Sources of contaminants to Boston Harbor:

Revised loading estimates

Massachusetts Water Resources Authority

Environmental Quality Department

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Revised Loading Estimates

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Executive Summary

The contaminants that end up in Boston Harbor sediments come from sewage effluent, combined sewer overflows (CSOs), stormwater runoff, rivers, industrial discharges, groundwater, the atmosphere, and, until December 1991, sewage sludge. In this report we have estimated the loads of metals (copper, lead, and zinc), polynuclear aromatic hydrocarbons (2-methylnaphthalene, pyrene, benzo(a)pyrene), nutrients (nitrogen, phosphorus), and conventional contaminants (biochemical oxygen demand, total suspended solids) to the Harbor from each of the above sources.

Estimating the loading of contaminants to Boston Harbor is useful for comparing the present situation both with the past, when sludge was being discharged to the Harbor, and the future, when treated effluent will no longer be discharged. Loading estimates are also useful for determining the relative importance of various contaminant sources, and for identifying where to focus source reduction or mitigation efforts. Finally, these estimates are useful for studies of contaminant fate and transport.

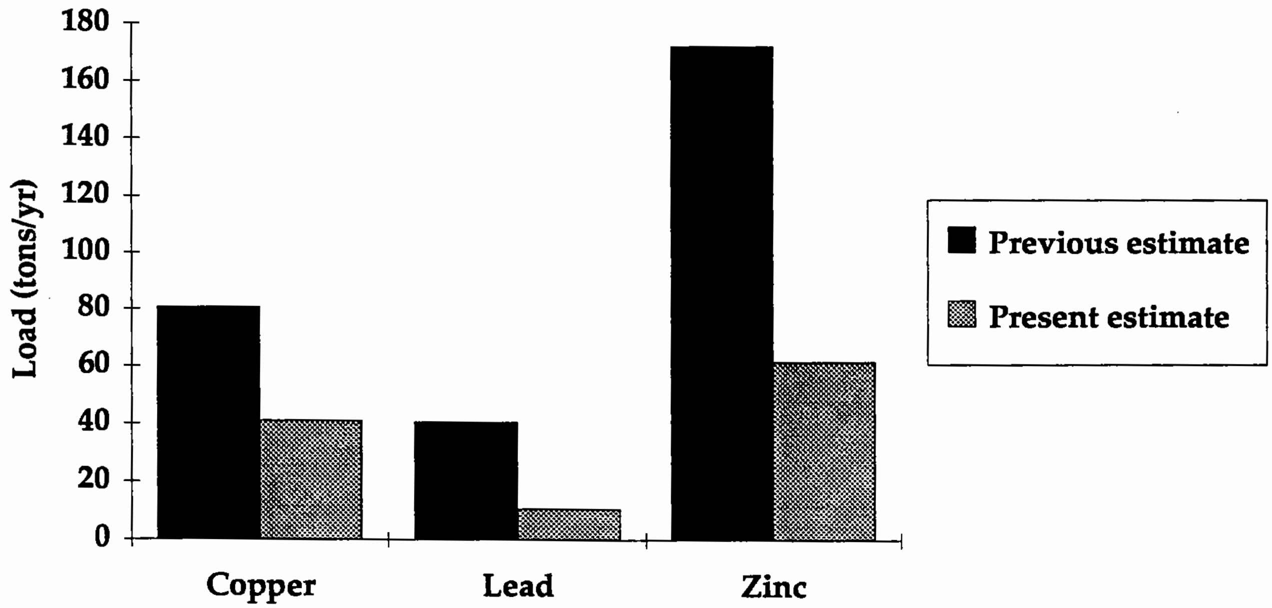
Current estimates of loadings have generally decreased in comparison to loading estimates done previously for the MWRA (Menzie *et al.* 1991). Current estimates were all based on data collected during the period January 1990 through June 1993, whereas previous estimates were from 1988 and earlier. Estimated metal loadings have decreased as follows: copper loading estimates have decreased from 81 to 41 tons per year, lead loading estimates have decreased from 41 to 11 tons per year, and zinc loading estimates have decreased from 173 to 62 tons per year (Fig. i-1). The removal of sludge accounts for 26-61% of this decrease (sludge accounted for 24 tons of copper, 8 tons of lead, and 52 tons of zinc per year). The rest of the decrease can be attributed to source reduction and to improved contaminant estimates.

Estimates of conventional contaminant loadings have also decreased, from 106,000 tons each of BOD and TSS per year to 77,000 tons of BOD, and 47,000 tons of TSS (Fig. i-2). The removal of sludge accounts for 58 and 43% of this reduction, respectively. The remaining decrease can again be attributed to source reduction and improved estimates. Estimates of nutrient loads have not changed substantially: phosphorus loadings have decreased slightly, from 2,900 to 2,300 tons per year, whereas estimates of nitrogen have remained at 14,100 tons per year (Fig. i-3). The slight differences in nutrient loading are not necessarily indicative of a different trend for nutrients than for other contaminants examined. Rather, we attribute it to the fact that previous estimates were based on only 1 or 2 forms of the nutrient in question, whereas the current estimate is based on measurements of all forms of both nitrogen and phosphorus.

Current estimates of the load of individual PAH compounds, which contribute between 0.02 and 2 tons per year, could not be compared with previous estimates since they were not reported as individual compounds. Of the three model compounds evaluated in this report, effluent accounted for 94% of the load of the low molecular weight compound (2-methylnaphthalene), 31% of the mid-weight compound (pyrene), and 29% of the high molecular weight compound (benzo(a)pyrene).

MWRA effluent is a major source of most metals, nutrients, and conventional contaminants entering the Harbor, ranging from 61% of the lead to 94% of the phosphorus. Completion of the new primary and secondary treatment plants at Deer Island will decrease the amount of contaminants released in effluent. From the perspective of the Harbor, the major change in contaminant loading will come once the new effluent outfall tunnel is completed. Removing the effluent from the Harbor will increase the relative importance of the remaining sources of contaminants, such as rivers, stormwater runoff and atmospheric deposition (wetfall and dryfall).

Fig. i-1. Estimated metal loads to the Harbor have decreased.



In this and each of the figures that follow, the previous estimate is from Menzie *et al.* (1991), and is based primarily on information from 1988 and earlier. The present estimate is based on information from 1990 through 1993. These figures represent average estimates.

Fig. i-2. Estimated contaminant loads to the Harbor have decreased.

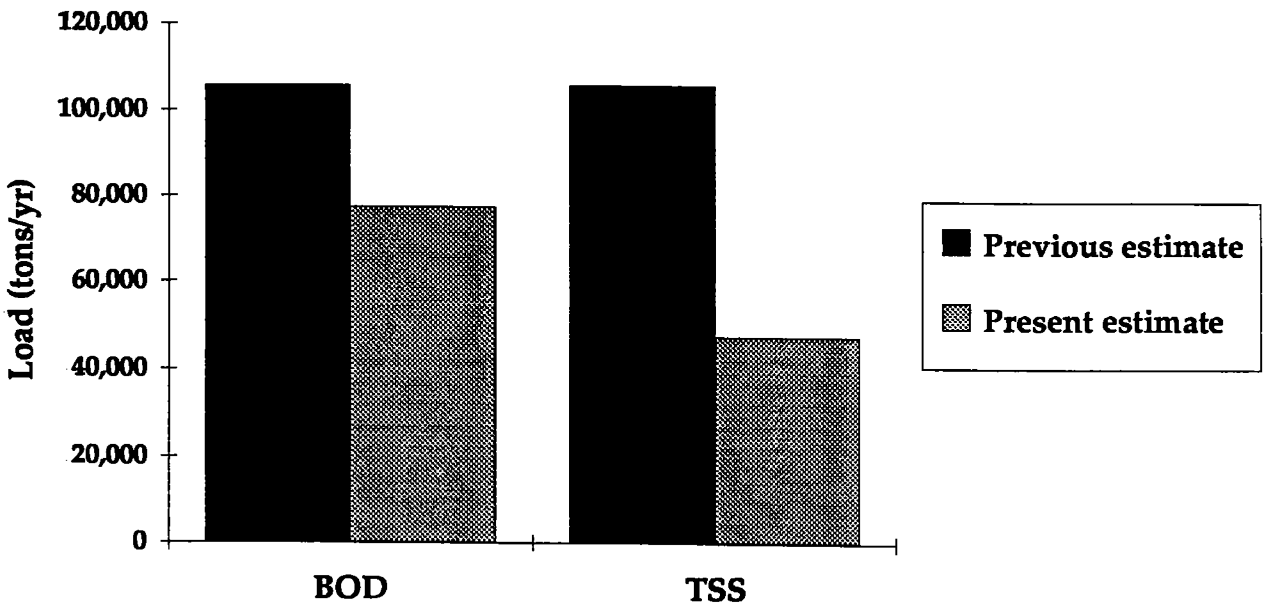
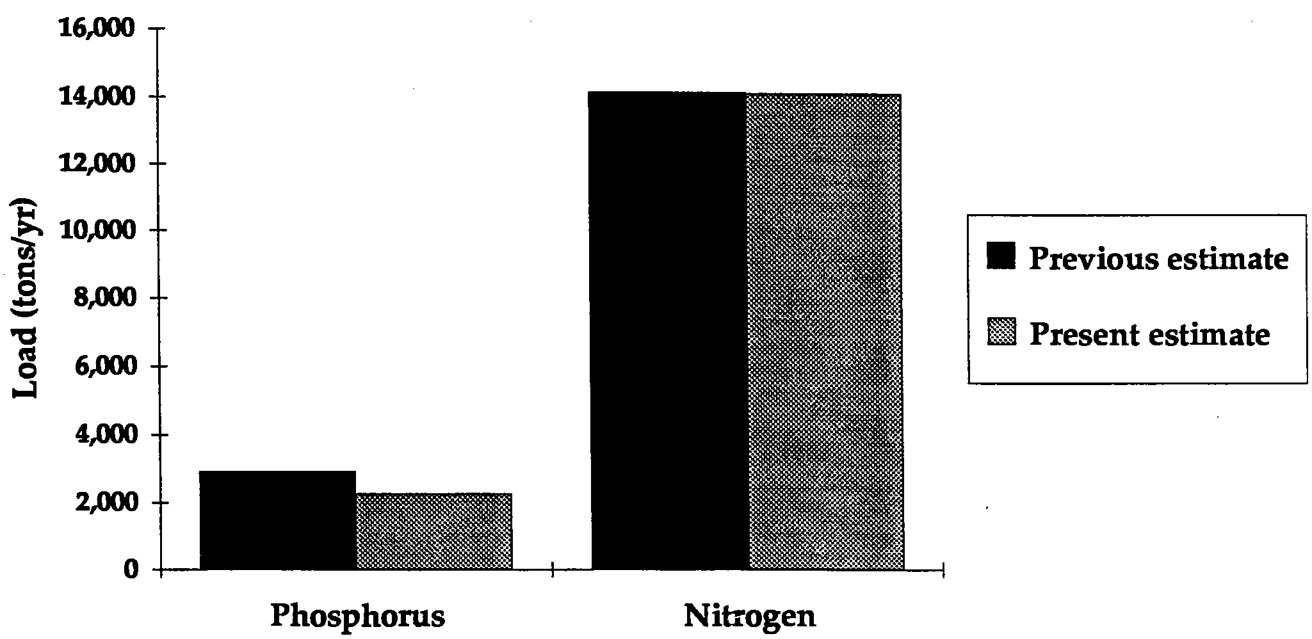


