterized during the field studies. These locations had to represent the range of possible environments, population/land use zones, water types, and aid types operated by the Coast Guard. Given the large number of lighted fixed aids, selection of the locations had to be based both on the representation of the many test variables at each site and on the likelihood that primary batteries would be found at the location. Some locations are more environmentally sensitive than others or represent critical variables (such as the presence of fresh water), and were thus included as study sites. In addition, the likelihood of exposure through any of the pathways (i.e., inhalation, skin, or ingestion) was included in the selection criteria. Thus, terrestrial locations and aquatic areas easily accessible to humans (such as those in shallow water) were studied.An important selection criterion was the environmental or human health sensitivity of the location. AtoNs where human exposure was more likely warranted investigation, including: a) those deployed on land (0' of water) thereby accessible on foot; b) those in recreational areas; c)those where bottom types are particularly sensitive (such as coral reefs); or d)those that may promote the entrapment of elemental mercury (such as fine particulate soils) or the creation of methylmercury. Based on the findings of the Morel-Mason study and other environmental characterizations, four characteristics affect the likelihood of formation of harmful forms of mercury in aquatic systems and can be used for site selection. These characteristics are: 1) the salinity of the water (fresh vs. salt); 2) the organic content of sediment (high/low), higher organic content promoting the formation of methylmercury (Preston, 1989); 3) the sediment type or quality, ranging from coarse to fine grained where fine grained sediments attract metallic particles; and 4) the degree of mixing or " flushing" of the system.

Locations were chosen for study that represented a range of these four characteristics to provide data on particularly sensitive environments. Estuarine systems, such as those chosen for four of the six prototypes, were studied because they exhibit variety in salinity zones, bottom types, biota, and sediment quality.

Bottom types are often subdivided into a large number of categories, depending on the rockiness, muddiness, or sandiness of the sediments. Sixty-two percent of all fixed aids are located in some form of mud, and another 7 percent are found in " earth" bottoms (ATONIS, 1993). In this sense, AtoNs selected for study that were located in " muddy" bottoms represent most of the bottom types of AtoNs in the field. However, the national distribution of AtoN location bottom types is not easily replicated at the state or even Coast Guard District level, since bottom types are more specific to certain areas of the country than are water depths. In addition, bottom types affect the likelihood of battery breakage, mercury entrapment or dissolution, and the presence of biota likely to ingest any released mercury. Thus it was critical that a variety of bottom types be represented in the study, even if the number of locations exhibiting those characteristics was relatively small.Thirty-six percent of all fixed aids are located on shore (i.e., in zero feet of water), 29 percent are in water more that 20 feet deep, 20 percent are in 0 to 10 feet of water, and 15 percent are in 10 to 20 feet of water. Therefore, AtoNs were selected from all water depths, where possible, in each of the environments studied.The locations chosen represent sensitive environments, such as estuaries, a variety of salinity levels, ranging from fresh water to open marine environments; bottom types, including mud, sand, rock, and shells; and water depths ranging 0 to 50 feet. The sampling results for the Chesapeake Bay, Tampa Bay, Tennessee River, Puget Sound, Midway Island, and California Channel Islands represent the majority of depths, salinities, and bottom types where AtoNs are located. Based on this representation, generalizations can be made about most fixed AtoNs operated by the Coast Guard, with respect to the number of batteries likely to be found, the condition of the batteries, the level of mercury likely to be found in sediments. Generalizations can even be made about cleanup time and expected costs.

2.2.1 Chesapeake Bay

The Chesapeake Bay, located on the eastern coast of the United States, is one of the largest and most productive estuaries in the world. The main stem of the Bay extends approximately 190 miles from Cape Henry, Virginia, to the mouth of the Susquehanna River. The Chesapeake Bay is a submerged river valley, a remnant of the Susquehanna River Valley, which was inundated with rising sea level after the most recent glacial period.

The most important feature that distinguishes an estuary from a river or ocean is the temporal and geographic variations in salinity levels. In the Chesapeake, salinities range from about 35 parts per thousand at its outlet to the ocean to near zero at the head of the Bay and its estuarine tributaries. This variation in salinity is directly related to the quantity of freshwater inflow to the Bay from its tributaries. The estuary is fed by more than 50 tributaries comprising the 64,000 square mile drainage area; however, 90 percent of the freshwater contributed to the Bay originates in five major tributaries, the Susquehanna, Potomac, J ames, York, and Rappahannock Rivers. The Susquehanna,

draining from Pennsylvania and New York, provides approximately half of the Bay's freshwater.

As with most estuaries, the Chesapeake Bay supports a highly productive biological community. This, in turn, supports a large commercial and sport fishery quite important to the regional economy. The Bay is also an important recreation area for the region's nearly 15 million residents and, in turn, provides a lucrative source of tourism for the economy. The Bay has also served for centuries as a commercial shipping center, with two major port complexes connected by interstate highway, air, and rail systems to important inland points.

Several different bottom types and AtoN structures were characterized in the study on the Chesapeake. These ranged from a large, caisson structure surrounded by riprap, a multiple pile structure located in Annapolis Harbor, and two single pile AtoNs located in silty-bottom areas.

2.2.2 Tampa Bay, Florida

Tampa Bay is Florida's largest open water estuary and consists of a connected group of estuaries and embayments, which include Old Tampa Bay, Hillsborough Bay, Boca Ciega Bay, Terra Ceia Bay, and the Manatee River, as well as Tampa Bay proper.

Tampa Bay is a naturally shallow estuary, having an average depth of about 12 feet (Goodwin, 1984) and a maximum depth of about 90 feet in the Egmont Channel at the mouth of the bay. Sediments and bottom features in Tampa Bay are generally uniform, with the majority of coverage being unconsolidated sediments or soft bottom. Surface sediments in Tampa Bay consist of predominantly quartz sand. The average size of sediment particles increase from the upper to lower reaches of Tampa Bay. Organic sediments and fine silts and clays are found primarily in the upper portions of Hillsborough Bay. Sediments in the lower portion of the bay consist primarily of fine to coarse sands.

2.2.3 The Tennessee River

The Tennessee River is one of three major rivers (Tennessee, Cumberland, and Mississippi) that drain the state of Tennessee, providing hydroelectric power through the Tennessee Valley Authority Dam System. The study areas selected from the Tennessee River include Lakes Chickamauga and Nickajack, which are located in Hamilton County, Tennessee. Lake Chickamauga is multi-purpose reservoir providing flood control, hydroelectric power, and recreation. Lake Nickajack is a run-of-the-river system providing similar benefits to the area. The tail waters of Lake Nickajack and the deep pool area of Lake Chickamauga border Chattanooga, with the dam at Lake Chickamauga located northeast of the city. The normal pool area of Lake Chickamauga covers approximately 35,400 acres at elevation 682.5 mean sea level (msl). Lake Nickajack surface area at normal pool is 10,370 acres at elevation 34 msl. Bottom types throughout the lake and river system are soft, muddy, highly organic material.

2.2.4 Puget Sound

The Puget Sound system was created by mountain building and glacial activity. The area (4,973 square meters) encompasses the San J uan Islands to the north, Hood Canal to the west, and the Tacoma Narrows to the south. The numerous inlets and bays form a rare dendritic system that makes up the Puget Sound.

The sediment and biotic sampling sites for the Puget Sound study were chosen from Budd Inlet, which is a shallow estuary at the extreme southern end of Puget Sound. Located north of the city of Olympia, Budd Inlet is the major waterway connecting Olympia and Tumwater, and the Deschutes River is its major freshwater source. The inlet is approximately 6.9 miles long, with an average width of 1.15 miles and a maximum width of 1.61 miles. It is a partially mixed shallow estuary with muddy substrates. The average depth is 27 feet at mean low water. The shoreline and intertidal areas are moderately steep, and only the intertidal mud flats are located at the southern end of the inlet near Olympia Harbor. Puget Sound enters Budd Inlet through the Tacoma Narrows and Dana Passage, and is diluted at the inlet head by the Deschutes River. Water properties in Budd Inlet reflect these saltwater and freshwater sources. At times of high runoff, a surface layer of low-salinity water is observed in the inlet.

2.2.5 Midway Islands

The Midway islands are flat and formed on reefs surrounding a central lagoon. According to classical geological theory, an atoll is formed when a volcanic island subsides and sinks gradually into the sea. The encircling fringing reef grows upward at the same rate that the island sinks because corals thrive in the warm sunlit shallow water. The corals grow better on the seaward side than on the side facing the island because the currents bring more food, and so an ever-broadening channel is formed between island and reef. Finally when the island is completely submerged, a central lagoon remains, surrounded by a ring of reefs. Storms sweep coral debris together, and islands are formed on which living organisms can gain a foothold.

Midway Island was inhabited for commercial use in the early 1900s, leading to the development of shipping facilities. In the 1940s, the island was extensively developed into a naval air station.

2.2.6 Channel Islands

Four Channel Islands located in the Gulf of Santa Catalina, off the Coast of California, were included in the investigation. The Islands included were San Clemente, San Nicholas, Santa Barbara and Santa Catalina.

2.2.6.1 San Clemente Island

San Clemente Island is an active Navy facility (part of the Pacific Missile Range (PMR)) and civilian access to the island is prohibited. The island is located approximately 50 miles south southwest of San Pedro/Point Fermin in the Outer Santa Barbara Channel. The United States Government has owned the island since 1848.

Most of the Navy facilities are located at the northern end of the island with the remainder being used as bombing and shelling ranges. The southern shore, where China Point and Pyramid Head AtoNs are located, is heavily used as a shelling area and ordnance is visible on the ground surface. The area is generally actively used four or more days a week and all civilian activity is restricted from the near shore area during the period of active use. During other times civilians are allowed to bring boats to the shallow area off the southern end of the island for recreational purposes (primarily diving) but are not allowed on the shore or island.

The China Point and Pyramid Head AtoNs are located at the top of rocky cliffs. At both locations the soil and vegetative cover is very thin. At Pyramid Head there are both grasses and cactus while at China Point the vegetative cover is limited to grass clumps. The AtoN sites are barren and inaccessible.

2.2.6.2 San Nicolas Island

San Nicolas Island is an active Navy installation (part of the PMR) and no civilian or unauthorized access is allowed. The island is located 54 miles west of Port Hueneme and 24 miles southwest of Santa Barbara Island. Three AtoN sites (North Side, East End, and South Side) are located on the eastern tip of San Nicolas Island. In contrast to San Clemente Island, the three lights on San Nicolas are near the shore and not located on the top of cliffs. The land around the North Side Light is sandstone and hard packed wind-blown soils, with little or no vegetative cover. The soil and vegetation around the South Side AtoN are similar except that the AtoN is adjacent to a drainage ditch which channels surface runoff to a beach area during rain events. The conditions at East End light are generally similar to the North Side light except there is some sandy loam soil supporting some native plant growth.

Santa Barbara Island is owned and controlled by the National Park Service (NPS) as part of the Channel Islands park system. The NPS maintains a permanent presence on the northeastern shore of the island. There is a landing adjacent to the NPS facility and boat

landing at other shoreline positions is not feasible due to an unfavorable shore line topography. Use of the island for recreational purposes is strictly controlled and limited to designated hiking trails and camping areas run by NPS personnel.

Santa Barbara AtoN is at the northern tip of the island at the top of a steep slope which grades to a vertical cliff. Both the slope and cliff are exposed rock. The AtoN site is relatively flat with thin soil cover and sparsely vegetated with grasses. There are no designated recreational use areas in the vicinity of the AtoN. The NPS limits access between J anuary 1 and May 1 each year due to the nesting of the birds.

Santa Catalina Island is the largest of the four islands addressed in this report and it is also unique in that it is privately owned. The island is owned and managed by the Catalina Island Conservancy (CIC) as a nature preserve and recreation area. The island is located approximately 18 miles south southwest of San Pedro/Point Fermin in the San Pedro Channel. There are landing areas and beach access at several locations around the island, but none are present at the eastern end of the island where the East End Light AtoN is located. The AtoN is on a narrow, relatively flat, shelf on a near vertical cliff. Due to the gradient and exposure the soil and vegetation cover is very thin on the cliff face. There are isolated and sparse grass and low shrub patches in the flatter areas of the cliff, such as around the AtoN. Accessing the site is difficult. The USCG services the light by lowering personnel by cable from a helicopter.

2.3 Sampling Design Development

Environmental risk assessments involve numerous endpoints and complex receptors and varying levels of acceptable risk. Consequently many methods of estimating risk are also required. This complexity does not allow for the application of a standard set of procedures to all situations. Reference books on the subject strongly recommend a phased approach to environmental risk assessment. For instance, EPA (EPA 1993) guidance recommends a phased investigation allowing for the identification of potential problem areas before conducting detailed investigations of specific environmental media and receptors. This phased approach focuses attention and resources on areas of potential risk, eliminating media and receptors determined to be of no risk based on adequate data and simple screening techniques.

The environmental characterizations were designed to measure two types of AtoN battery risk; the direct effect on humans due to ingestion of mercury, and the environmental risk due to mercury releases into nearby sediments. If evident, human health risk results from inhalation of mercury vapor or from bioaccumulation of mercury--i.e. consumption of marine animals that consume smaller biota contaminated with mercury from batteries. Environmental risks to the biological community in nearby sediment at AtoNs results from release of the contents of spent batteries. These two types of risk are inter-related since lower-level organisms are the food of higher-level (trophic) organisms, and evaluation of the impact on the biotic community translates into an estimate of broader animal effects.

2.3.1 Aquatic Sites

Benthic biota and attached organisms were chosen for study to evaluate both human health and environmental risk because they were the best indicators of battery-specific effects. While humans normally consume larger marine animals, analysis of these species alone is an insufficient indicator of bioaccumulation risk directly attributable to mercury releases from spent batteries. The aquatic characterizations have focused on measuring the concentration of mercury in the benthic sediment layers and biota attached to or near batteries.

In addition to the selection of sediments and biota to characterize, the field sampling design had to account for variation in battery condition and dispersal around the base of the AtoN. Batteries were routinely found in varying states of decay, and varying locations near AtoNs. It was thought that concomitant variations in the exposure of battery contents to the environment and resulting measured mercury concentrations could result. The result of the program design effort was a detailed Sediment and Aquatic Biota Tissue Sampling and Analysis Plan (including Health and Safety Plan and Quality Assurance and Quality Control Plan) for each prototype investigation. The field investigation program was modeled after Superfund sampling and analysis efforts and incorporated approved methodologies and critical Quality Assurance/Quality Control Measures such as:

- Collection and analysis of duplicate samples

- Analysis of blank and spiked samples

- Complete chain of custody procedures

- Independent supervision of sample collection

- Decontamination and sealing of all sample containers

- Use of EPA approved laboratories for analysis

An aquatic sampling and analysis effort, evaluating both sediment and organisms, was implemented at all prototype locations (Chesapeake Bay, Tampa Bay, the Tennessee River, Puget Sound, and Midway Island. The objective of the sediment collection was to determine:

Whether mercury was being released from the batteries to the sediments.

- The extent that it accumulated and migrated.

- The form in which it occurred in the sediments.

The investigation was designed to address these questions by collecting sediments close to discarded batteries, at increasing distances from batteries and AtoNs, and at background locations where batteries had never been used. Sediment samples were collected using a tube that was carefully inserted into the sediment. When extracted, the tube contained an undisturbed core of sediment in the same state and configuration as it had existed on the sea floor. This procedure allowed analysis of sediment at increasing depths to describe mercury migration.

2.3.2 Terrestrial Sites

Terrestrial sites were sampled at the Tampa Bay and Channel Island locations. Two terrestrial Tampa locations were included as part of the prototype investigation and seven Channel Island AtoN locations were investigated after battery removal.

2.3.2.1 Tampa Bay

In addition to the aquatic effort in the Tampa area, land-based (or terrestrial) AtoNs were evaluated. Two representative locations were examined: an active AtoN surrounded by dry land on Egmont Key and an inactive light surrounded by wetlands on Anclotte Key. Terrestrial locations were included in the study due to the multiple exposure pathways to humans that can be encountered at this type of location.

The additional possibility of exposure to contaminants through inhalation exists at terrestrial locations, whereas the exposure pathways at aquatic locations are limited to drinking contaminated water, consuming a contaminated organism (such as fish or shellfish), or absorbing a contaminant through the skin while diving. Many terrestrial AtoNs are located in or near recreational areas, such as game preserves or state or national parks, increasing the likelihood of human exposure to mercury released from discarded batteries. Of particular concern is the possibility of exposure to mercury vapor, since discarded batteries may be piled above ground at some of these locations. Therefore, the possibility of harmful effects from mercury vapor was studied at the terrestrial sites.

The study program for each terrestrial AtoN had the following components:

Monitor air quality near battery piles for mercury vapor.

Collect and analyze soil samples outside the observed battery perimeter to use as background concentrations.

Collect and analyze soil samples adjacent to and/or beneath broken and unbroken batteries.

Collect and analyze soil samples at increasing distances from battery groups.

Collect and analyze groundwater and surface water if it is adjacent to batteries.

Describe physical attributes of the AtoN and surrounding area.

Locate, describe, and count batteries at each AtoN.

2.3.2.2 Channel Islands

The investigations at the Channel Islands conformed to the National Plan developed from the results of the prototype studies and closely paralleled the components of the Tampa Bay terrestrial sites. Subsequent to a human health risk assessment based upon comparing preliminary data to risk based concentrations, an ecological impact assessment was conducted to further evaluate ecological risk.

The ecological impact investigation at the Channel Islands had the following objectives:

Determine a realistic estimate of mean mercury and zinc concentrations in soils surrounding selected AtoNs.Determine an indication of the mercury methylation rate, by measuring percent methyl mercury at selected locations.

Measure mercury and zinc concentrations in tissue to estimate uptake rates from soil, to plants, to animals.

Conduct observations to refine a site conceptual model for ecological receptors.

2.3.3 Sampling Densities

The number of samples and their spatial distribution addressed the general distribution of potential contamination at AtoN sites. The sample design also reflects NOAA's recommendation to *"determine the overall effects from contamination immediately around the ATON site, not to characterize the specific pattern of contamination relating to a particular battery"* (Hoff and Beckvar 1993 p1). Determination of an appropriate number of samples and their spatial distribution was difficult to achieve since the pattern of contamination was unknown, therefore several assumptions had to be made and the sampling plan adopted based on information available for the location.