Fig. i-3. Estimated nutrient loads to the Harbor remain relatively constant.



For explanation of figures, see Fig. i-1.

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Abbreviations used in this report:

BOD	Biochemical oxygen demand
BWSC	Boston Water and Sewer Commission
CSO	Combined sewer overflow
MWRA	Massachusetts Water Resources Authority
n	number of observations
NADP	National Acid Rain Deposition Program
NPDES	National Permit Discharge Elimination System
PAH	Polynuclear aromatic hydrocarbon
s.d., std dev	standard deviation
std err	standard error
TRAC	Toxic Reduction and Control
TSS	total suspended solids

Units:

l	liter
mgal	million gallon
ng	nanogram
ug, µg	microgram
mg	milligram
kg	kilogram
km	kilometer
mton	metric ton
ppm	parts per million (µg/gram dry weight)
s, sec	second
yr	year

Chemicals:

Ag	silver
Cd	cadmium
Cr	chromium
Cu	copper
Hg	mercury
NH_3	ammonia
Ni	nickel
NO_3	nitrate
NO_2	nitrite
Pb	lead
PO_4	orthophosphate
Zn	zinc

1.0 Introduction

Estimating the loading of contaminants to Boston Harbor is important for several reasons. First, it provides a picture of the current situation, which can be compared both with the past, (*e.g.* when sludge was discharged to the Harbor), and the future, (*e.g.* when treated effluent is no longer discharged to the Harbor). Second, determining the relative importance of various contaminant sources enables one to identify where to focus source reduction or mitigation efforts. Finally, it serves as the input term for studies of contaminant fate and transport.

The contaminants in Boston Harbor come from wastewater treatment plant effluent, combined sewer overflows, stormwater runoff, industrial discharges, groundwater discharge, atmospheric deposition, and rivers (Fig. 1.0-1). In addition, treatment plants discharged sludge until December, 1991. In 1990, Menzie-Cura and Associates estimated contaminant loads from these sources into Boston Harbor (Menzie *et al.*, 1991). Their estimates were largely based on information from 1988 and earlier. Since that time, there has been a decrease in the amount of contaminants being discharged to the Harbor by the Massachusetts Water Resources Authority (MWRA), due to improvements in sewerage system operations and the cessation of sludge dumping to the Harbor. In addition, there have been studies done by the MWRA and numerous other agencies and universities which give us improved estimates of the concentrations and flows of pollutants from many contaminant sources to the Harbor. The present report synthesizes this new information to provide an updated estimate of contaminant loading to Boston Harbor.

1.1 Substances selected for evaluation

This report examines the loading of metals, polynuclear aromatic hydrocarbons (PAHs), nutrients, and conventional contaminants to Boston Harbor (Table 1.1-1). For those contaminants for which data exist from several contaminant sources, we have estimated overall budgets of contaminant loading to the Harbor.

1.1.1 Metals

The following eight common metals were included whenever data were available: copper, lead, zinc, cadmium, chromium, mercury, nickel, and silver. Of these, only copper, lead, and zinc were quantified in enough sources to be able to estimate overall loading budgets for the Harbor.

1.1.2 Polynuclear aromatic hydrocarbons

There are 16 PAH compounds on the EPA priority pollutant list. Although many of the studies used in this report analyzed samples for these 16 compounds, they were not usually detected. This is because detection limits in most of the studies is approximately 10,000 ng/l, which is much greater than both actual concentration in the samples and EPA water quality criteria. (EPA water quality criteria ranges from 16 to 710 ng/l for individual PAHs.)

Menzie-Cura and Associates, of Chelmsford, MA are currently working on a project for the Massachusetts Bays Program to determine concentrations of PAHs in various sources to Boston Harbor and Massachusetts Bay. As part of this effort, they have used gas chromatography combined with mass spectrometry to look for a suite of 39 analytes. Their analysis has a detection limit of 1 ng/l. Their complete analysis of PAH compounds should be available from the Massachusetts Bays Program in 1994.

In this document, we present preliminary data from the Massachusetts Bays Program study as well as data from a few other studies that were able to detect PAHs. We present information for three common PAH compounds: 2-methylnaphthalene, pyrene, and benzo(a)pyrene. These were chosen because they represent low, mid, and high molecular weight (MW) compounds, respectively. Low MW compounds come primarily from fuel oil, high MW compounds are formed as combustion products, and intermediate weight compounds probably come from a combination of the two. These three compounds have been shown to have different distributions in Boston Harbor and Massachusetts Bay (Wade, 1994). We were able to estimate loading budgets for each of the three compounds.

1.1.3 Nutrients

Data for nitrogen and phosphorus were included where available. Nitrogen was variously measured as ammonia (NH_4), nitrate (NO_3), nitrite (NO_2), or total Kjeldahl nitrogen (TKN, which measures organic N plus ammonia). Phosphorus was measured as orthophosphate (PO_4) or total phosphorus (TP). We were able to estimate loading budgets for total nitrogen (defined as TKN plus NO_3 plus NO_2) and total phosphorus.

1.1.4 Conventional pollutants

Five-day biochemical oxygen demand (BOD_5) and total suspended solids (TSS) were usually measured in all data sets, so we were able to estimate loading budgets for both.

1.2 General approach

Pollutant loading estimates are presented for each of the various sources of contaminants to the Harbor: treatment plant effluent, treatment plant sludge, combined sewer overflows, stormwater runoff, airport runoff, tributaries, atmospheric deposition, groundwater discharges, and permitted NPDES (National Pollutant Discharge Elimination System) discharges to the Harbor other than from MWRA treatment plants. In this analysis, tributaries that discharge to the Harbor are considered a source of contaminants. Any contaminants that enter rivers directly (*e.g.* CSO and stormwater runoff, atmospheric deposition, NPDES dischargers, groundwater) are taken into account in the tributary load to the Harbor.

In keeping with the approach of Menzie *et al.* (1991) we divided the Harbor into two areas for loading estimates, North and South Harbor (Fig. 1.0-1). In this division, the North Harbor has an area of 51 km^2 and a land drainage area (for groundwater and stormwater runoff) of 64 km^2, and the South Harbor has an area of 57 km^2 and a land drainage area of 34 km^2. In contrast to the extent of the Menzie *et al.* (1991) map, the North Harbor drainage area used in this analysis includes one additional sub-basin, which drains into the Mystic/Chelsea Rivers downstream of the Amelia Earhart dam.

Loads are estimated from each contaminant source that discharges directly to the Harbor. Since loads are the product of concentration and flow, we present the concentrations and flows as well as the loads of contaminants from each source.