First, a logical area which could be defined as "immediately around the ATON site" had to be established. A 20-meter radius plot generally centered on the AtoN was selected based upon the findings of battery reconnaissance operations conducted in the Chesapeake Bay. Later, results of a demonstration battery removal program in Tampa Bay supported the selection of the 20-meter radius field. Utilizing this overall field size, the inner field was defined as within 10 meters of the AtoN. In Tampa Bay, 62.5 percent of all batteries found were within a 5-meter radius of the base of the AtoN; 95 percent were found within 20 meters of its base (Borener 1994).

The number of samples taken at sites (10 per AtoN) reflects a sampling density of 126 square meters per sample for all the prototype investigations except Midway Island. Sampling at Midway Island included 27 samples with a sampling density of 46 square meters per sample. The number of samples collected at each AtoN in the preliminary investigation varied from three to ten. Samples gathered for the validation investigation (12 per AtoN, 3 per background) reflect sampling densities of 104 square meters per sample at AtoNs. Table 2-1 compares the AtoN sampling program with other sediment sampling programs to show the level of consistency in the sampling density. Where applicable, the data were divided into (1) " Inner Zone" areas where the potential for elevated concentration of contaminants was the greatest and (2) the total area studied. For example, in the AtoN battery studies, the near-field areas were considered most likely to be affected by zinc and mercury (i.e., Inner Zone). At Midway Island, only an inner zone broken into subplots, and a reference subplot, were studied. All subplots had a sampling density of 4 meters squared per sample. A brief description of each project is included in Appendix B.

Since the sampling was not intended to be source-point-specific, a stratified random sampling approach was chosen. This approach reflected NOAA's concerns: *"we recommend against focusing sampling effort near visible batteries: the batteries may have moved over time, and may not represent all areas of contaminated sediment; inputs from buried batteries will be unaccounted for; sampling effort will focus on a few areas*

and may not represent the area of concern; and lastly, a battery-focused sample design will likely require greater sampling effort and provide less useful information for risked determination than a randomized approach." (Hoff and Beckvar 1993). Sample stratification was implemented to reflect the observed distribution of batteries around the base of the AtoN (CH2M HILL 1993) (Borener 1994).

Table 2-1 Sampling Densities

Site Type	Study	Site	Site Area (m^2)	Number	m$^{2/}$
AtoN	Prototype Investigation	Inner Zone	314	5	62
AtoN	Prototype Investigation	Total Site	1,256	10	126
AtoN	Midway Island Prototype Investigation	Total Site	1,256	27	46
AtoN subplot	Midway Island Prototype Investigation	Subplot	39	9	4
Other	Midway Island Prototype Investigation	Reference	39	9	4
AtoN	Channel Islands Ecological Impact Assessment [1]	Inner Zone	1,256	12	104
Other	Channel Islands Ecological Impact Assessment	Reference Subplot	1,256	3	418
Superfund	Eagle Harbor	Total Site	80,963	53	1,527
Superfund	Sullivan's Ledge	Total Site	52,025	30	1,734
Superfund	Pine Street	Total Site	15,793	5	3,159
Superfund	Ice Creek	Inner Zone	21,774	4	5,444
Superfund	Ice Creek	Total Site	43,548	6	7,258
Superfund	Bay Drum	Inner Zone	70,899	10	7,090
Superfund	Bay Drum	Total Site	80,207	12	6,684
Superfund	Commencement Bay	Total Site	1,876,206	53	35,400
Other	Florida Survey	Total Site	1,786,000	972	1,837
Other	Morton Beverly	Inner Zone	11,288	16	706
Other	Morton Beverly	Total Site	66,890	21	3,185
Other	Seal Beach	Total Site	80,936	23	3,519
Other	Lake Martin	Inner Zone	230,667	11	20,970
Other	Lake Martin	Total Site	2,480,688	43	57.960

(1) Information was not available for Channel Islands Human Health Assessment

2.4 Biological Sampling

The intent of the biological sampling and analysis program was to determine the potential uptake and bioaccumulation of mercury in animals in close proximity to discarded batteries.

2.4.1 Aquatic Sites

In the Chesapeake and Tampa Bays, organisms attached to batteries or other hard surfaces associated with AtoNs were collected and analyzed, to determine whether mercury concentrations in such biota exceeded concentrations in similar organisms in other portions of the estuary. Attached organisms were studied because they are immobile. Their immobility removes the possibility that any elevated mercury concentrations found in the organisms could have been accumulated at a different location. Similarly, if the levels were not elevated in animals that had been attached to batteries for their entire life) it would be unlikely that more transient animals, like fish or crabs, would accumulate mercury from batteries. The biological collection procedures used were designed specifically for the particular environments in which they were implemented. In the Chesapeake Bay, blue mussels (*Mytilus edulis*) were collected, where possible, because NOAA (NOAA 1989) and the EPA have used this mussel to evaluate national trends in water pollution, and there is a wealth of information on mercury concentrations in that species. Application of this planned procedure was limited by the absence of this species in sufficient numbers in the Chesapeake and Tampa Bays, and was modified for the Tennessee River, Puget Sound, and Midway Island studies. In the Tennessee River and Puget Sound studies, organisms dwelling within the sediments were analyzed. A deposit feeder *(Holothuria atra)* and territorial herbivorous fish *(Stegastes fasciolatus and Chaetodon fremlii)* were analyzed in the Midway Island study**.**

2.4.2 Terrestrial Sites

Biological samples were collected at the Channel Islands to evaluate ecological impact and refine estimates of the intensity of exposure to ecological receptors, including the island fox which was not sampled but was evaluated using exposure models. Organisms sampled were selected to represent three different exposure pathways. The types of organisms collected were:

- Plants

- Invertebrates

- Small Mammals.

Each sample was analyzed for mercury, zinc, lead, and copper. Plant sample locations were selected randomly within a 20 meter radius plot generally centered about the Aton, or about an arbitrarily selected point at the background area.   Soil invertebrates were collocated with vegetation samples in the area, although in a few cases no invertebrates were collected.

Due to logistical considerations, small mammals were only collected at San Nicolas East End Light and San Nicolas background areas. The small mammals were captured using live traps which were set in a transect pattern, resembling a "X" at the San Nicolas AtoN area and a "T" at the San Nicolas background area.

2.5 Summary

The site investigations were designed to asses contamination from metals released from batteries found at AtoNs. Initial site investigations revealed that the only contaminants of concern were mercury and zinc (the components of primary batteries) since few secondary batteries were found at any AtoN. Of the two contaminants, mercury is considered the more potentially harmful to humans and biota, however, the investigations continued to assess both zinc and mercury levels since both metals were present in primary batteries.

The sampling program was conducted in locations that represented the variety of the water depths, bottom types, currents and salinities of most AtoNs. The program followed a typical approach to site investigation used at Superfund sites, including a high sampling density near the " hot spots" of contamination. Uncertainties exhibited at AtoNs, such as expected contaminant dispersal and concentration warranted sampling density at AtoNs an order of magnitude higher than at most Superfund site investigations. Sampling stratification was implemented to address potential variability in contaminant dispersal due to movement of batteries.

The biological sampling conducted was, by necessity, site-specific. Biological samples were collected at the prototype and Channel Island sites. Variability among locations chosen for study sometimes required that different biota be collected, and that the method of collection be adapted to field conditions. Where possible, species with known or previously characterized normal mercury levels were collected during the study. The biological sampling program provided an estimate of the intensity of exposure for organisms that were likely to experience the highest potential total exposure.

3. Environmental Characterization Results

3.1 Individual Site Results – Sediment and Soil Concentrations

Aquatic and terrestrial locations were studied in the Chesapeake Bay, Tampa Bay, the Tennessee River, Puget Sound, Midway Island and California Islands using the sediment, soil and biota analysis techniques described in the previous section. These results demonstrate low contamination (if any) in substrate associated with spent batteries, no human health risk and minimal biological impacts.

3.1.1 Chesapeake Bay

Mercury concentrations in sediments adjacent to AtoNs in the Baltimore Area of the Chesapeake Bay were generally the lowest detected concentrations in all the prototype investigations. Levels at the three AtoNs evaluated were low compared to background levels both measured and reported in the literature (Long and MacDonald 1992). (Figure 3-1). The levels were also below the ecological benchmark concentrations levels "ecological effects range median" (ER-M) and "low"(ER-L). [*]
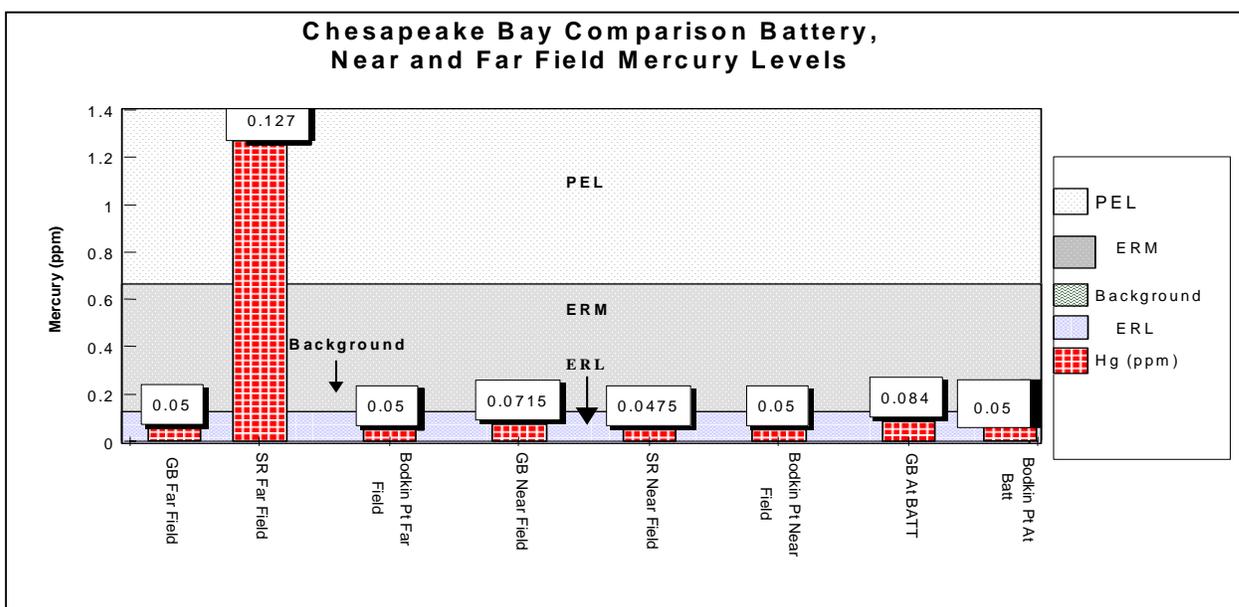

Figure 3-1. Chesapeake Sediment Results

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[*] A full description of the sources of these values their calculation appears in Appendix C.
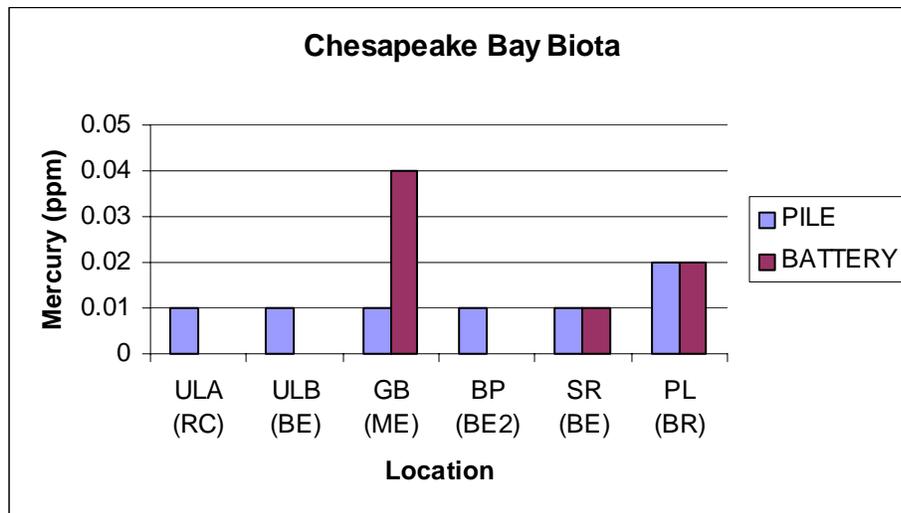
Figure 3-2. Chesapeake Biological Results

There was a strong statistical correlation (r^2 of 0.72) between the concentration of mercury and physical characteristics of the sediment seen at the Chesapeake Bay AtoNs (CH2M HILL, 1993b). In areas were there were fine grain sediments and abundant organic matter the concentrations were higher than in areas with larger grain size material such as sand. This correlation held whether there were batteries present or not.

Due to species abundance at the locations studied in Chesapeake Bay, biological samples of the same species could be collected within an AtoN site and among different AtoNs. The concentrations of mercury in biota at the AtoNs were generally at or below background levels, and well beneath the levels associated with risk in humans (CH2M HILL, 1993a).

3.1.2 Tampa Bay

The Tampa Bay Prototype investigation discovered large numbers of discarded batteries at several AtoNs, and a very high percentage of these were broken. The sediment mercury concentrations reflected this condition; at most of the AtoNs sampled, the nearfield sediment concentrations were above both the measured and the literature reported background levels (CNMS 1992) (Figure 3-3). At approximately half the AtoNs the concentrations were above the more protective ecological benchmark for sediment dwelling organisms (ER-L).
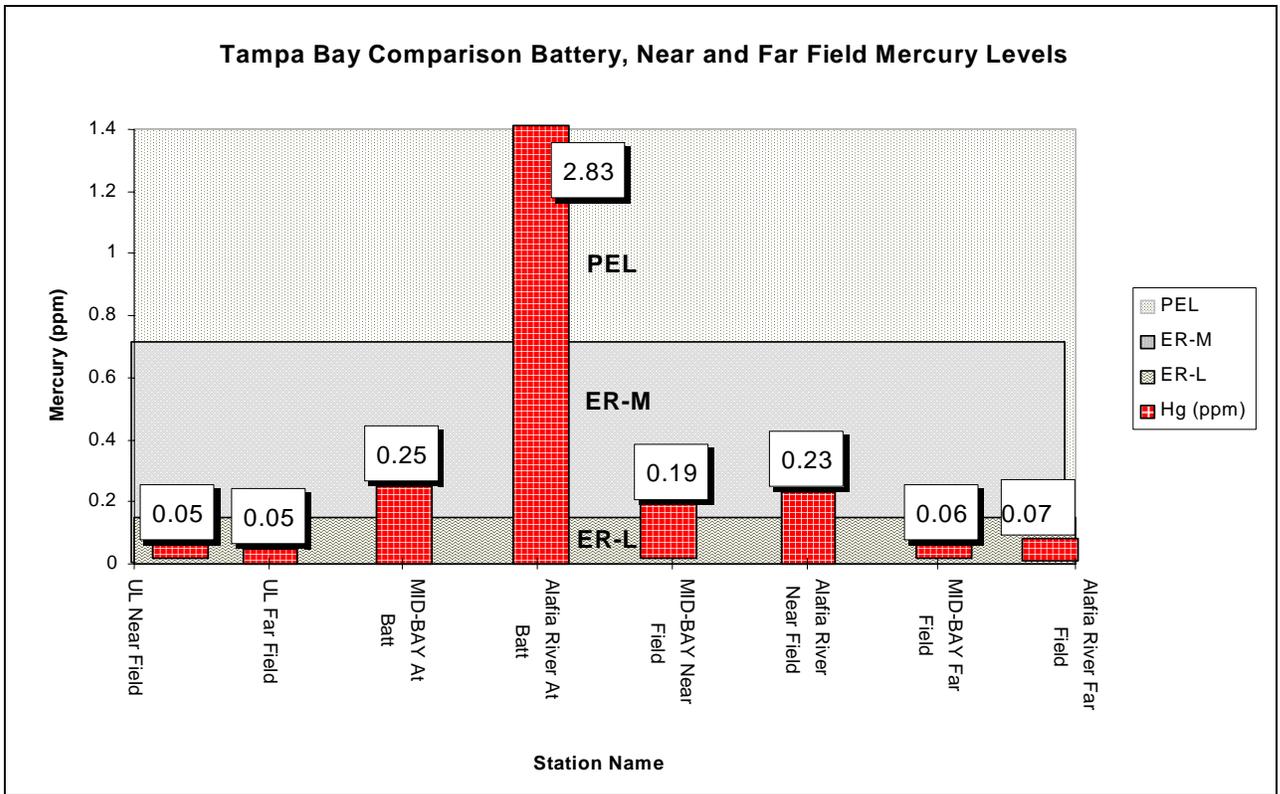
24

Figure 3-3. Tampa Bay Sediment Results

Although concentrations found in animals were less than the FDA action level indicating risk to human health, metal concentrations in sediments indicated some potential risk to marine organisms in small, localized areas close to high concentrations of batteries. Levels adjacent to batteries frequently exceeded concentrations usually associated with ecological effects (Long and Morgan, 1991) and always exceeded the most conservative concentrations considered to be associated with effects on sediment dwelling animals. Within 10 meters of AtoNs mercury levels did not exceed levels generally associated with effects but frequently were above the most protective ecological benchmarks. Beyond 10 meters no elevated levels were noted.

The eastern portion of the Tampa Bay system (Hillsborough Bay), have been previously documented as having a high silt and organic carbon content and elevated mercury levels from a variety of sources (CNMS 1992). The AtoNs sampled at the mouth of the Alafia River reflected this condition and at one AtoN (Alafia River Range Front Light) even exceeded the Hillsborough Bay background levels of 0.35 ppm. (Table E-3)

A wide variety of marine species were collected in Tampa Bay and mercury concentrations in all samples where well below benchmark values (NOAA, 1991) (Figure 3-4). The broad food web spectrum of animals collected, all with low mercury concentrations, in combination with the low percentages of methylmercury measured provides strong evidence for a lack of human health or environmental risk. However the broad range of animals collected, with little overlap among AtoNs and conditions within AtoNs, makes it difficult to compare samples and evaluate bioconcentration of mercury

originating from batteries. Even though all samples showed low levels there were some indications that the animals attached to batteries had slightly higher levels than similar animals attached to structures a few meters away. The animals on the AtoN structures adjacent to piles of batteries generally showed mercury concentrations at or below levels seen at reference stations with no batteries.
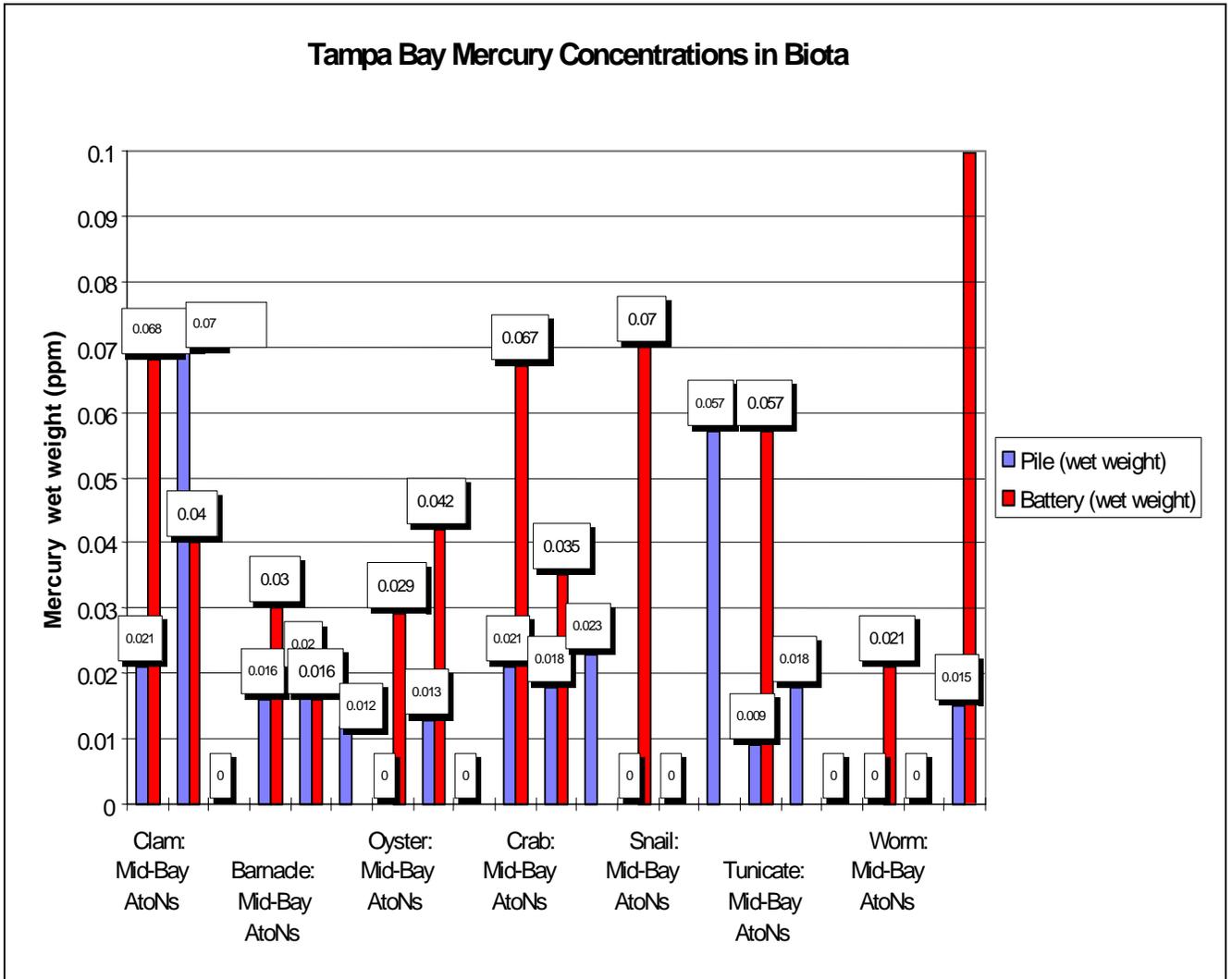

Figure 3-4. Tampa Bay Biological Results

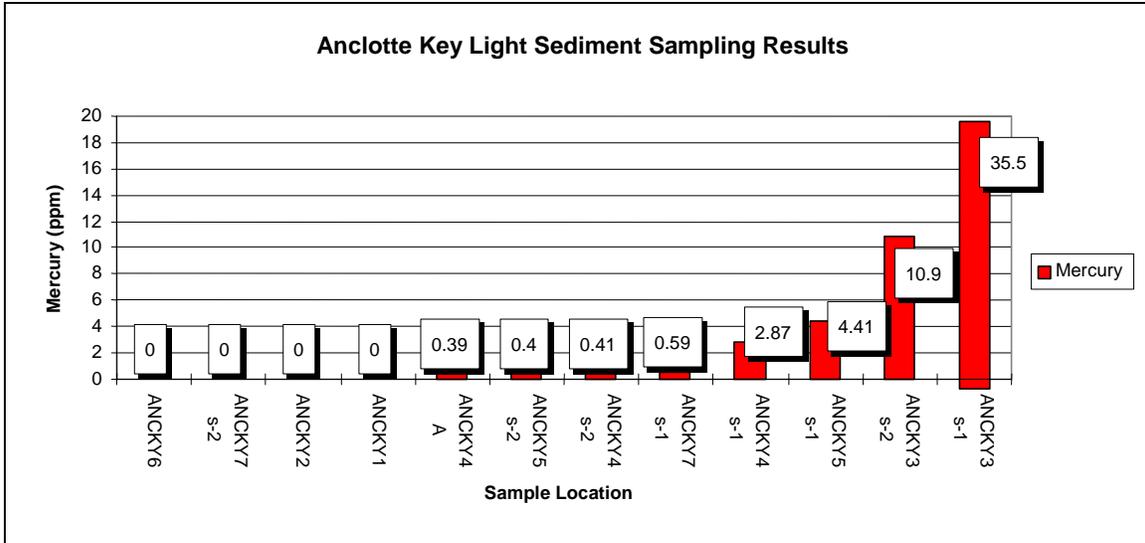**Anclotte Key Light Sediment Sampling Results**

Figure 3-5. Terrestrial Location Results - Anclotte Key Light

At the two terrestrial locations examined, Anclotte Key Light and Egmont Key Light, numerous batteries were located and the soil under and adjacent batteries piles (ANCKY3, EGKYG6) had elevated mercury levels (Figure 3-5 and Figure 3-6). However, the elevated levels were confined to a small area within a meter of the batteries and surface water samples collected within a meter of a battery pile had non-detectable levels of mercury. Even maximum soil mercury levels found were well below levels associated with human health risk.
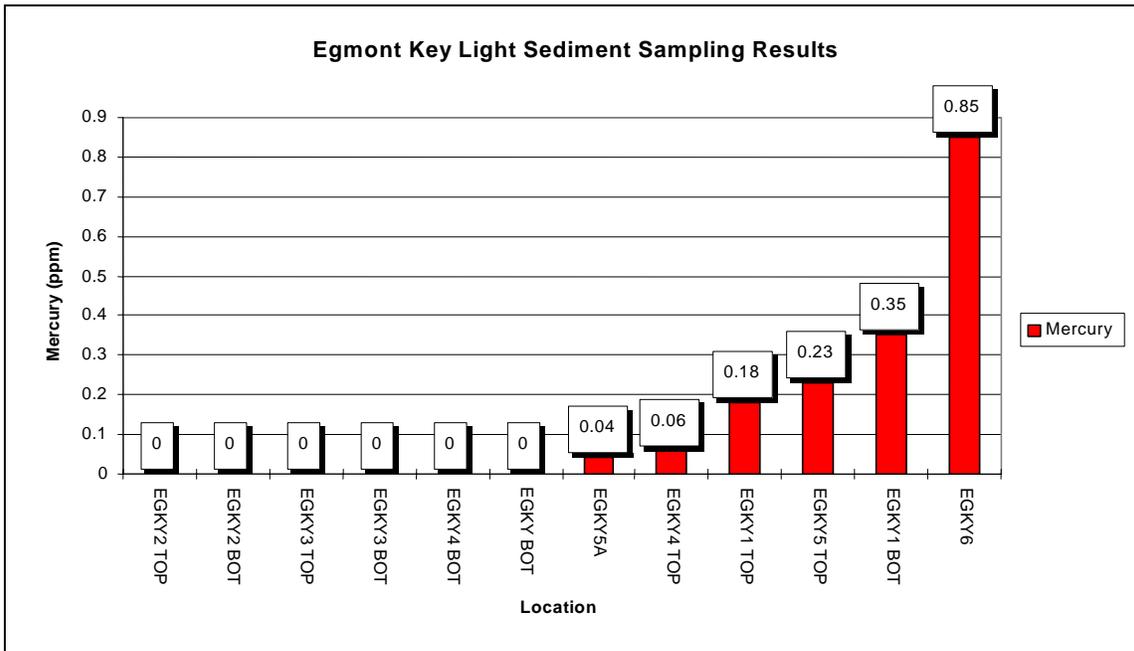
2.1.1

Egmont Key Light Sediment Sampling Results

Figure 3-6. Terrestrial Location Results - Egmont Key Light

3.1.3 Tennessee River

The evaluation of sediment mercury concentrations at Tennessee River AtoNs revealed no patterns relative to number of batteries present or proximity to battery piles. Mercury values at all AtoNs were below literature reported background levels but generally comparable to or above background values measured as part of the investigation at unlighted AtoNs (Figure 3-7). Two AtoNs, Patton Island lower (PTL) and upper (PTU) had noticeably elevated mercury levels but the available literature indicated that the samples were taken at the mouth of a tributary with documented mercury contamination in the watershed.
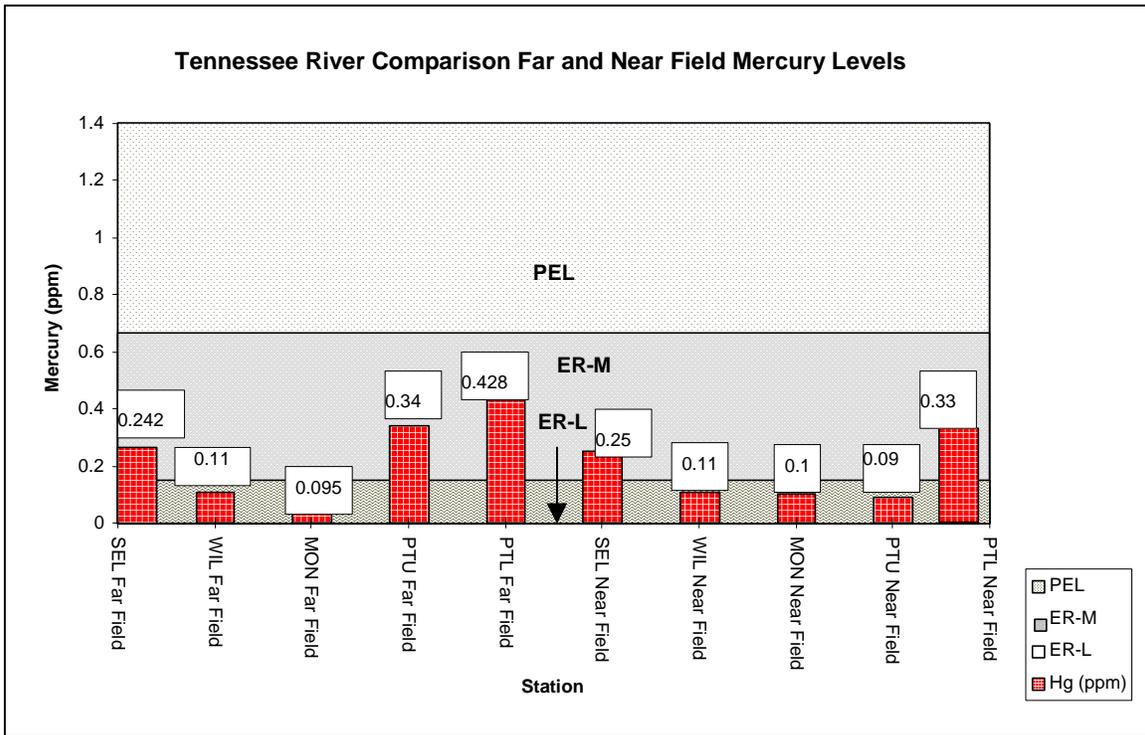

Figure 3-7. Tennessee River Total Mercury in Sediment

Similar to the sediment results, the analysis of biological tissue samples from the Tennessee River revealed no pattern of total mercury concentration relative to number or position of batteries (Figure 3-8). They also exhibited low concentrations relative to background, and in comparison to levels associated with risk. The levels of methylmercury in the sediments were also low, substantiating the finding of low bioavailability and bioconcentration and thus low risk.
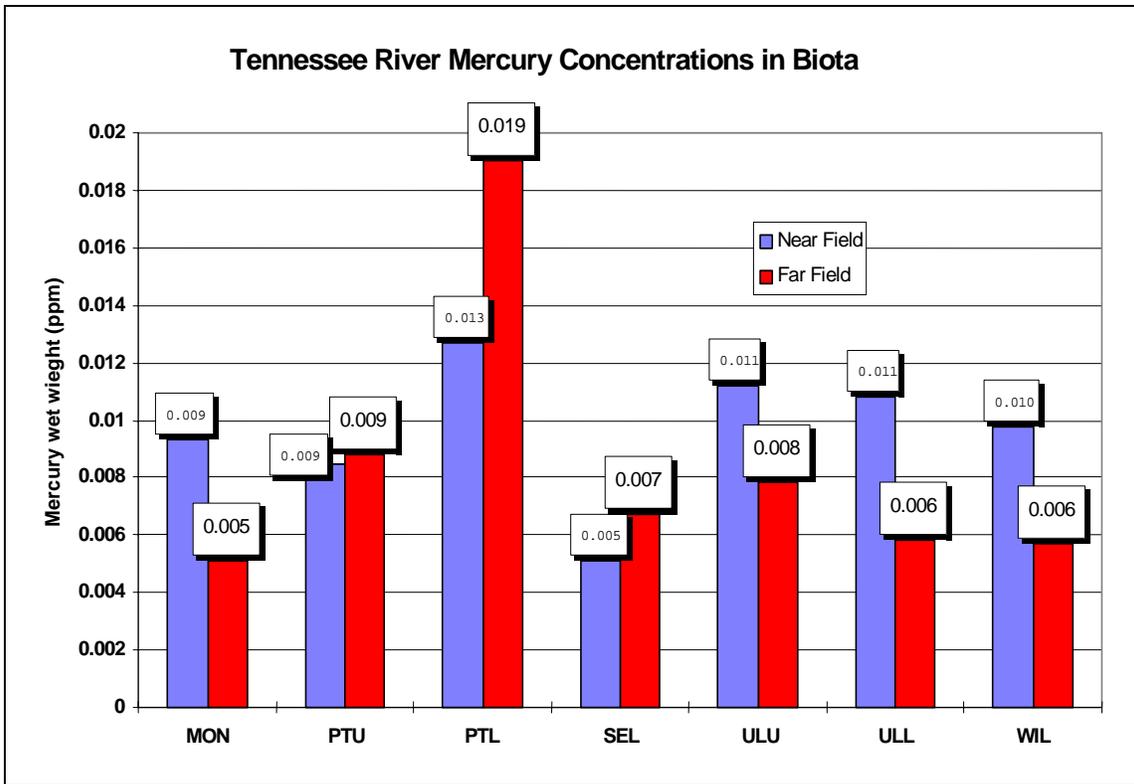
Figure 3-8. Tennessee River Biological Results

3.1.4 Puget Sound

The results of investigations in the Puget Sound revealed that metal concentrations showed no increase with proximity to batteries and were similar at lighted and unlighted AtoNs. Average mercury (Figure 3-9) and zinc sediment levels at AtoNs were similar to performance standards established in the Puget Sound Estuary Program for Puget Sound reference sites (i.e. uncontaminated sites) and background data from nearby areas in Budd Inlet not influenced by batteries. The highest concentrations of metals measured at the AtoN sites in Budd Inlet were well within the range of mercury and zinc measured at typical sites in Puget Sound, and even the highest concentrations observed were well below state standards for sediment mercury and zinc.
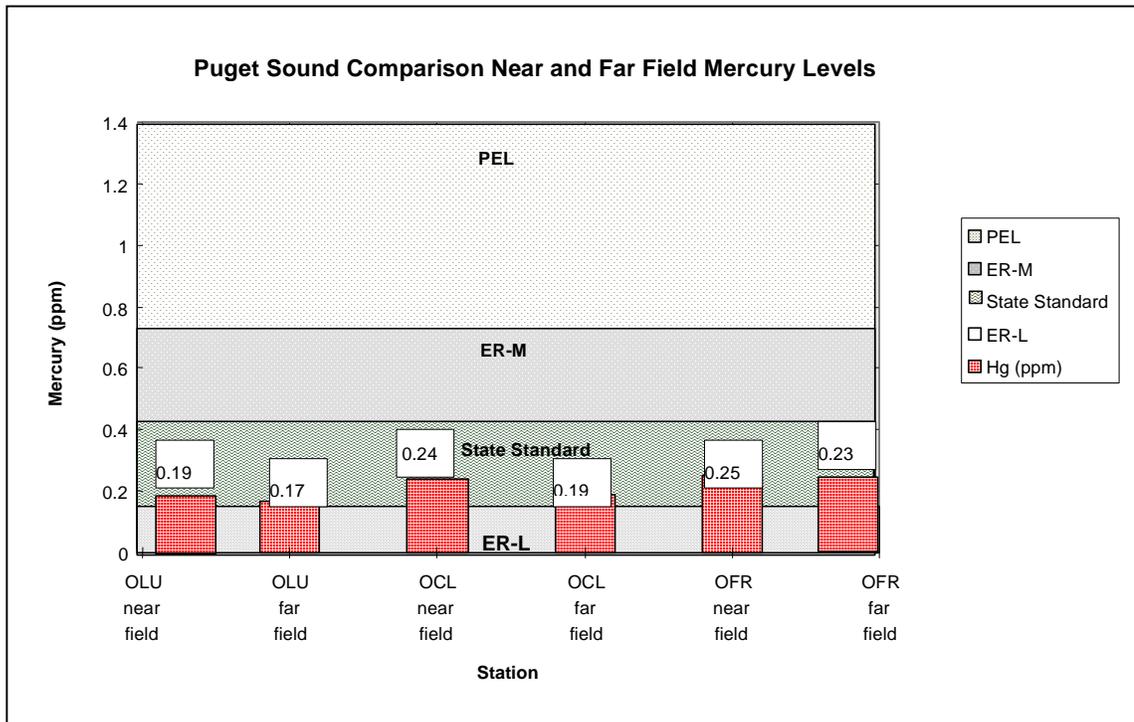
Figure 3-9. Puget Sound Total Mercury in Sediment