1.3 Data analysis

1.3.1 Time frame

Because contaminant loading has been changing over time, especially in treatment plant effluent, we limited this report to reflect data from January 1990 to June 1993, insofar as that was possible. Where new data were not available, we have presented older estimates, clearly labelled as such. Since most of the current estimates are less than those estimated previously, those loads based on older data are probably higher than what is currently being added to the Harbor.

1.3.2 Criteria for including data sets

Since individual compounds were often below analytical detection limits, we only used data sets where the measured concentration was greater than the detection limit in at least half the analyses. Within data sets that met this criteria, we calculated overall average concentrations by using half the detection limit for those samples where the concentration was less than the detection limit.

Data sets were not used unless there were at least five measurements that covered at least three discrete sampling events, with one exception: if we had estimates from most other sources, all measurements were included to give us an indication of loading from that source for a total loading budget.

1.3.3 Averaging

We used arithmetic average concentrations and loads in our calculations. Although geometric means are indicators of the central tendency of a log-distributed population, and are appropriately used to compare different distributions, they are not appropriate estimates of total load. The arithmetic mean, by definition, is a measure of the average of the data. For a constant flow, if concentration is plotted against time, the product of the arithmetic mean concentration of a data set and the time interval over which the data were gathered (distance along the x-axis), provides an estimate of the total loading for that time period (integrated area under the curve). The geometric mean multiplied by the same time interval would always underestimate the same area.

In cases where there was more than one data set, we combined all observations to calculate an overall average. For example, 38 observations of effluent copper concentration in one data set were combined with 27 in a second, resulting in a sample size of 65 used to estimate the overall mean (see Table 2.1-2).

High and low loading estimates were calculated as the arithmetic mean plus or minus the standard deviation (s.d.) of all the daily loading estimates, where that was possible. In cases where concentration and flow were not measured concurrently and had to be estimated separately, we calculated loading as average analyte concentration plus or minus the s.d. times the flow. Where there was a high and low flow estimate, we used average analyte concentration plus the s.d. times the high flow estimate as the high load estimate, and the converse for the low load estimate. In all cases, overall average annual load was calculated as average daily load multiplied by 365.25 days per year.

1.3.4 Uncertainty

The flows and concentrations presented in this report reflect our current best estimates of contaminant loading. For each contaminant source we present an average estimate as well as both high and low estimates of loading to the Harbor. The wide ranges associated with several of the numbers presented in this document are due to actual fluctuations in loads at different sites and different times, as well as to differences in laboratories and analytical procedures. The process of refining these estimates is ongoing. As analytical techniques and quality control procedures continue to improve, so too will our estimates of loading.

1.3.5 Comparisons with previous estimates

For each contaminant source, the concentrations and flows used to calculate loads in the current estimate are presented along with those used in the previous estimate of contaminant loading to the Harbor (Menzie *et al*. 1991). For each source, these values are compared using a t-test, according to the following formula:

$$t = \frac{\text{Mean of present estimate - Menzie } et\ al. \text{ (1991) estimate}}{\text{Standard error of present estimate}}$$

Differences are considered significant if $p < 0.05$. Note that although the value used by Menzie *et al.* (1991) was only an estimate of the mean of the population, this formula assumes that it was equivalent to the actual parametric mean. This assumption will tend to increase the likelihood of a Type I error (identifying differences between the two estimates when they were not in fact different).

In many cases, the present estimates are much lower than those estimated previously. This is partly due to source reduction, and partly due to an improvement in laboratory analytical capabilities (*e.g.* achievement of lower detection limits).

Individual PAHs were not reported separately in previous estimates, and it is not always clear which compounds were included. Present estimates of PAH concentrations therefore could not be compared with previous estimates.

1.4 Data gaps

The present report represents our best current estimate of contaminant loading to the Harbor. There are several ongoing studies that will yield new information that will improve these estimates. More complete information on the atmospheric deposition of metals and individual PAH compounds will be available once the Massachusetts Bays Program study by Dr. Dan Golomb at U Mass/Lowell is completed in 1994. A second study being performed for the Massachusetts Bays Program by Menzie-Cura and Associates on individual PAH concentrations and loading estimates is also forthcoming, and will be available in late 1994.

Two ongoing MWRA projects will also improve our estimates. First, a new study to characterize MWRA effluent at the Deer Island treatment plant using lower detection limits was begun in June 1993. This will provide more complete information on many of the metals, as well as on individual PAH compounds. Second, the results of the MWRA CSO System Master Plan Project will provide a better estimate of CSO flows and loads.

We found very little new information with which to update contaminant loading from rivers and groundwater. Determining the loading of contaminants from rivers is particularly important, as they account for approximately half of the flow discharged to the Harbor, and, after effluent, are often the next largest contributor of metals, nutrients, and conventional contaminants. A priority should be placed on refining estimates of river loads, as they will become the largest source of many contaminants once effluent is no longer discharged to the Harbor.

Table 1.1-1. Substances evaluated in this report.
Bold denotes data were available to estimate loading budgets to Boston Harbor. Substance abbreviations are also listed.

Metals	
Cadmium	Cd
Chromium	Cr
Copper	**Cu**
Lead	**Pb**
Mercury	Hg
Nickel	Ni
Silver	Ag
Zinc	**Zn**
Polynuclear aromatic hydrocarbons	
2-methylnaphthalene	
Pyrene	
Benzo(a)pyrene	
Nutrients	
Ammonia	NH3
Nitrate	NO3
Nitrite	NO2
Total Kjeldahl nitrogen	TKN
Total nitrogen	**TN**
Orthophosphate	PO4
Total phosphorus	**TP**
Conventional Pollutants	
Biochemical oxygen demand	**BOD**
Total suspended solids	**TSS**

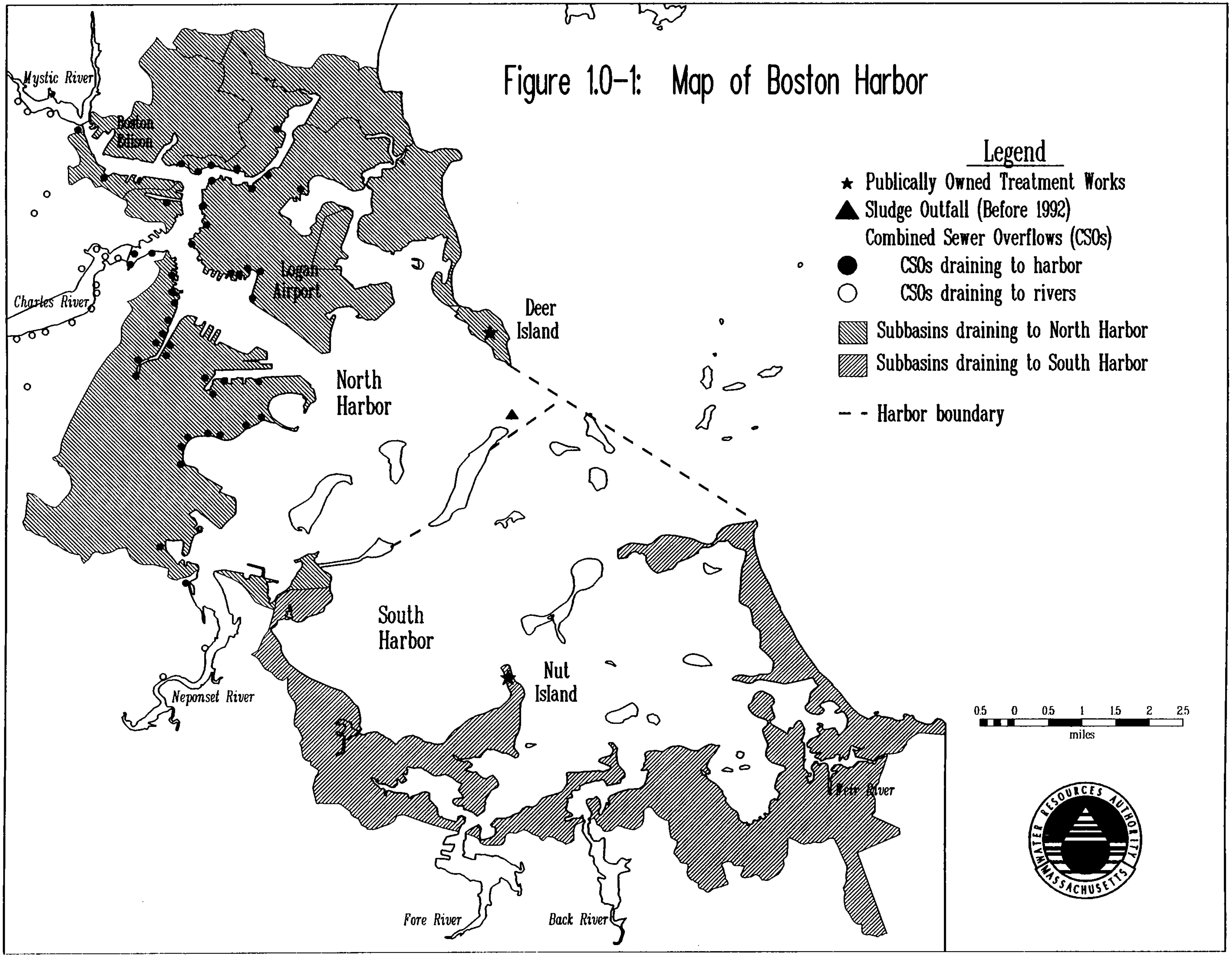


Figure 1.0-1: Map of Boston Harbor

2.0 Sources

2.1 Effluent

MWRA currently has two primary wastewater treatment plants, one located on Nut Island and the second on Deer Island, that discharge effluent into Boston Harbor (Fig. 1.0-1).