The sediment concentrations of mercury and zinc were below the levels (ERM) at which ecological impacts to benthic infauna are considered "likely" to cause effects (Long and MacDonald, 1992). There were, however, areas where concentrations exceeded levels reported in the literature to cause possible effects (ER-L) (Figure 3-9). The measured mercury concentrations exceeded ER-L levels at all sites, including the reference site, ULO. The most conservative benchmarks were exceeded by background levels measured at the reference site, which cannot be directly attributed to batteries. The risk indications to benthic infauna are minimal based upon low total and methylmercury levels.
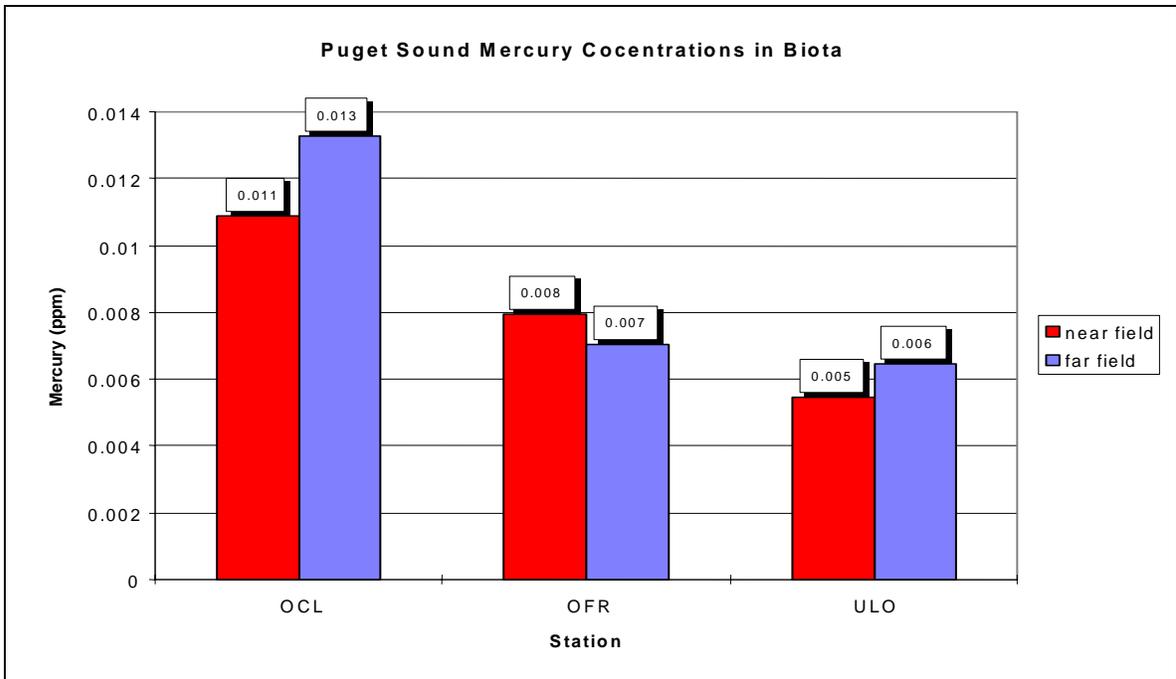
Figure 3-10. Puget Sound Biological Results

Extremely low concentrations of metals were measured in animals collected from the AtoNs. (Figure 3-10) The maximum mercury concentrations measured in all organisms were less than 0.1 ppm (wet weight). These organisms included clams found in areas where batteries could have been significant contributors to the total metal uptake. None of the mercury found in tissue samples could be linked to batteries, since far-field samples had higher concentrations, on average, than those taken near batteries.

3.1.5 Midway Island

The concentrations of total mercury and zinc in the sediments of the study area at Midway Island were very low (Figure 3-11). However, zinc and methylmercury showed an increase with proximity to batteries, and the area with the largest battery pile (Plot A) had significantly greater zinc concentrations compared to areas with fewer or no batteries.
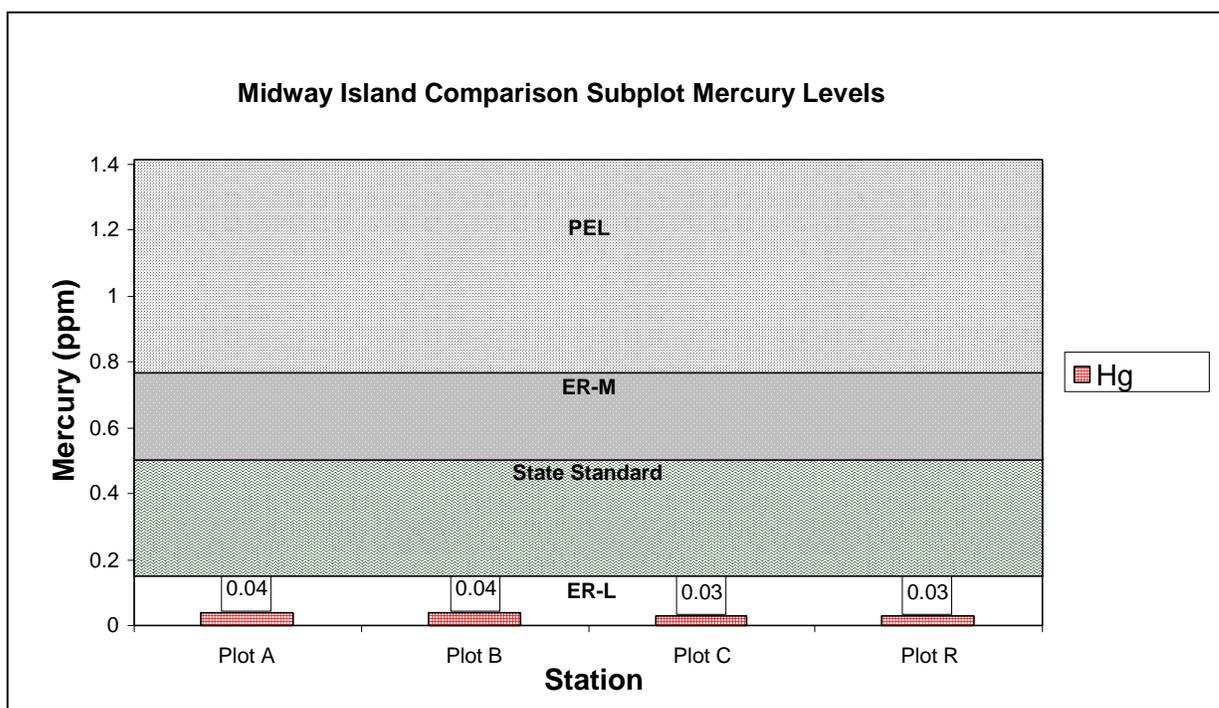
Midway Island Comparison Subplot Mercury Levels

Figure 3-11. Midway Island Total Mercury in Sediment

Although the data indicated that batteries may be affecting the concentration of zinc in sediments in localized areas around large battery piles (greater than 30), the highest measured concentrations of these constituents were not above mercury and zinc concentrations measured at typical sites at Midway or other uncontaminated sites in the North Pacific. Also, the metal concentrations at both AtoN and Reference stations were an order of magnitude below published benchmarks (Long and MacDonald 1992). Since the average mercury and zinc concentrations measured in the sediment at the AtoN and Reference were well below benchmark guidance values, it was concluded that levels of sediment metals in the presence of batteries were well below levels associated with adverse effects in benthic organisms.

Mercury concentrations in both the deposit feeding sea cucumber (Holothuria atra) and the territorial herbivore damsel fish (Stegaste fasciolatus) were not correlated with proximity to battery piles nor the size of the battery piles. Although tissue levels were extremely low, damsel fish collected at the Plot A located at the AtoN in the largest

battery pile (84 batteries), had higher mercury concentrations than areas with fewer or no batteries (Figure 3-12). In contrast, the average mercury tissue concentration in the sea cucumber showed the opposite effect, having higher concentrations in the Reference station than at the AtoN. All tissue concentration were below the FDA advisory limit of 1.0 mg/kg (wet weight).
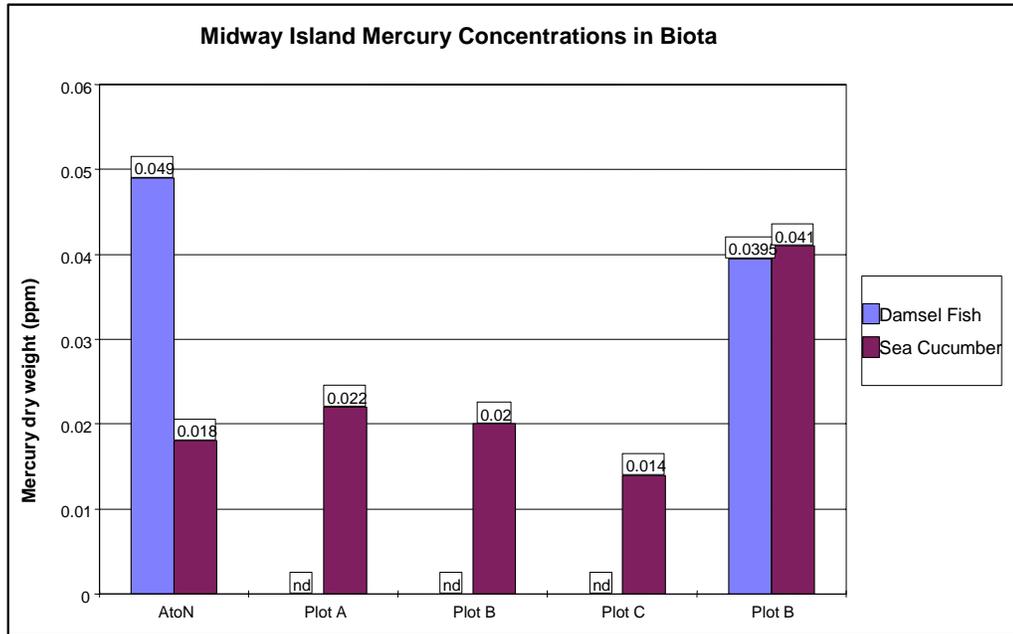
Figure 3-12. Midway Island Biological Results

3.1.6 Channel Islands

Sampling conducted about one year after battery removal showed that any initial limited releases of mercury during the removal process are quickly attenuated in the environment (CH2M HILL, 1997). This was true of not only mercury which was not detected in the later sampling, but also for zinc, lead, and copper (Table E-3). Since the higher concentrations documented during battery removal were determined to not pose a human health risk based upon comparisons to applicable risk based concentrations (CH2M HILL, 1996b), there was no need to evaluate risk to human health for the lower concentrations detected in the later sampling effort.

The mercury concentrations measured in the, plants, invertebrates and small mammals during the later investigation showed little or no difference from the concentrations found at background locations in those media (Figure 3-13, Figure 3-14, Figure 3-15, Figure 3-16). The concentrations present in the soils were compared to concentrations known to be safe for ecological receptors. Concentrations present in the plants and animals studies were also compared to concentrations determined to be safe for animals consuming these food sources, specifically the island fox. These comparisons showed that concentrations present in the soil were not harmful to ecological receptors, nor were the concentrations

present in food sources harmful to any animals feeding on those sources, specifically island fox.

Channel Islands Mercury Concentrations in Biota

Mercury wet weight (ppm)

Location	Vegetative	Invertebrates	Rodents
San Nicolas Island East	0.03	0.17	0.02
San Nicolas Island Background	0.04	0.08	0.02
Santa Catalina Island East	0.04	0.09	
Santa Catalina Island Background	0.04	0.16	

Figure 3-13. Channel Islands Biological Results for Mercury

Figure 3-14. Channel Islands Lead Concentrations in Biota
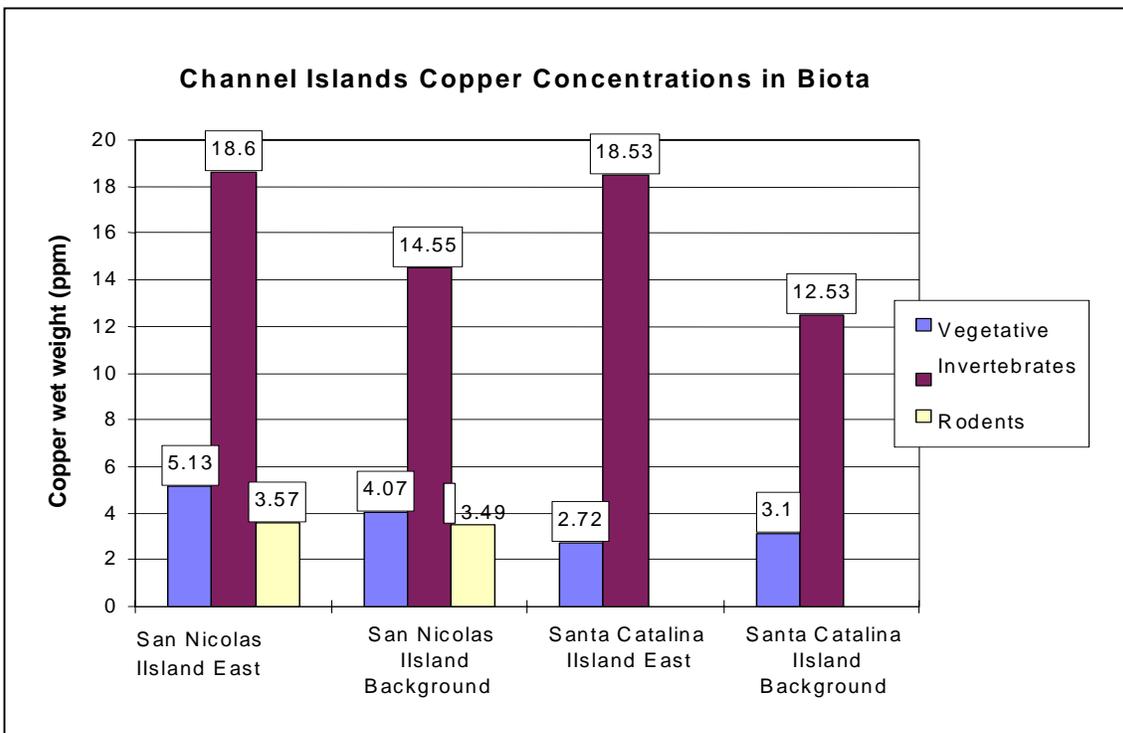
Figure 3-15. Channel Islands Copper Concentrations in Biota

Sampling conducted about one year after battery removal showed that any initial limited releases of mercury during the removal process are quickly attenuated in the environment (CH2M HILL, 1997). This was true of not only mercury which was not detected in the later sampling, but also for zinc, lead, and copper (Table E-3). Since the higher concentrations documented during battery removal were determined to not pose a human health risk based upon comparisons to applicable risk based concentrations (CH2M HILL, 1996b), there was no need to evaluate risk to human health for the lower concentrations detected in the later sampling effort.

The mercury concentrations measured in the, plants, invertebrates and small mammals during the later investigation showed little or no difference from the concentrations found at background locations in those media. The concentrations present in the soils were compared to concentrations known to be safe for ecological receptors. Concentrations present in the plants and animals studies were also compared to concentrations determined to be safe for animals consuming these food sources, specifically the island fox.   These comparisons showed that concentrations present in the soil were not harmful to ecological receptors, nor were the concentrations present in food sources harmful to any animals feeding on those sources, specifically island fox.
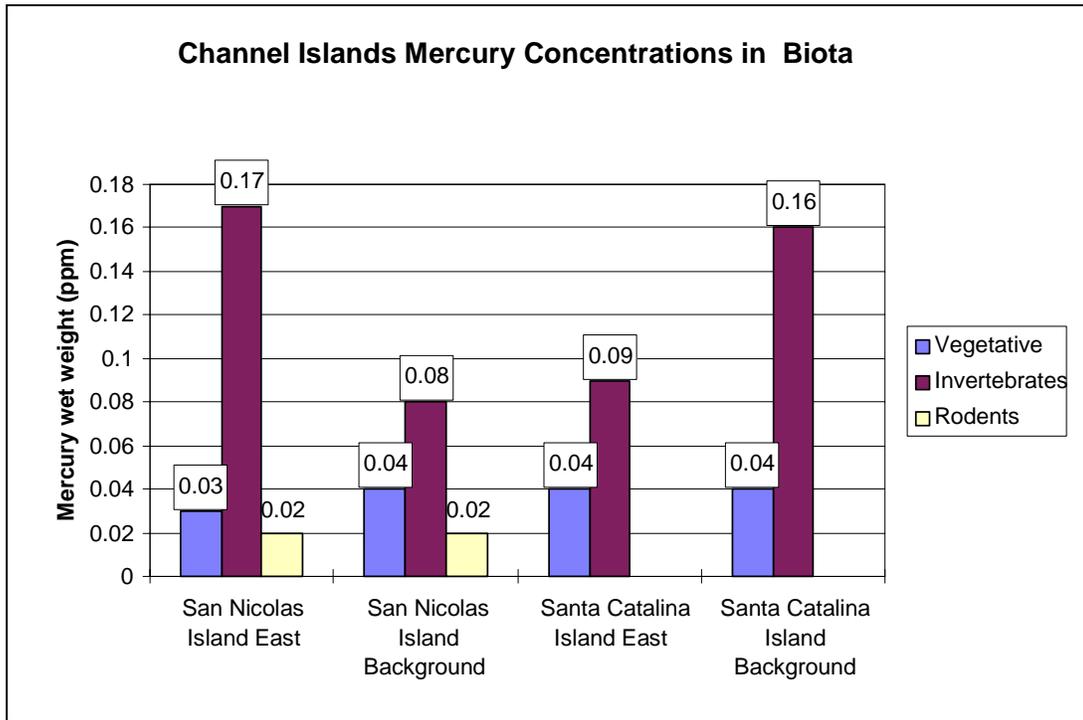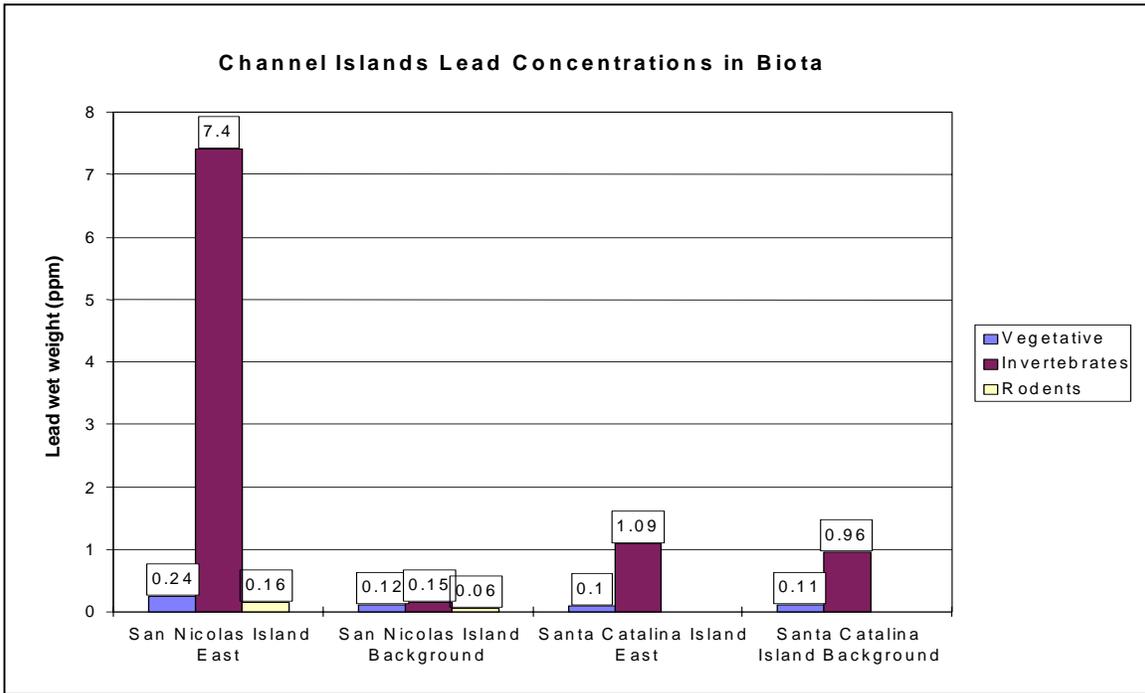

3.2 Methylmercury Results

Initial planning for the investigation considered an assessment of methylmercury important because of the potential biological effects. However, there were no benchmarks for comparison or assessment of effects, so several assumptions were made to add insight to the meaning of the data. The percentage of total mercury present in the methyl form was used for comparison because it provides some indication of methylation rates and bioavalability relative to other locations

Methylmercury was measured in approximately 20% of the sediment samples to asses the form of mercury present and provide insight to the potential biological effects of mercury in the sediment. Methylmercury is generally considered to be more toxic than other forms of mercury and more easily accumulated in tissue of aquatic organisms (USEPA 1985). However, methylmercury is rarely measured in marine samples, limiting the quantifability of toxicity or bioavailability of the methyl form in sediment.

Consequently, the actual levels of methylmercury found could not be compared to any screening levels or other benchmarks.

Instead, the relative proportion of methylmercury present in sediments, compared to similar background stations or values reported in the literature was used to assess results. Methylation rates are difficult to measure and generally only attempted under highly controlled conditions. It was not feasible to measure methylation rates as part of this investigation. In the absence of direct measurements, the percentage of total mercury present in the methyl form was used as a relative measure of methylation rate. This is based on the assumption that all other variables being similar, the higher the percentage of methylmercury, the higher the rate of methylation or the presence of a source of methylmercury. If higher rates, or a source of methylmercury was indicated, there could be cause for concern. Methylmercury occurring as approximately one percent of total mercury, as reported in the literature (Baudo et al. 1990), was used in this investigation as

the expected range. A percentage above this level was considered an indication of either higher than expected methylation rates or a direct source methylmercury. This is only an assumption, however, no other data were available to more accurately assess rates of methylation or concern over levels of methylmercury in sediments.

Organisms at the highest trophic levels bioaccumulate mercury predominantly through the food chain; the higher the trophic level of the fish or animal, the greater the likelihood of biomagnification. This is especially true for longer-lived organisms such as predatory fish, fish-eating mammals, and predatory birds. Since methylmercury is more easily assimilated and it can readily bioaccumulate, it is an important factor to be considered in sediment studies involving ecological risk .

The assessed level of methylmercury sampled during the prototype investigations was less than one percent of total mercury in all locations except Midway Island (where methylmercury was affected by the use of one half the detection limit for total mercury). The following graphs illustrate both the low percentages of methylmercury in sediment samples, and the fact the methylmercury levels are uncorrelated to the total mercury levels in sediments.

3.2.1 Chesapeake Bay

In the Chesapeake Bay, the methylmercury values reported for AtoN stations were minimal, less than one percent at all locations, and except for the very silty areas (UL2), less than 0.3 percent (Figure 3-16). These percentages were at the low end of the range
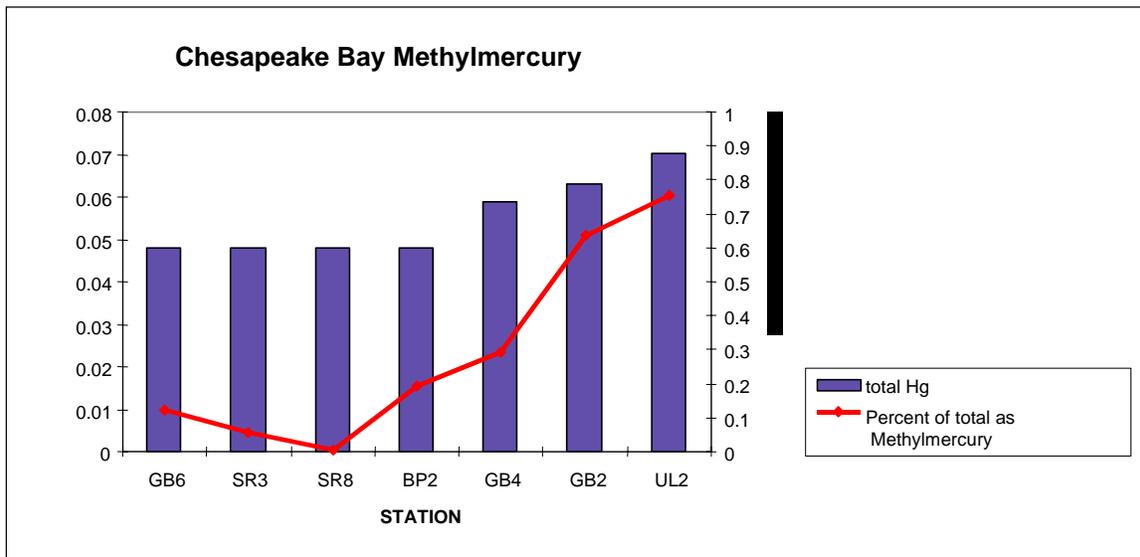
reported in the literature (Baudo et al. 1990).

Figure 3-16. Chesapeake Bay Methylmercury

3.2.2 Tampa Bay

The percent methylmercury found in Tampa Bay samples ranges form 0.01 percent to 0.57 percent, and concentrations ranged from 0.000006 mg/kg to 0.000749 mg/kg (Figure 3-17). The sample with the lowest percentage of total mercury as methylmercury was collected at the Alafia River Rear Range AtoN. A sample with a similar low percentage

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of methylmercury (0.012 percent) was collected at the Gadsen Point Channel Day Beacon 10 (the UB AtoN). Samples with the highest percentage of mercury as methylmercury were collected at station ER1 and ER5. These samples had methylmercury percentages of 0.571 and 0.434. With the exception of the two samples collected at the E Cut Rear Range AtoN, all of the samples had methylmercury values below 0.3 percent. These percentages are at the low end of the range reported in the literature.

Tampa Bay Methylmercury
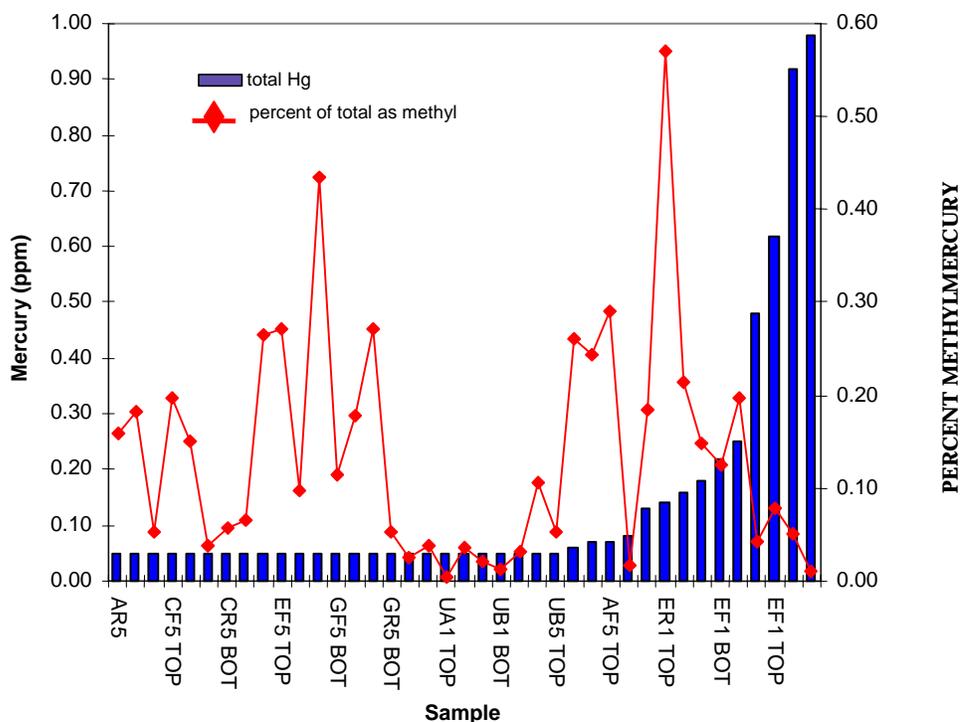
Figure 3-17. Tampa Bay Methylmercury

3.2.3 Tennessee River

Methylmercury in the Tennessee River samples ranged from 0.04% (Sample SEL4) to 0.23% (Sample PTU); concentrations ranged from 0.00009 mg/kg in samples ULU3 to 0.00045 mg/kg in sample SEL3 (Figure 3-18).   In Lake Chickamaugua, the data exhibited a trend with respect to location similar to that of total mercury, increasing with distance downstream from Station MON to Station PTL and then decreasing to Station ULU. This pattern corresponds to the increasing and decreasing total organic carbon and clay, suggesting that the sediment characteristics have the expected influence on methylmercury concentrations in sediments.However, there does not appear to be any relationship between methylmercury concentration and batteries. This lack of relationship can be seen in Figure 3-18.
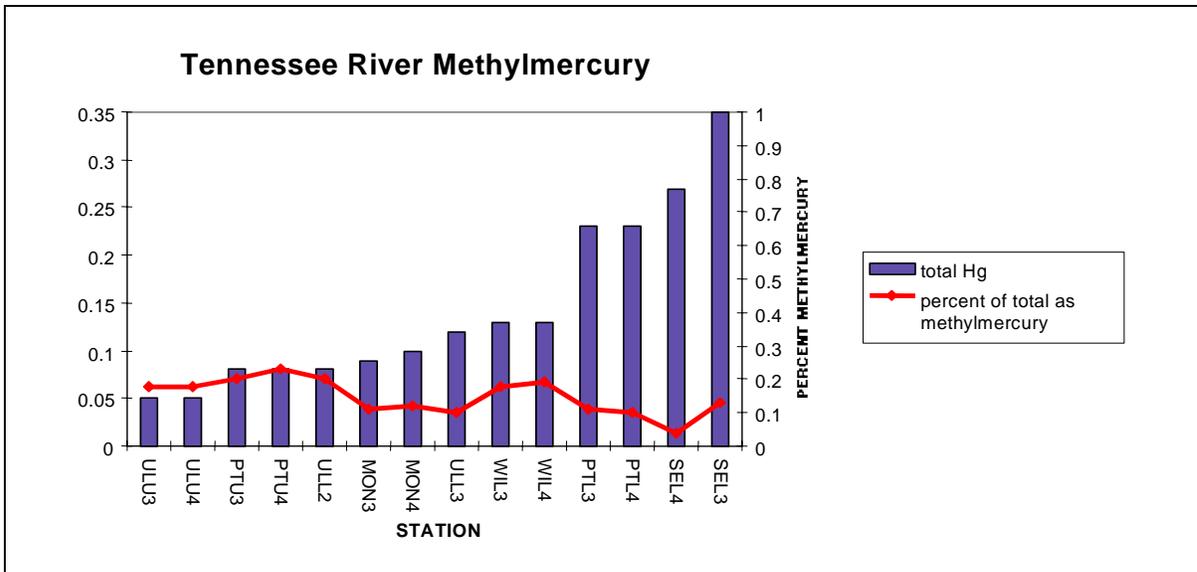
Figure 3-18. Tennessee River Methylmercury

Methylmercury generally represents 0.1 to 1.0 percent of the total mercury in marine sediments.   In all samples, methylmercury values were below 0.23 percent, which is at the low end of the range reported in the literature. Based on this comparison, there does not appear to be a risk to benthos due to methylmercury.

3.2.4 Puget Sound

The percent methylmercury for the Puget Sound samples ranges from 0.34 (Sample OFR 2) to 1.10 (Sample OCL 10); concentrations range from 0.000696 mg/kg to 0/0001862 mg/kg.

2.1.2

2.1.3
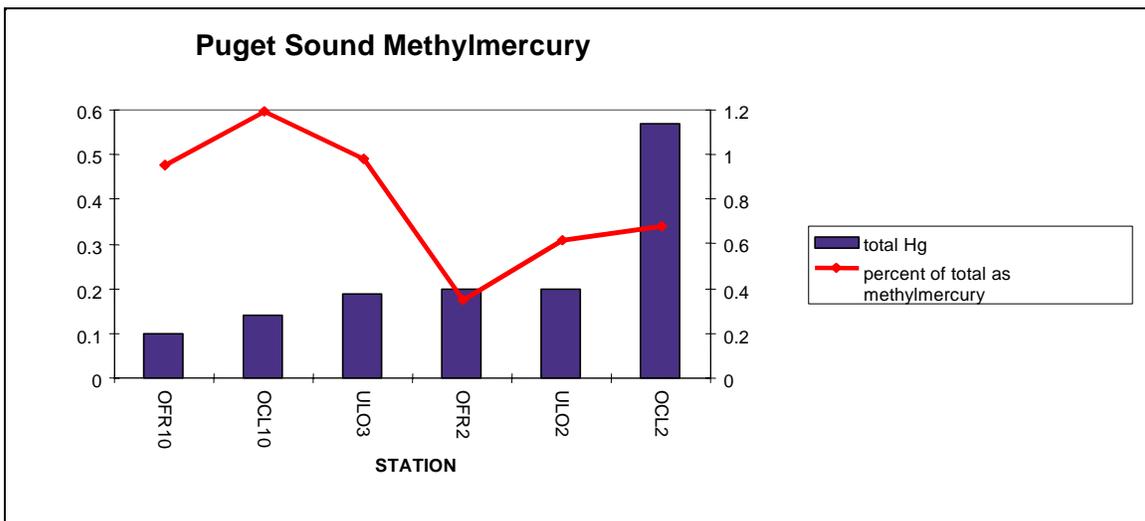
Figure 3-19. Puget Sound Methylmercury

2.1.4

Figure 3-19 illustrates the percent of total mercury as methylmercury for Puget Sound samples. The data were variable and do not indicate a pattern with respect to battery proximity. The methylmercury concentrations measured in Sample 3 (0.001962 mg/kg) collected well away from a group of batteries was between the range of methylmercury values measured in sediment Samples 2 (0.000696 mg/kg) and 10 (0.003857 mg/kg), collected near a group of batteries.

The results of methylmercury analyses from all locations revealed no levels in exceedance of 1.0 percent methylmercury. No location indicated a cause for concern.

3.2.5 Midway Islands

Three sediment samples from each of three plots (A,B,C) as well as a reference plot were analyzed for methylmercury. One sample in each of plots A and B were collected from under batteries and were analyzed for methylmercury (Figure 3-20).

Island Front Range lighted AtoN. However, the percentages were influenced by the fact that total mercury was not detected at those locations.