2.1.1 Flows

Average daily flows (calculated from hourly flow data) were used to calculate monthly average flow at each plant. Table 2.1-1 presents the annual average of the monthly data as well as the overall average flow during the 42 month period from January 1990 through June 1993. Average monthly flows were used to calculate loads of nutrients and conventional pollutants to the Harbor. Loads of metals and PAHs were calculated using the flow measured on the sampling date, as described below.

2.1.2 Metals

Concentrations--We used two different data sets to estimate total metal concentrations at the plants. The first data set is collected in conjunction with the toxicity test performed monthly for compliance with the MWRA National Pollutant Discharge Elimination System (NPDES) permit. The second set of measurements, also performed monthly, is collected by the MWRA Toxics Reduction and Control (TRAC) department as part of their effort to regulate industrial discharge into the sewerage system.

NPDES Toxicity testing: Toxicity test samples are collected on three days within a period of six consecutive days per month, usually scheduled during the second full week of the month. Samples are collected with an automatic 24-hour time-composite sampler on days 2, 4 and 6. The three days are composited into one sample prior to analysis. Data were compiled for the period January 1990 through February 1993. Samples were analyzed by Enseco Incorporated of Marblehead, MA, between January 1990 and February 1991, and Energy and Environmental

Engineering (E^3I) of Somerville, MA, between March 1991 and February 1993.

TRAC: Samples are collected at the same time as those for toxicity testing, on the same three days. However, the three daily samples are analyzed individually, generating three separate observations. These three analyses were averaged before calculating loads. Data were compiled for the period between March 1991, when sampling for the program began, and June 1993. Sample analysis is conducted by New England Testing, Inc. of Bedford, MA.

Average and standard deviation metal concentrations reported in both the NPDES and TRAC analyses are in Table 2.1-2. The number of samples (n) represents the number of data points including the non-detects (which were assigned concentration values of half the detection limit). Of the eight metals we were tracking (see Table 1.1-1), only four in the NPDES analyses and three in the TRAC analyses were detected frequently enough to meet our criteria for inclusion. Detection limits and frequency of detection of the remaining metals are reported in Table 2.1-3.

Loads: Average daily load within a given month was calculated from each data set as follows. Loads for the NPDES data set were calculated as the product of the average of the concentration measured in a given month's three-day composite and the average flow measured on those three days. For the TRAC data set, average daily load within a month was calculated as the average of the three load estimates, each of which was the product of the concentration measured on a given day and that day's measured flow.

Average daily loads over the 38 month period were then multiplied by 365.25 days/yr to get an estimate of annual load. The average annual loads in Table 2.1-4 are the mean and s.d. of all estimates from the above sources of data. High and low end estimates are the mean loading estimate plus or minus the standard deviation, respectively.

2.1.3 PAHs

Concentrations--There are two sources for concentration data: MWRA and the Massachusetts Bays Program.

PAH concentrations in effluent from both plants were analyzed for MWRA by Battelle Ocean Sciences of Duxbury, MA during three days in November 1991 and three days in June 1992. A suite of 24 PAH compounds were measured using a gas chromatographic technique with a detection limit of 10 ng/l. This work is ongoing, and effluent from Deer Island has been analyzed twice monthly since June 1993 using this technique.

Menzie-Cura and Associates have analyzed effluent samples collected from the MWRA treatment plants in April and October 1992 and January 1993 as part of their PAH study for the Massachusetts Bays Program.

All observations within a given month were averaged to get an average concentration for that month. The data in Table 2.1-5 represent the average of the five months of measurements from both data sets.

Loads--For each the above data sets, loads were calculated as the product of the concentrations of PAHs times the flow measured on the day of sampling. All observations within a given month were averaged to get an average daily load for that month. The average loads in Table 2.1-6 are the mean of the estimates from each of the months represented in the above sources of data (multiplied by 365.25 days/yr to estimate annual load), with high and low end estimates calculated as the mean loading estimate plus or minus the standard deviation, respectively.

2.1.4 Nutrients

Concentrations--The laboratories at both treatment plants measure phosphorus as total phosphorus and orthophosphate (PO_4). Nitrogen is measured as ammonia (NH_3), nitrite (NO_2), nitrate (NO_3), and total Kjeldahl nitrogen (TKN, which equals organic N plus NO_2 plus NO_3). Ammonia is also measured as part of the monthly NPDES compliance sampling, and these data are also included.

At Nut Island, samples are from a 24-hour composite taken one day during the month. At Deer Island, samples are from one grab sample taken on the last day of the month up through April 1993. Starting in April, sampling frequency at Deer Island increased to analysis of four seven-day composites per month. We used the average of the weekly data taken within a month as the concentration in our calculations for this period. Data were compiled for the 42 month period between

January 1990 and June 1993 (Table 2.1-7).

Loads--Since we did not always know the actual date of sampling, average daily loads for various nutrients at each plant were estimated as the product of each month's average concentration times that month's average daily flow. Annual loads were calculated by multiplying daily loads times 365.25 days/yr (Table 2.1-8).

2.1.5 Conventional pollutants

Concentrations--Total suspended solids (TSS) and biochemical oxygen demand (BOD_5) are currently analyzed every weekday at each plant. The average monthly concentrations were compiled for the 42 month period between January 1990 and June 1993 (Table 2.1-9).

Loads-- Loads were calculated as monthly average concentration times that month's average daily flow, multiplied by 365.25 days/yr (Table 2.1-10).

2.1.6 Comparison with previous estimates

Previous estimates of contaminant concentrations and flows (Menzie *et al.* 1991) were based on information from the Secondary Treatment Facilities Plan (MWRA 1988), and did not distinguish between the two treatment plants. These are compared to the present estimates in Table 2.1-11.

Both flow and concentration estimates used in the present analyses are lower than those estimated previously. Part of this reduction is probably due to improved analytical techniques. However, there have also been actual decreases in both flows and contaminant concentrations. Flows have decreased as the result of general improvements to the sewerage system (Alber *et al.* 1993). The decrease in metal and TSS concentrations is due in part to industrial pretreatment regulations imposed in the 1970s, the efforts of MWRAs Toxics Reduction and Control Department, and increased willingness of the public to use products that are environmentally safer and to take precautions when disposing of potentially hazardous materials.

Table 2.1-1 Effluent flow estimates.
Calculations are described in Section 2.1.1.

	Deer Island (m3/sec)	Nut Island (m3/sec)
1990 Mean	11.8	6.0
Std Deviation	1.1	1.1
No. Samples	12	12
1991 Mean	11.5	5.2
Std Deviation	1.0	1.1
No. Samples	12	12
1992 Mean	10.9	5.4
Std Deviation	1.3	1.2
No. Samples	12	12
1993 Mean	12.7	6.6
Std Deviation	3.0	1.8
No. Samples	6	6
Overall Mean	11.6	5.7
Std Deviation	1.6	1.3
No. Samples	42	42

Table 2.1-2. Effluent Metal Concentrations at Deer Island (a) and Nut Island (b). Calculations are described in Section 2.1.2.

(a) Deer Island

	Copper (mg/l)	Lead (mg/l)	Mercury (mg/l)	Zinc (mg/l)
NPDES Mean	0.057	0.012	0.0005	0.074
Std Deviation	0.016	0.005	0.0013	0.019
No. Samples	38	38	38	38
TRAC Mean	0.068	0.012	n.a.	0.111
Std Deviation	0.016	0.007	n.a.	0.065
No. Samples	27	27	n.a.	27
Overall Mean	0.061	0.012	0.0005	0.089
Std Deviation	0.017	0.006	0.0013	0.048
No. Samples	65	65	38	65

(b) Nut Island

	Copper (mg/l)	Lead (mg/l)	Mercury (mg/l)	Zinc (mg/l)
NPDES Mean	0.057	0.007	0.0003	0.062
Std Deviation	0.014	0.002	0.0005	0.012
No. Samples	38	38	38	38
TRAC Mean	0.063	0.014	n.a.	0.091
Std Deviation	0.013	0.017	n.a.	0.045
No. Samples	28	28	n.a.	28
Overall Mean	0.059	0.010	0.0003	0.074
Std Deviation	0.014	0.011	0.0005	0.034
No. Samples	66	66	38	66

n.a. not available

Table 2.1-3. Effluent Metal Detection Limits in TRAC and NPDES data sets

	% Samples above detection limit		Method detection limit (mg/l)	
	Deer Island	Nut Island	Minimum	Maximum
TRAC				
Silver (Ag)	42	31	0.002	0.01
Cadmium (Cd)	9	11	0.001	0.01
Chromium (Cr)	40	28	0.003	0.014
Mercury (Hg)	10	10	0.0002	0.01
Nickel (Ni)	32	27	0.006	0.02
NPDES				
Silver (Ag)	29	29	0.003	0.02
Cadmium (Cd)	18	8	0.001	0.004
Chromium (Cr)	26	34	0.005	0.009
Mercury (Hg)	61	55	0.0002	0.0002
Nickel (Ni)	18	39	0.009	0.017

Table 2.1-4. Effluent Metal Loads at Deer Island (a) and Nut Island (b)

Calculations are described in Section 2.1.2.