Mercury was not detected in most samples but for the two samples in which mercury was detected, the percent methylmercury was less than 0.7. The data displayed a pattern of higher methylmercury levels with respect to battery locations. The average methylmercury concentration measured for all samples in Plot A (0.000076 mg/kg), collected inside the zone of concentrated batteries, was at least 3 times the average methylmercury sediment concentration in plots with less than half the battery count (Plot B, 0.000025 mg/kg) or no batteries (Plot C, 0.00001 mg/kg and Reference, 0.000007 mg/kg) (Figure 3-21). These data indicate that batteries may be affecting the levels of the methylated form of mercury localized in sediments at the Midway.
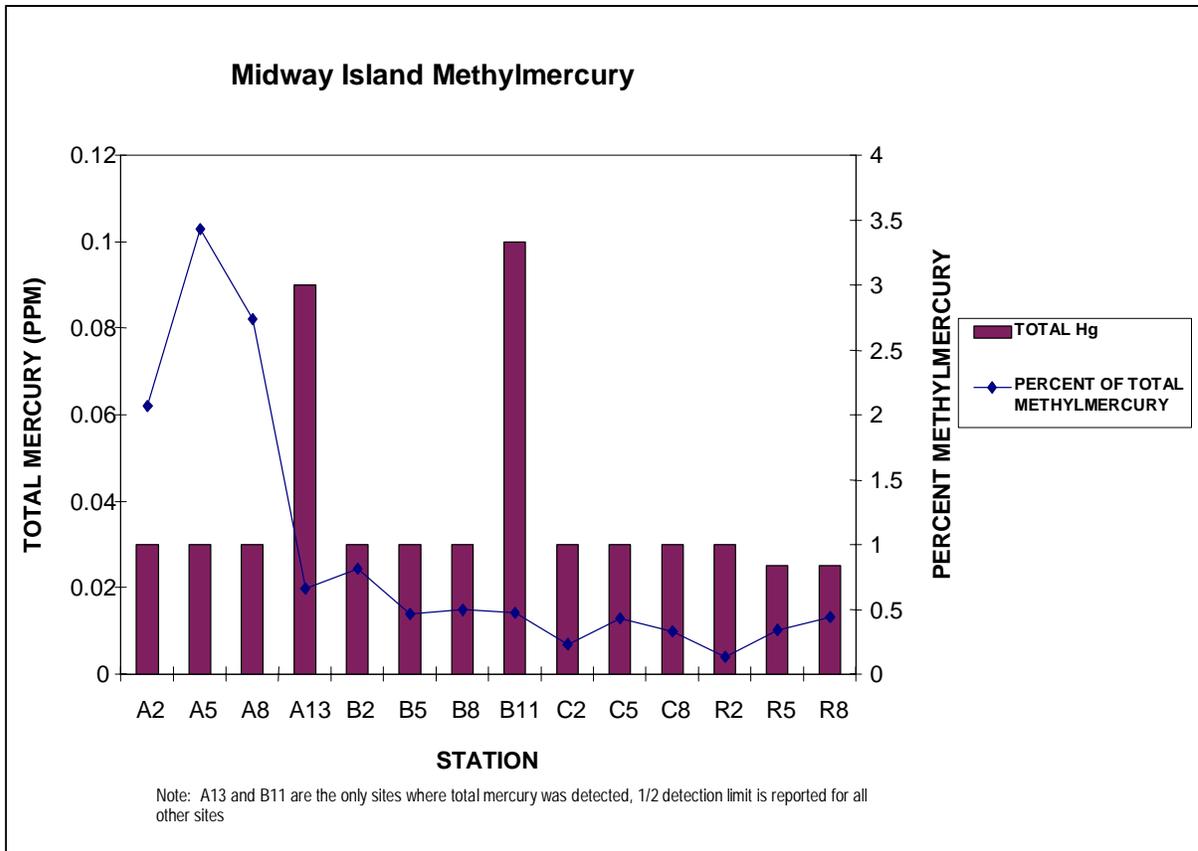
Figure 3-20. Midway Island Methylmercury

2.1.5

2.1.6   3.2.6 California Channel Islands

A total of five samples, two from each AtoN and one from a background site, were analyzed for methylmercury during the validation investigation. Concentrations of methylmercury were all below 0.002 mg/kg. The maximum concentration of methylmercury was several orders of magnitude below the potential risk threshold of 1.0 percent. As was the case with the prototype investigations, these levels are well within the normal percentages of methylmercury at sites not affected by known anthropogenic sources of mercury (Baudo et al. 1990).

Channel Island Methylmercury

Note: total mercury was not measured at Santa Catalina
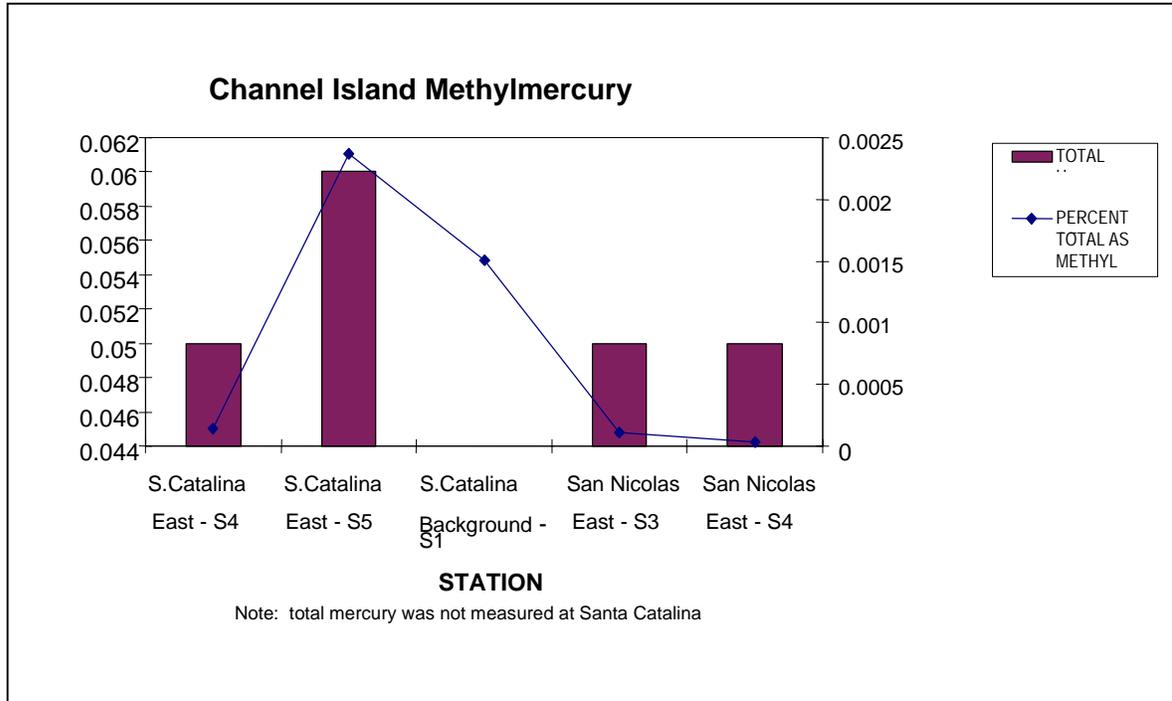
Figure 3-21. Channel Island Methylmercury

3.3 Post Removal Demonstration

The Volpe Center also conducted a demonstration cleanup project in the Tampa Bay area. The purpose of this project was to address the immediate remedial requirements in Tampa Bay and to develop a standard method for addressing other removal actions. Confirmatory sediment sampling and clean-up documentation was produced for each site. Volpe Center staff and contractors began battery removals in the Tampa Bay area immediately following a battery site sampling and removal prototype effort on J anuary 31, 1994. Battery removals took place at locations identified during a previous aquatic survey conducted by Law Engineering, Incorporated (Law Engineering, 1993). That survey identified 29 sites (of their surveyed 47) that had visible batteries, and they predicted that about eight hundred in total could be removed. The actual number exceeded 1300.

Sediment samples were collected during the demonstration project.   Some AtoNs surveyed during the Tampa Bay prototype were resampled during the demonstration project; that is, after battery removal was conducted.   Before and after comparisons at those sites, as well as the sediment sample results at other sites are included in this report. As with all other locations, the important comparison criteria for AtoN battery sediment sample results are the established background levels (based on perimeter sampling) and the NOEL, ER-L, ER-M and ER-H levels. The former, "background" level, was established at each location based upon the value of the "perimeter" of 20 meters. This level established an on-site comparison mercury–level value for each study location. The other values presented in Figure 3-9 reflect the state and nationally established levels of concern for these metals in sediment. These levels are established by a complex statistical method described in the notes following at the end of this chapter. The important point regarding these criteria is that they provide comparison values at which various environmental or health effects might be expected.

In most cases, sample values were at or below the ER-M levels, however, there were some elevated levels detected during post removal sampling. In some cases the level of mercury in comparable samples before and after removal increased by over 800%, but they were not typical. Since the number of cases of increases are low (in fact in some cases the percent changes are negative), it appears that either the sample randomly discovered a "concentration spot" or battery removals contributed to a transient recontamination of the field.
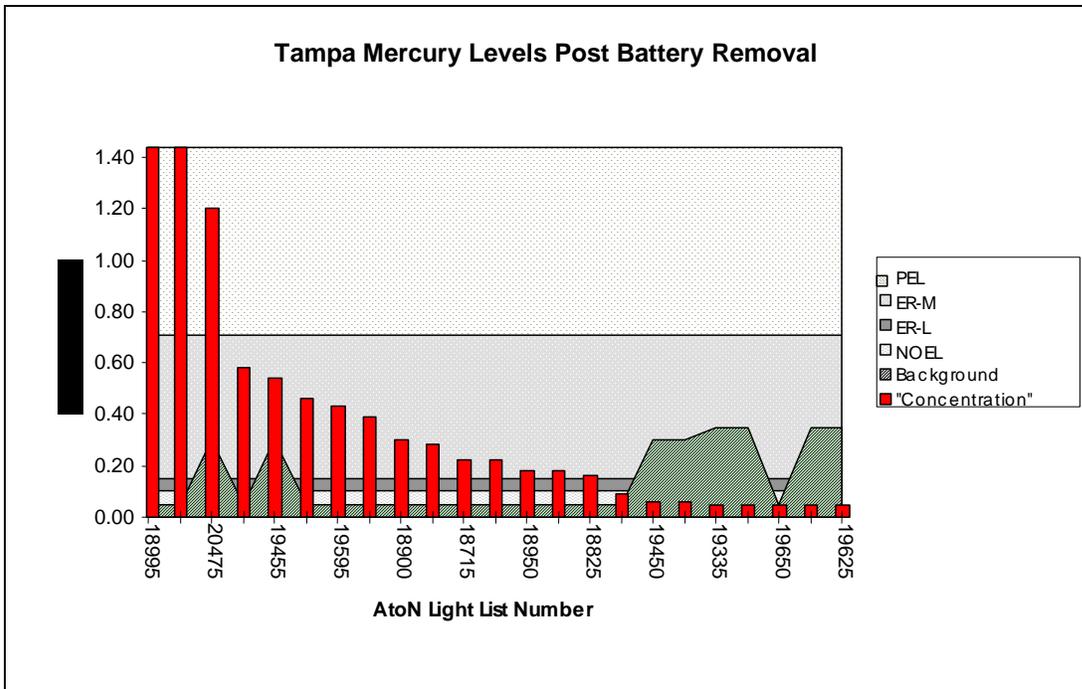
Figure 3-22. Tampa Bay Post Battery Removal Total Mercury in Sediment

3.4 Summary of Results

Sediment and biological sampling was conducted at five locations, as part of the prototype investigation program. The results of these investigations revealed a pattern which indicates little, if any, detectable risk due to spent primary AtoN batteries. For example, the Pooles Island Light, examined as part of the Chesapeake Prototype investigation, exhibited a combination of characteristics that could result in environmental risk. The habitat around Pooles Island Light is abundant with fish, crabs, and other marine organisms that could accumulate mercury. Discarding batteries onto the rip rap (e.g. large rocks used to inhibit erosion) at the base of the light resulted in a large number of broken batteries, and the oyster bar substrate could prevent mixing of the mercury from the batteries into the sediment. The result could be relatively high concentrations of mercury at the sediment interface. However, investigations at the site revealed a pattern of association of mercury levels that correlated with the sediment type, not with the presence of batteries. The lack of any evidence of mercury risk due to batteries at this type of site supports the conclusion that batteries pose a very small risk to the aquatic environment in general.

While the results of the prototype investigations varied by location, some common trends were noted.   A full description of each study is available in individual reports for each prototype investigation.   In general the findings were:

The extremely low percentage of methylmercury, and thus low risk potential, was common at all of the characteristic aquatic environments examined. Very low mercury concentrations were detected in the aquatic organisms, even those attached to batteries. These findings indicate no significant risk to human health or the aquatic food chain.

The limited spatial distribution of mercury within the sediment was another common pattern detected during the prototype program. In most cases elevated sediment

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concentrations, if any, were confined to the immediate vicinity (less than one meter) of batteries and in all cases if there were any slightly elevated concentrations detected beyond one meter, the condition was limited to 10 meters or less from the AtoN.

In almost all cases, even the highest mercury concentrations measured around AtoNs was within the range of background concentrations measured as part of the investigation or reported in the literature for the general prototype investigation area.

There appear to be elevated sediment concentrations of mercury associated with high density of discarded batteries, and also with broken batteries. When both of these conditions occur, the sediment levels approach and in some cases even exceed levels associated with adverse effects on sediment dwelling organisms. However, even in the areas of highest battery concentrations and greatest percentage of broken batteries, methylmercury concentrations and levels in aquatic organisms are well below those that pose a potential risk to humans or the aquatic food chain.

There are special circumstances and conditions that occur at AtoNs, such as high biological productivity, hard sea bottom, and high number of broken batteries, which in combination can produce relatively high mercury concentrations and sensitive exposure pathways and thus potential environmental risk.

The prototype and demonstration programs estimated the risk associated with spent primary batteries in terrestrial and aquatic environments.

Risk indicators included:

an assessment of total mercury in sediments

an assessment of the percent of total mercury in methyl form

and an assessment of the level of mercury in biota.

The findings of the prototype investigations showed:

- low to non-detectable levels of total mercury in sediments;
- little, if any, evidence of bioavailability of mercury as measured by the percent of total mercury in methylated form, and
- no evidence of harm to aquatic biota as measured by total mercury in biological tissue.

The results of the demonstration removal program at Tampa Bay indicated that battery removals may have a short-term effect of elevating the level of mercury in sediments immediately following removals. Results of the post removal investigation at Tampa Bay human health and ecological impact assessment conducted at the Channel Islands corroborated this conclusion.

4.0 Results and Conclusions

The risk evaluations resulting from the prototype, battery removal and Channel Island investigations are presented in this section. These conclusions consider the concentrations of contaminants of concern in the substrate (sediment for aquatic sites, soil for terrestrial sites), the results of comparisons to conservative environmentally protective thresholds and background levels.

4.1 Areas Investigated

The potential for ecological trophic impacts was evaluated by studying the concentrations of methylmercury in substrate and organisms selected based upon their having a high potential for exposures. The result of all these efforts indicate that there is little potential hazard associated with the AtoN batteries at aquatic locations, and essentially a nonexistent potential for impact at terrestrial locations.

4.1.1 Sources of Potential Concern

The long-term potential for human health or environmental concern from AtoN batteries is limited to the uncontrolled release of metals. Other contents of the battery either pose no hazard, such as the plastic casing, or rapidly dissipate and cause no long-term threat, such as acid or caustic solutions. Since the batteries of concern (primary batteries, which represent over 99 percent of the type found) have generally not been used since the mid-1980s, only long-term effects are of concern. The metals present in batteries and thus of potential concern are lead, zinc, and mercury. The demonstration and prototype investigations revealed that virtually all the batteries found at AtoN locations were primary batteries, which contain only zinc and mercury. Prototype investigations in the Chesapeake Bay and in Tampa Bay analyzed the sediments in the vicinity of batteries for lead and found no correlation of lead concentrations with lighted AtoNs, proximity to batteries, condition of batteries, or number of batteries. Consequently, it was concluded and fully substantiated that lead, which is present in secondary but not primary batteries, was not of concern and posed no hazard at U.S. Coast Guard AtoNs.
Elevated concentrations of both zinc and mercury were found associated with at least some of the lighted AtoNs investigated during the prototype study. Consequently, these metals were determined to be the potential contaminants of concern, and the concentrations of each metal were recorded at each prototype site. Because of the greater toxicity and bioaccumulation potential of mercury, however, the following discussion focuses on mercury.Mercury in AtoN batteries was originally present as an elemental amalgamate coating the electrodes. As the batteries were used to light the AtoN, laboratory investigations indicate that much of it vaporized to the atmosphere. The remaining mercury dissolved in the solution within the battery, remained on the electrodes, or adsorbed to the particles associated with the discarded battery.If mercury released from batteries is present in freshwater or marine systems, it will be more concentrated in the sediments than in the water column. Most of the mercury associated with batteries has low solubility (as determined by the laboratory portion of this study), and thus is associated with particles. In fact, studies have found that over 90 percent of mercury in lakes has been associated with the sediments (Foust and Aly 1981).

Similarly, at the one AtoN where mercury was measured in the water (in the Chesapeake Bay), all of the detected mercury was particulate, and none of it had dissolved. Even if mercury from batteries does dissolve into the water column, the constant flushing, dilution, and dispersion, which is associated with tidal, riverine, and large lake systems where AtoNs are most commonly located, would diminish concentrations significantly below those of concern. These findings strongly support the conclusion that mercury from AtoN batteries is much more of a concern when in the sediments than in the water column. If there is not a very strong and extensive indication of hazard in the sediments, there is no reason to consider pathways associated with the water column at most AtoN locations. For this reason, the prototype investigations focused on sediments, and future consideration of potential hazards associated with AtoNs should generally be directed at sediments.

4.1.2 Fate and Availability of Mercury

Most of the mercury from batteries discarded in the vicinity of AtoNs does not enter a human health or environmental exposure pathway.

If the casings of the discarded batteries were broken, the liquid contents were released immediately. In those cases, the dissolved ionic and methylated forms were quickly diluted and transported away from the AtoN. The elemental forms remaining on the electrodes, or other forms associated with the batteries, dissolved very slowly and were then also rapidly diluted and dispersed away from the AtoN. Some of the dissolved mercury was most likely scavenged by particles, some of which were deposited in the immediate vicinity of the battery. Similarly, it is likely that some of the soluble mercury was converted and settled in the immediate vicinity of the batteries. In this case a portion of the particulate material associated with the batteries was likely deposited close to the AtoN, and the mercury adsorbed to the particles deposited in the sediment.