(a) Deer Island

	Copper (kg/yr)	Lead (kg/yr)	Mercury (kg/yr)	Zinc (kg/yr)
NPDES Mean	20,138	4,395	164	26,264
Std Deviation	5,775	1,705	416	8,361
TRAC Mean	23,477	4,213	n.a.	38,772
Std Deviation	5,861	2,814	n.a.	20,867
Overall Mean	21,525	4,319	164	31,459
Std Deviation	5,998	2,215	416	15,997

(b) Nut Island

	Copper (kg/yr)	Lead (kg/yr)	Mercury (kg/yr)	Zinc (kg/yr)
NPDES Mean	9,460	1,248	51	10,449
Std Deviation	2,084	391	80	2,511
TRAC Mean	10,404	2,533	n.a.	14,969
Std Deviation	1,954	2,923	n.a.	5,571
Overall Mean	9,861	1,793	51	12,367
Std Deviation	2,069	2,011	80	4,642

n.a. not available

Table 2.1-5. Effluent PAH Concentrations.

Calculations are described in Section 2.1.3.

	2-methylnaphthalene (ng/l)	pyrene (ng/l)	benzo(a)pyrene (ng/l)
Deer Island Mean	3,871	127	12
Std Deviation	2,417	98	12
No. Samples	5	5	5
Nut Island Mean	843	49	11
Std Deviation	453	24	6
No. Samples	5	5	5

Table 2.1-6. Effluent PAH Loads.

Calculations are described in Section 2.1.3.

	2-methylnaphthalene (kg/yr)	pyrene (kg/yr)	benzo(a)pyrene (kg/yr)
Deer Island Mean	1,473	49	4
Std Deviation	1,129	41	4
No. Samples	5	5	5
Nut Island Mean	178	10	2
Std Deviation	132	5	1
No. Samples	5	5	5

Table 2.1-7. Effluent Nutrient concentrations at (a) Deer Island and (b) Nut Island. Calculations are described in Section 2.1.4.

(a) Deer Island

	Ammonia (mg/l)	Nitrate (mg/l)	Nitrite (mg/l)	TKN (mg/l)	Phosphorus (mg/l)	Phosphate (mg/l)
1990 Mean	11.7	2.10	0.97	20.5	3.7	2.2
Std Deviation	2.6	1.94	0.73	2.9	0.6	0.4
No. Samples	24	12	12	12	12	12
1991 Mean	12.4	1.85	1.09	21.7	3.9	2.6
Std Deviation	3.0	1.29	0.86	4.9	0.8	0.6
No. Samples	24	12	12	12	12	12
1992 Mean	13.7	0.63	0.21	21.8	3.7	2.4
Std Deviation	3.6	0.42	0.14	4.8	0.4	0.7
No. Samples	24	12	12	12	12	12
1993 Mean	11.6	0.61	0.14	22.3	3.6	2.1
Std Deviation	3.0	0.56	0.17	3.9	1.1	0.8
No. Samples	6	6	6	6	6	6
Overall Mean	12.5	1.40	0.67	21.5	3.7	2.4
Std Deviation	3.1	1.42	0.73	4.1	0.7	0.6
No. Samples	78	42	42	42	42	42

(b) Nut Island

	Ammonia (mg/l)	Nitrate (mg/l)	Nitrite (mg/l)	TKN (mg/l)	Phosphorus (mg/l)	Phosphate (mg/l)
1990 Mean	9.2	0.35	0.10	14.8	3.8	1.9
Std Deviation	2.6	0.23	0.10	2.5	1.3	0.7
No. Samples	24	11	12	12	12	12
1991 Mean	9.9	0.77	0.13	15.3	2.9	1.8
Std Deviation	3.4	0.73	0.04	3.9	0.8	0.7
No. Samples	24	3	2	12	12	12
1992 Mean	14.2	0.23	0.08	17.5	3.6	1.6
Std Deviation	7.6	0.31	0.13	4.4	1.9	0.6
No. Samples	24	11	11	12	12	12
1993 Mean	9.8	0.88	0.21	13.8	2.3	0.8
Std Deviation	5.8	0.35	0.28	4.5	0.6	0.4
No. Samples	6	6	6	6	6	5
Overall Mean	11.0	0.45	0.12	15.6	3.3	1.7
Std Deviation	5.5	0.42	0.15	3.9	1.4	0.7
No. Samples	78	31	31	42	42	41

Table 2.1-8. Effluent Nutrient loads at (a) Deer Island and (b) Nut Island. Calculations are described in Section 2.1.4.

(a) Deer Island

	Ammonia (mton/yr)	Nitrate (mton/yr)	Nitrite (mton/yr)	TKN (mton/yr)	Phosphorus (mton/yr)	Phosphate (mton/yr)
1990 Mean	4,328	799	355	7,610	1,374	820
Std Deviation	938	820	254	1,046	207	156
1991 Mean	4,482	667	386	7,904	1,398	926
Std Deviation	1,187	458	302	2,153	345	208
1992 Mean	4,697	212	71	7,470	1,257	820
Std Deviation	1,176	133	51	1,638	143	166
1993 Mean	4,431	234	53	8,760	1,405	806
Std Deviation	236	198	64	1,855	371	191
Overall Mean	4,497	513	239	7,818	1,352	848
Std Deviation	1,049	561	258	1,690	264	180

(b) Nut Island

	Ammonia (mton/yr)	Nitrate (mton/yr)	Nitrite (mton/yr)	TKN (mton/yr)	Phosphorus (mton/yr)	Phosphate (mton/yr)
1990 Mean	1,684	71	20	2,732	738	346
Std Deviation	390	58	24	257	342	117
1991 Mean	1,576	144	23	2,416	455	287
Std Deviation	471	146	8	303	119	90
1992 Mean	2,247	40	15	2,830	573	252
Std Deviation	932	60	24	485	236	57
1993 Mean	1,804	191	42	2,710	469	147
Std Deviation	764	128	51	530	76	49
Overall Mean	1,833	90	23	2,667	571	277
Std Deviation	700	99	31	409	254	104

Table 2.1-9. Effluent conventional pollutant concentrations.
Calculations are described in Section 2.1.5.

	Deer Island BOD5 (mg/l)	Deer Island TSS (mg/l)	Nut Island BOD5 (mg/l)	Nut Island TSS (mg/l)
1990 Mean	135	80	87	56
Std Deviation	23	11	20	10
No. Samples	12	12	12	12
1991 Mean	128	76	89	59
Std Deviation	13	7	18	15
No. Samples	12	12	12	12
1992 Mean	137	71	113	72
Std Deviation	10	5	20	10
No. Samples	12	12	12	12
1993 Mean	119	68	85	59
Std Deviation	18	7	14	12
No. Samples	6	6	6	6
Overall Mean	131	74	95	62
Std Deviation	17	9	22	13
No. Samples	42	42	42	42

Table 2.1-10. Effluent conventional pollutant loads.
Calculations are described in Section 2.1.5.

	Deer Island BOD5 (mton/yr)	Deer Island TSS (mton/yr)	Nut Island BOD5 (mton/yr)	Nut Island TSS (mton/yr)
1990 Mean	50,003	29,516	15,741	10,223
Std Deviation	8,350	3,453	2,167	1,323
1991 Mean	46,308	27,408	14,161	9,326
Std Deviation	5,327	3,517	1,599	1,252
1992 Mean	46,977	24,536	18,361	11,792
Std Deviation	3,524	2,636	1,382	1,573
1993 Mean	46,595	26,807	17,325	11,789
Std Deviation	5,747	4,120	2,249	1,178
Overall Mean	47,596	27,104	16,265	10,639
Std Deviation	6,010	3,758	2,429	1,692

Table 2.1-11. Comparison of present and previous estimates of effluent discharge.
Calculations are described in Section 1.3.4. If change is positive or negative, the current estimate is significantly greater or less than the previous estimate ($p<0.05$). If change is zero, the current estimate is not significantly different from the previous estimate. n.d. = not determined.
Note that the same concentrations were used for both treatment plants in the previous estimate.

		Deer Island			Nut Island		
	Previous	Mean	std err	Change	Mean	std err	Change
Flow (m3/sec)	14, 6	12	0.2	-	6	0.2	o
Metals (ug/l)							
Cu	70	61	2.1	-	59	1.7	-
Pb	17	12	0.8	-	10	1.4	-
Hg	0.2	0.5	0.2	o	0.3	0.1	o
Zn	116	89	5.9	-	74	4.2	-
Nutrients (mg/l)							
NH4		13	0.4	n.d.	11	0.6	n.d.
NO3		1	0.2	n.d.	0.4	0.1	n.d.
NO2		1	0.1	n.d.	0.1	0.0	n.d.
TKN		21	0.6	n.d.	16	0.6	n.d.
TN	17			n.d.			n.d.
PO4		2	0.1	n.d.	2	1	n.d.
TP	3.9	4	0.1	o	3	1	-
Conventional (mg/l)							
BOD	122	131	2.6	+	95	3.3	-
TSS	98	74	1.3	-	62	2.0	-

2.2 Sludge

Until December 1991, sludge from both Deer and Nut Island was discharged to the Harbor. The Deer Island sludge was mixed with effluent, whereas the Nut Island sludge was discharged at the tip of Long Island (see Fig. 1.0-1). The data presented here provide an estimate of sludge loading during the period from January 1990 to December 1991, which falls within the time frame of the present study.

2.2.1 Flows

The amount of sludge discharged to the Harbor was reported in the daily operations logs of the treatment plants at Nut Island and Deer Island. These data were used to calculate monthly averages (Table 2.2-1).

2.2.2 Metals

Concentrations--Two separate analyses of metal concentrations in the sludge were used. First, both treatment plants data analyzed sludge samples monthly, and we used their data from January 1990 through December 1991. In addition, E^3I of Somerville, MA, sampled monthly from January through August 1990 for the MWRA Residuals Management Program prior to the opening of the sludge-to-fertilizer plant. Samples were digested with nitric and hydrochloric acids according to EPA method 200.7, and then analyzed with either an atomic absorption spectrometer or an inductively-coupled plasma analyzer. Average concentrations of the eight metals being tracked in this report are in Table 2.2-2.

Loads--Average daily loads for each month were estimated as the product of the average metal concentration measured for a given month times that month's average daily discharge. The loads in Table 2.2-3 are the mean and s.d. of all estimates from the above sources of data (times 365.25 days/yr). High and low end estimates were calculated as the mean loading estimate plus or minus the standard deviation, respectively.

2.2.3 PAHs

Concentrations--During the final year of sludge discharge, Revet Environmental and Analytical Laboratories of Worcester, MA analyzed for the 16 priority pollutant PAHs in samples taken approximately once a month (March 1991 to December 1991 for Deer island; September 1990 to November 1991 for Nut Island). Two of the three PAHs being tracked in this report (Table 1.1-1) were detected frequently enough at Deer Island to meet our criteria for inclusion (Table 2.2-4). Priority pollutant PAHs were also analyzed by E^3I. However, these PAHs were not detected frequently enough to meet our criteria for inclusion (detection limits ranged from 5,000 to 10,000 ng/l).

Loads--Loads were estimated as described above for metals (Table 2.2-5).

2.2.4 Nutrients

Concentrations--Some forms of nitrogen and phosphorus were measured monthly as part of both the treatment plant and residuals program data sets. These are compiled in Table 2.2-6.

Loads--Nutrient loads were calculated by multiplying monthly nutrient concentrations times that month's flow average daily flow (times 365.25 days/yr) (Table 2.2-7).

2.2.5 Conventional pollutants

Concentrations--Percent solids were estimated monthly by the treatment plants (Table 2.2-6).

Sludge BOD_5 was not measured in any of these data sets.

Loads--At Nut Island, the actual dry weight of sludge was usually recorded and these data were used to calculate TSS load. At Deer Island, percent solids and flow were used to estimate TSS concentration, assuming sludge has a density equivalent to that of water. Average annual loads of TSS, calculated as described above for nutrients, are included in Table 2.2-7.

2.2.6 Comparison with previous estimates

Previous estimates of total weight and contaminant concentrations in sludge (Menzie *et al.* 1991) were based on information from the Secondary Treatment Facilities Plan (MWRA 1988). The present estimates indicate a drop in the total TSS load, from 23,000 metric tons to 17,600 metric tons. In addition, metal concentrations in sludge tend to be less than those used in the previous estimate (Table 2.2-8). This decrease may be attributable to source reduction, which resulted in lowered concentrations in influent metal concentrations. It may also be due in part to better estimation methods.

Present estimates of nutrient concentrations are higher than previous estimates. This may be a real increase, or it may be that the previous estimates were not in fact based on total nitrogen and phosphorus, but rather on one form of these compounds.

Table 2.2-1. Sludge flow estimates.
Calculations are described in Section 2.2.1.

	Nut Island (m3/sec)	Deer Island (m3/sec)
1990 Mean	0.0095	0.0090
Std Deviation	0.0005	0.0011
No. Samples	12	12
1991 Mean	0.0096	0.0120
Std Deviation	0.0000	0.0017
No. Samples	12	12
Overall Mean	0.0095	0.0105
Std Deviation	0.0006	0.0021
No. Samples	24	24

Table 2.2-2. Sludge metal concentrations at (a) Deer Island and (b) Nut Island. Calculations are described in Secion 2.2.2.

(a) Deer Island

	Cadmium (mg/l)	Chromium (mg/l)	Copper (mg/l)	Lead (mg/l)	Mercury (mg/l)	Nickel (mg/l)	Silver (mg/l)	Zinc (mg/l)
MWRA Mean	0.22	2.58	17.9	7.25	0.06	1.20	0.60	23.7
Std Deviation	0.09	1.14	4.94	2.76	0.02	0.39	0.49	6.98
No. Samples	24	24	24	24	24	24	24	24
E3I Mean	0.30	3.05	18.9	8.23	0.07	1.53	n.a.	25.1
Std Deviation	0.17	1.97	9.43	6.49	0.02	1.11	n.a.	9.89
No. Samples	8	8	8	8	6	8	0	8
Overall Mean	0.24	2.70	18.2	7.50	0.07	1.28	0.60	24.1
Std Deviation	0.12	1.37	6.19	3.91	0.02	0.64	0.49	7.65
No. Samples	32	32	32	32	30	32	24	32

(b) Nut Island

	Cadmium (mg/l)	Chromium (mg/l)	Copper (mg/l)	Lead (mg/l)	Mercury (mg/l)	Nickel (mg/l)	Silver (mg/l)	Zinc (mg/l)
MWRA Mean	0.14	1.02	15.0	3.71	NA	1.30	0.47	21.9
Std Deviation	0.08	0.41	5.35	1.46	NA	0.95	0.18	12.8
No. Samples	17	22	24	24	0	18	20	24
E3I Mean	0.15	1.65	19.18	3.98	0.14	0.92	n.a.	22.6
Std Deviation	0.10	0.82	10.22	1.85	0.05	0.29	n.a.	9.30
No. Samples	7	7	7	7	5	5	0	7
Overall Mean	0.14	1.17	15.97	3.77	0.14	1.20	0.47	22.0
Std Deviation	0.08	0.59	6.78	1.53	0.05	0.83	0.18	11.9
No. Samples	24	29	31	31	5	23	20	31

n.a. = not available

Table 2.2-3. Sludge metal loads at (a) Deer Island and (b) Nut Island.
Calculations are described in Secion 2.2.2.

(a) Deer Island

	Cadmium (kg/yr)	Chromium (kg/yr)	Copper (kg/yr)	Lead (kg/yr)	Mercury (kg/yr)	Nickel (kg/yr)	Silver (kg/yr)	Zinc (kg/yr)
MWRA Mean	72	835	5,893	2,394	22	392	193	7,828
Std Deviation	29	360	1,889	1,002	10	147	168	2,673
E3I Mean	92	942	5,823	2,523	21	470	n.a.	7,716
Std Deviation	53	627	2,992	1,994	7	343	n..a	3,169
Overall Mean	77	862	5,876	2,426	22	412	193	7,800
Std Deviation	36	433	2,161	1,283	9	209	168	2,752

(b) Nut Island

	Cadmium (kg/yr)	Chromium (kg/yr)	Copper (kg/yr)	Lead (kg/yr)	Mercury (mg/l)	Nickel (kg/yr)	Silver (kg/yr)	Zinc (kg/yr)
MWRA Mean	42	308	4,527	1,118	n.a.	390	144	6,588
Std Deviation	23	124	1,635	456	n.a.	277	56	3,763
E3I Mean	46	507	5,872	1,216	43	281	n.a.	6,929
Std Deviation	30	245	3,018	540	14	84	n.a.	2,710
Overall Mean	43	356	4,831	1,140	43	359	144	6,665
Std Deviation	25	179	2,049	468	14	115	56	3,514

n.a. = not available

Table 2.2-4. Sludge PAH concentrations at Deer Island.
Calculations are described in Section 2.2.3.

	2-Methylnaphthalene (ug/l)	Pyrene (ug/l)
Mean	58	17
Std Deviation	43	8
No. Samples	8	8

Table 2.2-5. Sludge PAH loads at Deer Island,
Calculations are described in Section 2.2.3.

	2-Methylnaphthalene (kg/yr)	Pyrene (kg/yr)
Mean	24	7
Std Deviation	19	4

Table 2.2-6. Sludge nutrient and solid concentrations at Deer Island (a) and Nut Island (b).

Calculations are described in Sections 2.2.4 and 2.2.5.