When primary batteries were discarded near the AtoN and not broken, a similar process has taken place, only over a longer time frame. In some cases, such as seen in the Tennessee River, the mercury is released very slowly, probably over several decades. In such cases, the dilution and dispersion during the release period results in such low concentrations that the presence of mercury, or ingestion by organisms (if any), cannot be detected above the natural variation. In areas such as Tampa Bay, the mercury was probably released over years, rather than decades, as the cases deteriorates and storms damage the batteries. In such cases, the releases may sometimes be detected.

The mercury which was released into the water column, either initially in the dissolved form from broken batteries or over time in other forms, entered the aquatic pool of mercury which undergoes extensive cycling and transformation. The mercury in this pool can enter exposure pathways through ingestion by aquatic organisms and vaporization. However, even on a very local scale the mercury from AtoN batteries is an insignificantly small fraction of the total mercury pool in the freshwater or marine system.Mercury which is deposited in the sediments close to the batteries can potentially be available for ingestion in or exposure to aquatic organisms. The quantity of mercury in the sediments close to batteries slowly decreases over time through (1) transformations followed by dissolution into the water column, (2) resuspension and transport of the sediment particles and the associated mercury, (3) burial and preservation in the sediments, or (4) ingestion by biota. Ingestion by biota is the pathway that can

potentially result in exposure and hazard to human health and the environment. The other possible destinies of the mercury associated with sediments in the immediate AtoN area could pose a hazard, but the degree of hazard is only a fraction of that from ingestion and exposure by sediment dwelling organism in the proximity of the AtoN. If this pathway shows no or minimal hazard, there is no concern about entry of the mercury in the other pathways.As described in detail in Section 1, mercury in the aquatic environment undergoes multiple and complex chemical transformations. The transformation of greatest concern is the formation of the organic or methyl form. Methylmercury is more soluble than the elemental form and also much more toxic and available for ingestion by organisms. The factors affecting and rates of methylation are not completely known but the process is complex and dynamic. Methylmercury in the sediments of aquatic systems generally represents only a small fraction of the total (about 1 percent or less) unless there is a source of methylmercury or conditions in the environment, such as flooded wetland soils, that accelerate the rate of methylation. Without exception, all of the prototype, post removal, and laboratory investigations of AtoN batteries revealed low methylation rates. The results established that batteries were not a source of methylmercury, and that methylation rates adjacent to batteries were not elevated above those of the locality studied. Methylmercury in AtoN batteries were measured in low concentrations in laboratory studies. At no location was the percentage of methylmercury higher near batteries or in areas with a high concentration of batteries than in a reference site for the same locality. Finally, the low concentrations of mercury and methylmercury found in organisms substantiates the conclusion that batteries have no effect on the bioavailability of mercury. In areas with high methylmercury concentrations, organisms accumulate mercury in the tissue directly from water and sediments and also through the food chain. At all the lighted AtoNs investigated the levels of mercury in tissue was within the range seen in areas not affected by batteries.

4.1.3 Potential Human Health Hazard from Discarded AtoN Batteries

Based on comparison to conservative and accepted media specific standards, mercury from discarded AtoN batteries do not pose a hazard to human health from pathways related to air, soil, surface water, sediment, or consumption of aquatic biota.
Multiple measurements of mercury vapor from batteries at terrestrial AtoNs in the Tampa Bay area revealed levels well below levels of concern. The measurements were taken directly over the batteries and thus represent the most exposed pathway. Consequently exposure by inhalation pathways does not pose a hazard.
Soil samples were taken at two Tampa Bay area terrestrial AtoNs and at seven AtoNs on the four Channel Islands. Samples were taken under, adjacent to, and at increasing distances from batteries. Although the mercury levels were slightly elevated at the batteries they were well below levels considered by the U. S. Environmental Protection Agency to pose a health hazard.As discussed above, batteries in aqueous situations are not expected to result in measurable levels of mercury in the water column. Thus the only potential hazard from dissolved mercury would be through ingestion by aquatic organisms and human consumption of the organisms. The same is true at locations where the most critical exposure pathways from sediments to human receptors are through consumption of aquatic organisms.

The laboratory analysis of batteries indicated the mercury is not in the available form. This is substantiated by the low percentage of methylmercury in sediments associated with lighted AtoNs. It is also directly confirmed by the measurement of low tissue levels of aquatic organisms in the vicinity of AtoNs.

During the prototype investigation mercury levels in aquatic organisms was only a fraction of the levels considered by the U.S. Food and Drug Administration (FDA) to result in a hazard from consumption. During all the prototype investigations, approximately 280 biological samples were analyzed for mercury. None of these samples were more than 10 percent of the FDA level and most were closer to 1 percent. Even this is a very conservative comparison because only total mercury was measured in the tissue and the FDA limit is based on methylmercury (which is generally on about 40 to 60 percent of the total in invertebrate tissue). Consequently consumption of aquatic organisms from areas around AtoNs is not expected to pose a health hazard to humans.

4.2 Mercury Concentrations in Substrate Associated with AtoNs

At most locations there was no indication that AtoN batteries resulted in elevated levels of mercury in the substrate (sediment and soils). Tampa Bay, where there were many batteries and a high percentage of broken cases, was an exception. The measurement of metals in sediments in Chesapeake Bay, Tennessee River, Puget Sound, and Midway Island showed no correlation with proximity to batteries or lighted AtoNs.

4.2.1 Chesapeake Bay

In the Chesapeake Bay the measured mercury concentrations correlated well with physical characteristics of the sediment, particularly organic carbon in the sediment. This is a common phenomena in certain estuaries were the small size particles associated with high organic carbon levels have large surface areas and thus more metal can adhere to the surface of the particles. In the Chesapeake Bay the relationship with sediment type was the same whether or not batteries were present. Neither the number of batteries found, the proximity of sediments to batteries, nor proximity of sediments to lighted AtoNs was found to affect sediment mercury concentrations in the Chesapeake Bay Prototype investigation. The mercury concentrations in sediments around AtoNs in the bay, were well within the range of reference concentrations reported in the literature for the portion of the bay investigated. Similarly the concentrations at lighted AtoNs was similar to or below the concentrations measured at unlighted (and thus no batteries present) AtoNs during the prototype investigation.

4.2.2 Tennessee River

In the Tennessee River investigation elevated mercury concentrations were found but associated with sources other than AtoN batteries in the subwatersheds of the river. Samples collected within 20 meters of AtoNs, revealed similar sediment concentrations regardless of proximity to batteries. Statistical as well as subjective evaluation of the data revealed no differences in concentrations between samples close to batteries (generally within 10 meters of the AtoN) and samples beyond the area where batteries were found. Except where a munitions manufacturing facility in the subwatershed was a documented source of mercury, measured concentrations at lighted AtoNs was within the range reported in the literature at unaffected areas and measured at unlighted AtoNs. Where elevated mercury levels were found, samples located 20 meters or more from batteries had similar concentrations to samples adjacent to battery piles**.**

4.2.3 Puget Sound

There is a relatively extensive body of information of background or reference area mercury concentrations in Puget Sound sediments. There has even been a background range established for unaffected areas of Budd Inlet, which is the inlet where the Puget Sound AtoN Prototype investigation was conducted. All of the samples collected at AtoNs, both lighted and unlighted had very similar concentrations and were within the established background range for Budd Inlet and Puget Sound. Samples were collected within and adjacent to battery piles and at increasing differences from the concentrations of batteries. Both statistical tests and qualitative assessments concluded there was no difference in mercury concentrations close to batteries compared to locations up to 30 meters away. Similar tests also concluded no difference between samples from lighted and unlighted AtoNs.

4.2.4 Tampa Bay

In Tampa Bay conditions varied considerably from those observed at the other prototype investigations. There were over 200 batteries found at some AtoNs and it was not unusual to have over 50 primary batteries per AtoN. Also, a high percentage of the batteries were broken, either when they were discarded or subsequently as the cases deteriorated. As a result of these conditions, the findings of the Tampa Bay prototype investigation indicate that mercury was released from the batteries and some accumulated in the sediments.

The distribution of mercury sediment concentration around the eight lighted AtoNs investigated in Tampa Bay showed a very similar pattern. The average concentration of samples taken 10 meters or more from the AtoN (where batteries were only rarely found) was comparable to concentrations at unlighted AtoNs and the background concentration reported in the literature (about 0.06 mg/kg). Within 10 meters of lighted AtoNs, where most batteries were found, the average concentration of mercury (about 0.20 mg/kg) was about four times background concentration. The average of samples collected adjacent to batteries, the concentration measured was even higher (0.25 mg/kg).

4.2.5 Midway

Mercury concentrations in sediments were measured at a variety of conditions on Midway Island. Samples were taken in areas: of large battery piles; small battery piles; no visible batteries but close to AtoNs; and no AtoN. In areas of batteries, samples were even taken directly under batteries. There was virtually no difference in mercury concentrations from the sediments of all these areas. Mercury was not detected in over 90% of the samples and where detected the concentrations were very low.

4.2.6 Channel Islands

Mercury was below detection limits (detection limits were set well below levels known to cause effects) in the soils at the Channel Islands AtoNs following battery removal. Mercury was detected in low concentrations in plants, invertebrates, and small mammals that reside in the area. However the concentrations in the biological tissue was similar at the reference and AtoN areas. Also the concentrations in tissue was well below levels which exert and adverse ecological effects.4.3 Potential Environmental Hazard from Discarded AtoN Batteries

AtoN batteries generally do not pose a hazard to organisms in freshwater or marine ecosystems through direct exposure to sediment or water column dwelling organisms or through bioaccumulation in the tissue of organisms. However, under certain combinations of environmental and AtoN conditions there may be hazard to sediment dwelling organisms in the immediate vicinity or batteries (i.e. less than 10 meters). The hazard is expected to be low and over a very small area and thus even in extreme cases there does not appear to be any hazard at the community level.

Hazard to aquatic ecosystems was investigated by examining both sediments (because as described above they are the most likely pathway of exposure) and tissue concentrations of sediment dwelling organisms (because they are the most likely and direct receptors). The investigation of sediment focused on the total and methylmercury concentrations in sediments around AtoNs.

Potential for hazard from mercury in sediments was evaluated by comparing measured concentrations at AtoNs to values reported in the literature to cause adverse effects to benthic animals and sediment values in reference areas. Possible hazards from mercury ingestion and bioaccumulation was evaluated in a similar fashion by comparing mercury concentration in animals collected on or near batteries to other values as was done for sediments.

4.3.1 Chesapeake Bay

In the Chesapeake Bay mercury concentrations in sediments were below even the most protective benchmark concentration [National Oceanographic and Atmospheric Administration Effects Range Low (ER-L), which represents the lowest 10 percent of concentrations found to produce an effect in sediment dwelling organisms] . All areas of all lighted AtoNs had values below the ER-L (0.15 mg/kg) even though the values found at the unlighted AtoN and values reported in the literature for the area were above 0.2 mg/kg. Consequently in the Chesapeake Bay, it is highly unlikely that mercury from AtoN batteries in sediments is affecting sediment dwelling organisms, which represent the segment of the marine community most likely to be adversely impacted. Investigation of mercury concentrations in tissues of marine organisms in Chesapeake was limited to collection of species of opportunity. Animals attached to batteries and the AtoN structure were analyzed and compared to background samples reported in the literature and at unlighted AtoNs. In the Chesapeake the samples collected on batteries and attached to lighted AtoNs were similar to specimens collected at the unlighted AtoN and within the range of background values reported in the literature. The values were also below concentrations reported in the literature associated with adverse effects. The applicability of the comparisons were limited because the same species could not be collected at every location and background values were not reported in the literature for all of the species collected.4.3.2 Tennessee River

The mercury concentrations found at AtoNs in the Tennessee River were slightly higher than those found in the Chesapeake Bay (average values ranging from 0.1 to 0.4 mg/kg), but they were well below the Effects Range Medium (ER-M) (the 50th percentile of reported values showing an effect, of 0.71 mg/kg). AtoNs within the subwatershed where there were documented sources of mercury were at the high end of the range but at other lighted AtoNs average values were below the ER-L. Consequently it is unlikely that batteries are causing an adverse effect to sediment dwelling and even where background concentrations are elevated, adverse effects do not appear to be likely.In the Tennessee River, two species were collected at almost all locations so the possible effects of mercury from batteries on sediment dwelling organisms from could be made on a species basis. The investigation revealed no elevated tissue concentrations compared to levels known to cause effects or background concentrations for the area. The spatial cover of the sampling and collocation with analytical samples permitted an evaluation of sediment concentration distribution. This evaluation showed no correlation with proximity to batteries or sediment concentrations. The lack of similarity with sediment concentrations is attributable to the very low concentrations in media and the high natural variability in sediment and biological tissue.

4.3.3 Puget Sound

Sediment concentrations of mercury found in Puget Sound were slightly higher than the ER-L, ranging from 0.1 mg/kg to 0.25 mg/kg. This was true for the unlighted as well as the lighted AtoN investigated. The samples collected adjacent to batteries were at the low end of the range and below the ER-L of 0.15 mg/kg. The state of Washington has also established a sediment standard of 0.41 mg/kg mercury for sediment quality that will result in *"no adverse effects"* on biological resources and *"no significant health hazard"*

to humans. All of the areas associated with AtoNs in Puget Sound were less than half this value. Consequently no adverse effects are indicated. The biological investigation for Puget Sound revealed almost identical conditions to those seen for the Tennessee River. The number of species collected were more diverse but general comparisons could be made. There was no indication of elevated tissue concentrations relative to batteries, background concentrations, or levels known to cause effects. Based on these findings it seems clear that mercury from batteries is not affecting biota at the AtoNs included in the Puget Sound or Tennessee River investigations.

4.3.4 Tampa Bay

The results from Tampa Bay differ somewhat from the findings from the other prototype locations with regard to potential impacts to sediment dwelling organisms. The results indicate that average concentrations 20 meters or more from the lighted AtoNs are well below even the most stringent benchmarks for protection of sediment dwelling organisms [ER-L, and the state No Observed Effects Level (NOEL) of 0.1 mg/kg] . In the area 10 to 20 meters from the AtoN, the average (about 0.06 mg/kg) value is well below the NOEL, but about 9 percent of the individual samples exceed the NOEL. The average value of the samples within 10 meters of the AtoN (about 0.2 mg/kg) was above the NOEL, and about 40 percent of the individual samples were above the most protective. Between 75 and 100 percent of the individual samples collected adjacent to batteries exceeded the NOEL. Approximately half the samples adjacent to batteries exceeded the ER-M and the state Probable Effects Level (PEL) of 1.4 mg/kg in the Alafia River area, which has a higher mercury background do to watershed sources and sediment characteristics. However none of the samples collected next to batteries exceeded the PEL or ER-M at the mid-bay AtoNs.
The results of tissue analysis from Tampa Bay were generally similar to the findings from Chesapeake Bay. Tissue levels were generally below values considered background and below levels reported in the literature as being associated with adverse effects. The findings did differ from those in the Chesapeake in that there was an indication that animals attached to batteries often had higher tissue concentrations than organisms of the same species attached to AtoN structures. All of these findings are qualitative and inconclusive because there were over a dozen species collected, most of which had no background values reported in the literature or comparable samples at unlighted AtoNs.

4.3.5 Midway

The sediment concentrations of mercury and zinc were below the conservative levels at which ecological impacts to aquatic animals are likely to cause effects (ERLs). There were no areas where concentrations exceed levels reported in the literature to cause possible effects. Although elevated levels of methylmercury and zinc were observed in one plot and attributed to batteries, there was no demonstrated risk to aquatic animals. The biological tissue measurements also indicated that there was no risk to aquatic communities. The maximum levels of mercury measured were less than 12 percent of concentrations known to produce minor subacute effects in aquatic animals (Viarengo et al. 1982 and Martin et al. 1984). Also, methylmercury body burden was at least three orders of magnitude lower than that shown by Hinton et al. (1973) to cause changes in the enzymatic activity in fish kidney and liver tissue.

4.3.6 Channel Islands

Soil concentrations of lead, zinc, copper and mercury at the Channel Islands were below levels suggestive of impacts. Soil concentrations did not pose a risk to plants and invertebrates based upon comparisons to published values. Tissue samples of plants, invertebrates and mammals showed that these contaminants were not significantly bioaccumulating and did not pose a risk to the environment. The concentrations present in soil and organisms were below calculated critical thresholds based upon estimated intensity of exposure from food for both small mammals and island fox.