(a) Deer Island

	Ammonia (mg/l)	TKN (mg/l)	Phosphorus (mg/l)	Phosphate (mg/l)	Solids (%)
MWRA Mean	835	2,004	342	73	2.9%
Std Deviation	237	550	108	45	0.7%
No. Samples	24	24	24	24	24
E3I Mean	916	1,379	297	n.a.	1.8%
Std Deviation	459	626	106	n.a.	0.6%
No. Samples	4	4	5	0	8
Overall Mean	846	1,915	334	73	2.6%
Std Deviation	284	436	107	45	0.8%
No. Samples	28	28	29	24	32

(b) Nut Island

	Ammonia (mg/l)	TKN (mg/l)	Phosphorus (mg/l)	Phosphate (mg/l)	Solids (%)
MWRA Mean	661	1,180	149	79	3.2%
Std Deviation	84	274	66	21	0.6%
No. Samples	24	24	24	24	24
E3I Mean	489	706	341	n.a.	2.3%
Std Deviation	371	490	94	n.a.	0.7%
No. Samples	5	5	6	0	7
Overall Mean	631	1,098	187	79	3.0%
Std Deviation	207	289	105	21	0.7%
No. Samples	29	29	30	24	31

n.a. = not available

Table 2.2-7. Sludge nutrient and solid loads at Deer Island (a) and Nut Island (b). Calculations are described in Sections 2.2.4 and 2.2.5.

(a) Deer Island

	Ammonia (mton/yr)	TKN (mton/yr)	Phosphorus (mton/yr)	Phosphate (mton/yr)	TSS (mton/yr)
MWRA Mean	270	660	115	24	9,682
Std Deviation	75	225	53	15	3,574
E3I Mean	283	428	91	n.a.	5,593
Std Deviation	142	197	33	n.a.	1,953
Overall Mean	272	627	111	24	8,660
Std Deviation	84	233	50	15	3,684

(b) Nut Island

	Ammonia (mton/yr)	TKN (mton/yr)	Phosphorus (mton/yr)	Phosphate (mton/yr)	TSS (mton/yr)
MWRA Mean	199	356	45	24	9,469
Std Deviation	26	86	21	6	1,780
E3I Mean	151	219	104	n.a.	7,074
Std Deviation	113	154	27	n.a.	2,282
Overall Mean	191	332	57	24	8,928
Std Deviation	52	111	32	6	2,123

n.a. = not available

Table 2.2-8. Comparison of present and previous estimates of sludge discharge.

Calculations are described in Section 1.3.4. If change is positive or negative, the current estimate is significantly greater or less than the previous estimate ($p<0.05$). If change is zero, the current estimate is not significantly different from the previous estimate. n.d. = not determined.

Sludge is no longer discharged to the Harbor. The present estimate is based on data from 1990 and 1991.

Note that the same concentrations were used for both treatment plants in the previous estimate.

Concentrations are presented on a per weight basis to make them comparable with previous estimates.

		Deer Island			Nut Island		
	Previous	Mean	std err	Change	Mean	std err	Change
Metals (ppm)							
Cd	16	9	1	-	5	1	-
Cr	161	100	9	-	40	4	-
Cu	957	679	44	-	541	41	-
Pb	304	280	26	o	128	9	-
Hg	5	3	0.2	-	5	1	o
Ni	96	48	4	-	40	3	-
Ag	8	22	4	+	16	1	+
Zn	2,043	901	56	-	746	71	-
Nutrients (ppt)							
NH4		31	2	n.d.	21	1	n.d.
TKN		72	5	n.d.	37	2	n.d.
TN	48			n.d.			n.d.
PO4		3	0.4	n.d.	3	0.1	n.d.
TP	3	13	1	+	6	1	+

2.3 Combined Sewer Overflows

Parts of the North Harbor have combined sewer systems, with pipes that carry both sewage and rainwater. During periods of heavy rain, more than 80 CSO outfalls in Boston, Cambridge, Somerville and Chelsea can divert excess flow into the northern part of Boston Harbor or its tributaries (see Fig. 1.0-1).

2.3.1 Flows

CSO flow directly to Boston Harbor was estimated two ways, one based on Boston Water and Sewer Commission data (BWSC), and one based on modelling being done for the MWRA. Flow estimates are in Table 2.3-1.

Boston Water and Sewer Commission (BWSC) models those CSOs owned by the city of Boston that discharge to the Harbor. Flow estimates of these CSOs are issued in quarterly monitoring reports (BWSC 1990, 1991, 1992). All of these (except BOS 093 and 095, which discharge into the Neponset River), empty directly into the Harbor. The only other CSOs that empty into the Harbor are those owned by Chelsea (CHE 002, 003, 004, and 008) and five of the MWRA CSO treatment facilities. Flow from the Chelsea-owned CSO outlets has not been estimated and is not included here. To estimate flow from the MWRA treatment facilities, we used modelled flow for Commercial Point and Fox Point, and measured flow for Constitution Beach, Prison Point, and Somerville Marginal.

Our first estimate of CSO flow is the sum of all of the BWSC-modelled flows (except BOS 093 and 095), plus flow from the CSO treatment facilities. For the years 1990, 1991, and 1992, average annual flow was equal to 1,459 million gallons, which was used as the low estimate of flow (standard deviation = 317 million gallons, n = 3 years).

The second estimate of flow was obtained using the preliminary results of a CSO model being developed for the MWRA Sewerage Facilities Development Department by Metcalf and Eddy (MWRA 1993). Because the new model is not yet available for a full year, we compared modelled flows predicted by the new model with those predicted by an earlier model that was developed by CH2M Hill as part of the CSO facilities plan (MWRA 1990). The facilities plan divided the Harbor into seven sub-basins, two of which empty directly into the Harbor (Dorchester Bay Basin and Inner Harbor Basin). When the two models were run for a July 1992 storm, an August 1992 storm, and an average three-month "design" storm, the new model predicted flows in these two basins that were much less than those predicted by the older facilities plan model, with differences ranging from 35 to 65% less than that predicted for the no-action alternative in the facilities plan. To be conservative, we decreased annual flow predicted by the old model for the two sub-basins by 35%. This resulted in an annual flow of 1,915 million gallons, which was used as our high estimate. This is in good agreement with the first estimate.

These flow estimates are only for those CSOs that discharge directly into the Harbor, so the total CSO flow from the MWRA system would be higher. However, note that the estimates provided here are still likely to be upper bounds on CSO loads to the Harbor. Additional estimates will be available in 1994 as the new model is completed for the MWRA Sewerage Facilities Development Department.

2.3.2 Metals

Concentrations--Metal concentrations were estimated from studies conducted by the Boston Water and Sewer Commission, by the MWRA NPDES Compliance Department, and by the MWRA Sewerage Facilities Development Department. Average concentrations are in Table 2.3-2.

BWSC measured metal concentrations during 13 different storms between April 1990 and October 1991 (BWSC 1990, 1991). Samples were taken at 10 different CSOs. Although they routinely analyzed samples for all eight metals being tracked in this report (Table 1.1-1), only copper, lead, and zinc met our criteria. Method detection limits for the other metals were as follows: cadmium (0.005 mg/l), mercury (0.0005 mg/l), nickel (0.025 mg/l), and silver (0.1 mg/l).

Metals are also measured by MWRA at six CSO treatment facilities as part of the NPDES Compliance Program. During each CSO activation, effluent grab samples are collected by facility personnel and transported to the Deer Island laboratory for analyses of contaminants. Samples are collected for up to four hours during discharge events (depending on the duration of discharge), at 0.25, 0.5, 0.75, 1, 1.5, 2, 3, and 4 hours from the onset of discharge, and flow-weighted to make a composite sample. Data were compiled for the period January 1990 to June 1993.

Five of the eight metals (see Table 1.1-1) met our criteria for inclusion. The detection limits for the other metals are as follows: silver (0.003-0.004 mg/l), cadmium (0.001-0.004 mg/l), and chromium (0.002-0.009 mg/l). Note that the detection limits vary as a consequence of sample dilution.

Metals were also measured for MWRA by Metcalf and Eddy at 19 CSOs during two November 1992 storms as part of their CSO study (MWRA 1993). These samples were analyzed for copper and zinc only.

Loads--The overall average concentration of each metal was multiplied by the average of the two CSO flow estimates to get an average annual loading estimate. The high loading estimate is the product of the average concentration plus the s.d. times the high CSO flow estimate, and the low loading estimate is the product of the average concentration minus the s.d. times the low CSO flow estimate (Table 2.3-3).

2.3.3 PAHs

Concentrations--PAHs in four CSO outfalls were measured by Menzie-Cura and Associates as part of their PAH study for the Massachusetts Bays Program during two rainfall events in November 1992. Average concentrations of the three PAH compounds are reported in Table 2.3-4.

Loads--PAH loads were calculated as described for CSO metals (Table 2.3-5).

2.3.4 Nutrients

Concentrations--Data sources for nutrient concentrations are the same as for CSO metal concentrations. Metcalf and Eddy measured nutrients as part of their interim CSO report (MWRA 1993), BWSC measured ammonia and phosphate released from CSOs during storm events (BWSC 1990, 1991), and MWRA measured ammonia and phosphorus as part of their NPDES permit compliance. Average concentrations are in Table 2.3-6.