Aton Name/Location		Sample (Mercury)	STDDEV	N
CHESAPEAKE BAY				
Bodkin Point	Battery	0.050*	0.0007	4
	Far	0.052	0.0000	2
	Near	0.050	0.0021	2
Greenbury Point Lt	Battery	0.084	0.0354	4
	Far	0.056	0.145	4
	Near	0.072	0.0219	2
South River	Far	0.127	0.1203	2
	Near	0.048	0.006	5
Unlighted	Near	0.288	0.1512	3
TAMPA BAY				
Alafia River				
Alafia River Rear	Far	0.074	0.0167	5
	Near	0.078	0.0295	5
	Battery	2.700		1
Alafia River Front	Far	0.050	0.0000	5
	Near	0.250	0.2800	4
	Battery	0.170	0.1131	5
Alafia Average	**Far**	**0.062**	**0.017**	**2**
	Near	**0.164**	**0.122**	**2**
	Battery	**1.435**	**1.789**	**2**
Midway				
C Cut Range Front	Far	0.050	0.0000	5
	Near	0.090	0.0735	4
	Battery	0.050	n/a	5
C Cut Range Rear	Far	0.050	0.0000	1
	Near	0.050	0.0000	4
	Battery	0.920	n/a	1
E Cut Range Front	Far	0.070	0.0447	4
	Near	0.535	0.1888	5
	Battery	0.180	n/a	1
E Cut Range Rear	Far	0.076	0.0581	5
	Near	0.295	0.2726	5
G Cut Range Front	Far	0.084	0.0760	5
	Near	0.168	0.2092	4

Appendix A: Table A-1, continued

Aton Name/Location		Sample (Mercury)	STDDEV	N
Midway, continued				
G Cut Range Fear	Far	0.050	0.0000	4
	Near	0.053	0.0050	2
Gadsen Point #8	Far	0.050	n/a	1
	Near	0.053	0.0050	3
Gadsen Point #10	Far	0.050	0.0000	4
	Near	0.050	0.0000	4
Midway Average	**Far**	**0.053**	**0.014**	**8**
	Near	**0.144**	**0.174**	**8**
	Battery	**0.383**	**0.322**	**3**
TENNESSEE				
Moon Light	Far	0.095	0.0058	4
	Near	0.102	0.0164	4
	Battery	0.080	n/a	1
Patton Island Upper	Near	0.086	0.1147	5
	Far	0.328	0.1128	4
Patton Island Lower	Near	0.340	0.0632	5
	Far	0.428	0.0082	4
Selcer Lt	Battery	0.130	n/a	1
	Far	0.243	0.1078	5
	Near	0.260	0.1322	1
Williams Island	Battery	0.120	n/a	1
	Near	0.110	0.408	4
	Far	0.114	0.0365	4
Chickamauga Unlighted	Far	0.135	0.0451	1
	Near	0.112	0.0356	4
Lake Nickajack Area	Far	0.050	0.0000	4
	Near	0.073	0.0287	4
PUGET SOUND				
Olympia Channel Lt	Battery	0.140	n/a	1
	Far	0.193	0.0556	1
	Near	0.238	0.1968	4
Olympia Inner Front Range	Battery	0.100	n/a	5
	Far	0.250	0.0707	4
	Near	0.260	0.1140	5
Reference - Unlighted	Far	0.168	0.0655	2
	Near	0.190	0.0173	5

* All values (.05) are reported as the observed level (even though this value is in fact the detection limit) in order to perform calculations on the data (such as estimating a standard deviation). The effect is to conservatively bias the resulting estimates.

TABLE A-2 : BATTERY ANALYSIS RESULTS

Battery Manufacturer	STATE:I=Intact B=Broken S=Spent (not submerged)	Wire from electrode (mg/kg)	Inside Contents (mg/kg)	Sediment Inside (mg/kg)	Surface Material (mg/kg)	Carbon Filament
Edison Carbonaiire	I	18	0.32		29	
McGraw Edison	I	152	0.06	0.21	<0.4	131
Edison Carbonaiire	I	973	0.02	33		40
McGraw Edison	I		0.02		<0.4	127
Edison Carbonaiire				126	33	
Edison Carbonaiire	B	70				
Edison Carbonaiire	B	169	149			54 +/- 13
Edison Carbonaiire	B	242	17	17	<0.4	56 +/- 19
Edison Carbonaiire	B	1210	227 +/-38			228
Eveready	B	2480	4040	821		296
Edison Carbonaiire	B	2720	59	<0.4		7.5
Edison Carbonaiire	B	3330 +/-502	87		24	
McGraw Edison	B		0.08		21	15

2. Appendix B: Superfund Sampling Locations

Morton Beverly Site

The Morton Beverly Investigation (CH2M HILL, 1993a), was a state hazardous waste site in Massachusetts. Tidal and subtidal areas in the Danvers River, which is a tributary of Massachusetts Bay, had elevated levels of mercury. The sampling plan was designed and implemented to determine the risk, extent of contamination, and area of sediments requiring mitigation.

Sullivan's Ledge

Sullivan's Ledge (Metcalf & Eddy, 1991) was a CERCLA investigation of a freshwater wetland contaminated with PCB. The sediments were the focus of the investigation and samples were collected not only to evaluate the extent of risk, but also to delineate the area requiring investigation.

Pine Street

The Pine Street investigation (Kappleman, 1993) was an evaluation of Lake Champlain Canal, declared a CERCLA site due to contaminated sediments and groundwater. Sampling was done in the canal delineate the extent of contamination and degree of human health and ecological risk.

Bay Drum Wetland Impact

Sediments were sampled in wetlands (1) to evaluate the ecological status of wetlands associated with the Bay Drums, Peak Oil, and Reves Southeastern hazardous waste sites near Tampa Bay and (2) to identify the possible sources of toxicity (EPA, 1993c). A total of 12 samples were collected, 10 from three wetland test sites (affected areas or hot spots) and 1 from each of two reference stations.

Ice Creek

This study represents an impact assessment rather than a risk assessment. The study site was a small stream in southeastern Ohio (EPA, 1993a). The stream received long-term waste discharges from a coke production facility before closing in the 1980's. The study included examinations of the surface water and sediment chemistry for organic and inorganic chemicals, as well as aquatic biota.

Commencement Bay

An ecological assessment of Commencement Bay, Washington, was performed near shore/tidal flats areas (EPA, 1993b). Field studies were designed to document the extent of sediment contamination and adverse biological effects, including sediment toxicity, alternation to benthic macroinvertebrate assemblages, chemical residues in tissues of crab

and English sole, and liver lesions in English sole. The study approach was based on three premises: (1) site-specific field data were needed to establish cleanup goals, (2) no single biological indicator could be used to define areas of risk, and (3) adverse biological effects were linked to sediment contamination, and chemical-biological relationships could be characterized empirically. The site was divided into nine study areas, depending on industry and associated waterways. A total of 53 sample stations were established.

Appendix C: National Status and Trends Program Approach (NSPTA)

Effects Level Criteria

There are a variety of complexities in establishing a reliable relationship between the measured level of a contaminant in sediment and a measurable biological effect due to that contaminant affecting the surrounding aquatic environment. Uptake (and therefore, effects) of sediment-associated contaminants is largely a function of bioavailability. Bioavailability is strongly influenced by an array of physical, chemical, and biological factors in sediments; that is, the contaminant can be adsorbed at particulate surfaces, bound to organic matter, sulfide-bound, matrix bound, or dissolved in the interstitial water. The relative bioavailability of trace metals associated with these phases has the effect of hindering the prediction of effects, based upon bulk sediment chemical analyses.

Ideally, sediment quality criteria guidelines should be developed from detailed dose-response data, which describe the acute and chronic toxicity of individual contaminants to sensitive life stages of aquatic organisms. Unfortunately, insufficient data are currently available to support the derivation of numerical sediment quality guidelines using the ideal approach. Only a limited number of controlled laboratory studies (i.e., spiked-sediment bioassays) have been conducted to assess the effects of sediment-associated contaminants on estuarine and marine organisms. Many more studies are available that match sediment chemistry to their corresponding biological effects data. This has led to other methods of developing sediment quality criteria.

Overall Approach

With no national adopted, office effects-based standards available, NOAA developed guidance for interpreting sediment data. A three-step approach was followed to complete the evaluation

- Report Review

- Determination of Contaminant Effects Ranges

- Evaluation of the NS&T Program Sediment data Relative to the Effects Ranges.

Report Review

The first step involved the compilation and review of available information in which estimates of the sediment concentrations of chemicals associated with adverse biological effects were determined or could be derived. Some reports included controlled laboratory studies of effects of sediments spiked with individual chemicals. Others included field studies that matched chemical and biological measurements. Calculations of unacceptable concentrations based upon theoretical partitioning principles were considered (Long and Morgan, 1991).

Determination of Contaminant Effects Ranges

The second step included screening the data by examining the degree of agreement between the biological and chemical data, sorting the remaining data in ascending order, and determining ranges associated with adverse effects. In order to develop a preponderance of evidence, data compilation and analysis was as inclusive as possible and no weighting were given to data derived from one approach or another. In addition, data derived in freshwater and saltwater were merged and treated equally, despite the possibility that bioavailability may differ between the two regimes and the concentration levels may affect the two different ecosystems differently (Long and Morgan, 1991).

Approximately 150 reports were reviewed for possible use, and about half were incomplete for the purposes of this analysis, and not used. An example of an incomplete data set is one that has no biological data to accompany the sediment chemistry data for that report. The data from the remaining 85 reports were assembled.

The reports were then subject to a screening step, where no reports were considered where the contaminant was not a likely contributor to the gradient in biological effects. These included studies where the investigators observed high concentrations of other harmful compounds that could have led to the observed biological effects. It is important to note that the screening step was not performed to force consensus where none existed. It was performed before the data were sorted, so that it was impossible to have a priori knowledge of the consensus range (Long and Morgan, 1991).

The remaining data after this screening step were from studies in which effects were either predicted or observed in association with increasing concentrations of the contaminant levels measured in the sediment. Then they were sorted in ascending order of the contaminant levels in the sediment. The selected sites were located throughout the United States in both saline and freshwater environments. The final sample size used for mercury and lead were 32 and 49 respectively. Two values were determined from the remaining data for each chemical: an ER-L and ER-M.

ER-L Effects Range Low

The ER-L level represents the lower 10-percentile concentration level of the sorted data set. In other words, it is the level measured in the sediment below which adverse biological effects were measured in the aquatic environment 10% of the time (Long and Morgan, 1991). It may be thought of as an approximation of the concentrations at which adverse ecological effects were first detected. Percentile rankings eliminate the undue influence of a single (possibly outlier) data point upon the establishment of the ER-L and ER-M ranges. For the contaminants of concern, the ER-L for mercury is 0.15 ppm, while the ER-L for lead is 35 ppm.

ER-M Effects Range Median

The ER-M level is similar to the ER-L level, except that it corresponds to the mercury level measured in the sediment below which adverse biological effects were measured 50% of the time (Long and Morgan, 1991). Both the ER-L and ER-M values have been determined objectively because they simply represent percentile points where sediment

levels can be attributed to ecological health effects. The ER-M levels for mercury and lead are 1.3 ppm and 110 ppm respectively.

Evaluation of the NS&T Program Sediment Data Relative to the Effects Ranges

The third step in the National Status and Trends Approach compared the ambient sediment chemistry data from the NS&T program with the respective ranges in chemical concentrations apparently associated with observations and effects. Contaminant field measurements conducted for the AtoN battery project can be compared with background levels and with the ERL and ER-M levels in order to make conclusions about the possibility of environmental harm due to battery disposal. However, it should be noted that NOAA clearly states that ER=L and ER-M concentrations maybe used by others as guidance in evaluating sediment contamination data, but there is no expressed or implied intent of establishing these values as official NOAA standards.

Strengths of the National Status and Trends Program Approach.

There are several advantages to the methodology sued in the NSTPA. One of the most important benefits is that it provides a weight of evidence approach to the assessment of sediment quality. Numerous biological effects-based approaches were employed for determining associations between chemical quality and biological effects. This adds to the credibility of the resulting guidelines.

For both mercury and lead, the degree of confidence in the ER-L estimate is considered by NOAA to be moderate, while the degree of confidence in the ER-M estimate is considered by NOAA to be high. With respect to mercury, data values cluster around 0.15 and 1.3 ppm values, suggesting that the ER-L and ER-M values are supported by a preponderance of evidence. A greater volume of data supports sediment quality measurements for lead. (Long and Morgan, 1991).

Another main advantage of the NS&T approach is that it can be conducted with existing data and no additional field work or laboratory investigations are required. The database can continue to be expanded to include the data and results of additional studies. The method facilitates the identification of ranges of contaminant concentrations which provide a mean of determining the probability of observing adverse biological effects at a given contaminant concentration.

Experts from have extensively reviewed the NSTPA across North America. It has been peer reviewed and been selected for incorporation into an EPA sediment classification document. Also, it has been adopted and/or modified for implementation by a variety of states (MacDonald, 1993).

Weaknesses of the National Status and Trends Program Approach

The main limitation of this approach is associated with the quality and compatibility of the available data. The data were often generated using different analytical procedures in numerous laboratories and considered many species and locations across the United States. Therefore, information on a wide variety of sediment types (i.e., with different particle sizes and concentrations of substances that influence bioavailability) were combined, and may have resulted in unknown biases. This amalgamation of the data may

have resulted in the interpretation of responses as being attributable to a single contaminant when, in fact, synergistic and/or additive effects were actually driving the response. The shortcomings may be compounded by locations where only a moderate amount of data exists, or only acute toxicity data are represented, and could result in inappropriate guidelines.

Florida Sediment Quality Assessment Guidelines (SQAG)Overall Approach

Several modifications were made to the NSTPA by the Florida Department of Environmental Regulation in order to increase its applicability to Florida. These modifications are designed to increase the quantity and suitability of data used to evaluate the biological significance of sediment-associated contaminants. This was done by incorporating data from Florida and other southeastern areas and recent data from elsewhere in North America, to increase the level of internal consistence in the database. The procedure developed by the Florida DER will subsequently be referred to as the Weight of Evidence Approach, or WEA.

One of the principal limitations of the original NSTP database on the biological effects of sediment-associated contaminants is its bias toward data derived from studies in northeastern and western coastal areas of the country. To address this, a major initiative was undertaken to expand the original NSTP database. Investigators in the field of sediment quality assessment located in the Gulf coast and southern Atlantic coast states were contacted and asked to identify studies they had conducted that contained matching sediment chemistry and biological effects data. Over the course of the study, more than 300 publications were retrieved and evaluated to determine their suitability for use in the derivation of the SQAGs. Acceptable data sets were integrated into the databases.

Derivation of Numerical Sediment Quality Assessment Guidelines

Each entry in the database was assigned an "effects/no effects" descriptor, based on the degree of concordance between the sediment concentration of the contaminant and the endpoint measured in the investigation. Those labeled "effects" comprised a database called BEDS (Biological Effects Data Set) in which specific adverse biological effects (as indicated from the results of sediment toxicity bioassays or benthic invertebrate community assessments) were observed at some of the sites samples. A separate data set was also established called NBEDS (No Biological Effects Data Set). These entries consisted of data from bioassays in which exposure of aquatic organisms to test sediments did not result in significant biological effects (MacDonald, 1993).

Concentrations of sediment-associated contaminants below the No Observed Effects Level (NOEL) are not considered to represent significant hazards to aquatic organisms. The level was defined by using a two-step process. First, a Threshold Effects Level (TEL) was calculated, and is considered to represent the upper limit of the range on sediment contaminant concentrations that is dominated by no effects data entries. The TEL was calculated as follows (MacDonald, 1993).

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TEL = $\sqrt{(BEDS\text{-}L)\ x\ (NBEDS\text{-}M)}$

where:

Where: TEL = Threshold Effect Level

BEDS-l = 15th percentile concentration in the biological effects data set;

NBEDS-M = 50th percentile concentration in the no biological effects data set.

The mathematical expression represents the geometric mean of the BEDS-L and NBEDS-M and is used because these data are not necessarily normally distributed. A safety factor was applied to the TEL to estimate a no observed effects level (NOEL) for the contaminant (MacDonald, 1993).

NOEL = TEL ÷ SF

Where:

NOEL = No Observed Effect Level

SF = Safety Factor of 2

Application of this safety factor was considered to provide a pragmatic means of compensating for the limitations on the database with respect to the lack of chronic toxicity data, and a resulting bias toward acute toxicity data. The NOEL is considered to represent the upper limit of the no effects range of contaminant concentrations. The resulting NOEL level s for mercury and lead are 0.1 ppm and 21 ppm, respectively.

PEL – Probable Effects Level
The probable effects level (PEL) is defined as the lower limit of the range of contaminant concentrations that are usually or always associated with adverse biological effects. The procedure utilized to calculate the PEL is designed to define a range of concentrations that is dominated by entries from the BEDS. Within the probable effects range, concentrations are considered to represent significant and immediate hazards to aquatic organisms. The PEL was calculated as follows: (MacDonald, 1993).

PEL = $\overline{\sqrt{(BEDS\text{-}M)\ x\ (NBEDS\text{-}H)}}$

Where:

PEL = Probable Effects Level

BEDS-M = 50th percentile concentration in the biological effects data set;

NBEDS-H = 85th percentile concentration in the no biological effects data set.

If there were a total of 100 entries in each of the data sets, the PEL would define the lower limit of a range of concentrations within which there would be, on average, 60 entries from the BEDS and 15 entries from the NBEDS. This is predicted to be the case because the PEL is calculated as the geometric mean of the 50th percentile of the effects

data set and the 85th percentile of the NBEDS. The geometric mean is used to account for uncertainty in the distributions of the data sets. The PEL levels for mercury and lead are 1.4 ppm and 160 ppm , respectively.

Strengths of the Sediment Quality Assessment Guidelines

The WEA is supported by a comprehensive database on the biological effects of sediment-associated contaminants. It provides a compelling rationale for placing a high degree of confidence on the resultant guidelines. By considering matching sediment chemistry and biological effects data from studies conducted in the field, the influence of mixtures of chemicals in sediments is incorporated from studies conducted in the resultant SQAGs. A large number of data were conducted from studies conducted in the southeastern United States (including Florida). Therefore, the resulting guidelines are probably most appropriate for implementation in Florida.

In addition, the procedure considers both BEDS and NBEDS for each chemical constituent, and does not rely heavily on individual data points. Thus, outliers do not carry much weight in the overall guidelines derivation process.

Weaknesses of the Sediment Quality Assessment Guidelines

Many of the weaknesses of the NSTPA also plague the WEA. For instance, it is not possible to express the guidelines in terms of the factors that influence the bioavailability of these contaminants. The reason is that t here is little comprehensive information with which to reliably predict the bioavailability of sediment-associated contaminants.

In addition, the method does not fully support the quantitative evaluation of cause and effect relationships between contaminant concentrations and biological responses. A wide variety of factors other than concentrations of the contaminant under consideration could have influenced the actual response observed in any situation. Only limited data exists on the chronic responses of marine and estuarine organisms to sediment-based contaminants. This should be recognized as a limitation to the approach.

However, the results of the evaluation indicate that SQAGs developed using the approach procedure outlined here are likely to be appropriate tools for conducting assessments of sediment quality in Florida. However, care should be exercised in applying these guidelines.

Summary

The chart below summarizes the national Status and Trends Guidelines as well as the SQAG guidelines:

Contaminant	NOEL ppm	ER-L ppm	ER-M Ppm	PEL Ppm
Mercury	0.1	0.15	0.71	0.7
Lead	21	35	110	160