Loads--Nutrient loads were calculated as described for CSO metals (Table 2.3-7).

2.3.5 Conventional pollutants

Concentration--Conventional contaminants are measured in both the influent and effluent of all six MWRA CSO treatment facilities. The mean influent and effluent BOD concentrations were equivalent (82 mg/l). However, effluent TSS (90 mg/l, s.d. = 106, n=582) was significantly lower (t-test, $p<0.001$) than influent TSS concentration (136 mg/l, s.d. = 184, n=581). We used concentrations in the present analysis. Since approximately half of the CSO flow in our project area is treated, using the influent TSS concentration will result in a slight overestimate of the TSS load. Average concentrations are included in Table 2.3-6.

TSS and BOD_5 were measured by Metcalf and Eddy for interim CSO planning (MWRA 1993), and TSS was measured by BWSC (BWSC 1990, 1991) (Table 2.3-6).

Loads--Loads were calculated as described above for CSO metals (Table 2.3-7).

2.3.6 Comparison with previous estimates

The flow estimates used here are considerably lower than those predicted by the facilities plan model (MWRA 1990). The facilities plan model was the basis of the Menzie *et al.* (1991) flow estimate of 7,938 million gallons per year, which is the sum of modelled flow in four sub-basins (Inner Harbor, Dorchester Bay, Neponset Estuary, and Quincy Bay/Outer Harbor) based on the "existing conditions" model run. The decreased flow estimates in the present study are consistent with new data that suggest that the older model greatly overestimated flow (Adams and Zhang 1991). Another difference is that discharge from Moon Island, which was included in the facilities plan model, is no longer operational. There is also evidence that there have been substantial decreases in CSO flow as a result of improvements to the treatment plants (Alber *et al.* 1993).

The concentrations of metals, nutrients, and conventional contaminants are also substantially less than those estimated previously (Table 2.3-8). These decreases may be a consequence of actual decreases in concentration, improved estimates, or both. Since load is the product of concentration and flow, the result of these dramatic decreases in our estimates of both these factors is that the estimated pollutant loads from CSOs are considerably less than those estimated by Menzie *et al.* (1991).

Table 2.3-1. CSO flow estimates.

Calculations are described in Section 2.3.1.

Note that 8,336 x m3/sec = mgal/yr.

	Low (m3/sec)	Mean (m3/sec)	High (m3/sec)
CSO flow	0.175	0.203	0.230

Table 2.3-2. CSO metal concentrations.

Calculations are described in Section 2.3.2.

	Copper (mg/l)	Lead (mg/l)	Mercury (mg/l)	Nickel (mg/l)	Zinc (mg/l)
BWSC Mean	0.07	0.10	n.a.	n.a.	0.18
Std Deviation	0.06	0.08	n.a.	n.a.	0.11
No. Samples	26	27	0	0	27
M & E Mean	0.04	n.a.	n.a.	n.a.	0.18
Std Deviation	0.02	n.a.	n.a.	n.a.	0.13
No. Samples	19	0	0	0	19
MWRA Mean	0.09	0.11	0.0004	0.01	0.23
Std Deviation	0.06	0.08	0.0004	0.01	0.13
No. Samples	93	94	94	94	94
Overall Mean	0.077	0.106	0.0004	0.011	0.215
Std Deviation	0.056	0.079	0.0004	0.007	0.126
No. Samples	138	121	94	94	140

n.a. = not available

Table 2.3-3. CSO metal loads.

Calculations are described in Section 2.3.2.

	Copper (kg/yr)	Lead (kg/yr)	Mercury (kg/yr)	Nickel (kg/yr)	Zinc (kg/yr)
BWSC Mean	424	659	n.a.	n.a.	1,175
Low	43	113	n.a.	n.a.	382
High	906	1,347	n.a.	n.a.	2,166
M & E Mean	224	n.a.	n.a.	n.a.	1,167
Low	79	n.a.	n.a.	n.a.	311
High	405	n.a.	n.a.	n.a.	2,243
MWRA Mean	561	680	2.50	69	1,471
Low	179	157	0.02	22	566
High	1,040	1,338	5.65	128	2,599
Overall Mean	489	675	2.50	69	1,373
Low	116	149	0.02	22	489
High	959	1,338	5.65	128	2,476

n.a. = not available

Table 2.3-4. CSO PAH Concentrations.

Calculations are described in Section 2.3.3.

	2-methylnaphthalene (ng/l)	pyrene (ng/l)	benzo(a)pyrene (ng/l)
Mean	248	290	119
Std Deviation	303	356	170
No. Samples	9	9	9

Table 2.3-5. CSO PAH Loads.

Calculations are described in Section 2.3.3.

	2-methylnaphthalene (kg/yr)	pyrene (kg/yr)	benzo(a)pyrene (kg/yr)
Mean	2	2	1
Low estimate	0	0	0
High estimate	4	5	2

Table 2.3-6. CSO nutrient and conventional contaminant concentrations.
Calculations are described in Sections 2.3.4 and 2.3.5.

	NH4 (mg/l)	NO3+NO2 (mg/l)	TKN (mg/l)	Phosphorus (mg/l)	PO4 (mg/l)	TSS (mg/l)	BOD5 (mg/l)
BWSC Mean	2.45	n.a.	n.a.	n.a.	0.58	306	n.a.
Std Deviation	2.04	n.a.	n.a.	n.a.	0.60	596	n.a.
No. Samples	22	n.a.	n.a.	n.a.	22	23	n.a.
M & E Mean	1.44	0.32	3.3	0.9	n.a.	88	36
Std Deviation	1.37	0.14	2.6	0.5	n.a.	57	20
No. Samples	18	8	19	19	n.a.	19	19
MWRA Mean	2.34	n.a.	n.a.	1.5	n.a.	136	82
Std Deviation	2.55	n.a.	n.a.	1.3	n.a.	184	63
No. Samples	94	n.a.	n.a.	94	n.a.	581	579
Overall Mean	2.23	0.32	3.3	1.4	0.58	141	81
Std Deviation	2.35	0.14	2.6	1.2	0.60	213	63
No. Samples	134	8	19	113	22	623	598

n.a. = not available

Table 2.3-7. CSO nutrient and conventional contaminant loads.
Calculations are described in Sections 2.3.4 and 2.3.5.

	NH4 (mton/yr)	NO3+NO2 (mton/yr)	TKN (mton/yr)	Phosphorus (mton/yr)	PO4 (mton/yr)	TSS (mton/yr)	BOD5 (mton/yr)
BWSC Mean	15.6	n.a.	n.a.	n.a.	3.7	1954	n.a.
Low	2.2	n.a.	n.a.	n.a.	0.0	0	n.a.
High	32.6	n.a.	n.a.	n.a.	8.5	6546	n.a.
M & E Mean	9.2	2.0	21.0	5.5	n.a.	562	230
Low	0.4	1.0	3.7	2.1	n.a.	172	89
High	20.4	3.3	42.8	9.7	n.a.	1050	405
MWRA Mean	14.9	n.a.	n.a.	9.4	n.a.	870	526
Low	0.0	n.a.	n.a.	1.2	n.a.	0	106
High	35.4	n.a.	n.a.	19.8	n.a.	2323	1055
Overall Mean	14.3	2.0	21.0	8.7	3.7	901	516
Low	0.0	1.0	3.7	1.0	0.0	0	100
High	33.3	3.3	42.8	18.5	8.5	2568	1042

n.a. = not available

Table 2.3-8. Comparison of present and previous estimates of CSO discharge.

Calculated as described in Section 1.3.4. If change is positive or negative, the current estimate is significantly greater or less than the previous estimate ($p<0.05$). If change is zero, the current estimate is not significantly different from the previous estimate. n.d. = not determined.

In those cases where means were not estimated the range of values is given.

	Previous	Mean	std err	Change
Flow (m3/sec)	0.96	0.17-0.23		n.d.
Metals (ug/l)				
Cu	90	77	5	-
Pb	128	106	7	-
Hg		0.4	0.0	n.d.
Ni		11	0.7	n.d.
Zn	264	215	11	-
Nutrients (mg/l)				
NH4		2.2	0.2	n.d.
NO3+NO2		0.3	0.0	n.d.
TKN	5.5	3.3	0.6	-
PO4		0.6	0.1	n.d.
TP	2.6	1.4	0.1	-
Conventional (mg/l)				
BOD	105	81	3	-
TSS	232	141	9	-

2.4 Stormwater

All of the South Harbor drainage basin as well as that part of the North Harbor basin not serviced by CSOs has separate pipes for stormwater. The present estimate of direct stormwater runoff is based on those sub-basins closest to the Harbor minus the area served by CSOs (Fig. 1.0-1). Although they used the same sub-basins in their estimate of stormwater runoff (with the exception of the basin just downstream of the Amelia Earhart dam on the Mystic River), Menzie *et al.* (1991) included the area served by CSOs.

2.4.1 Flows

The South Harbor drainage area, as estimated by MWRA using Massachusetts Geographic Information Systems, is 34 km^2. This is close to the estimate made by Menzie *et al.* (1991) for the South Harbor (36 km^2). The portion of the North Harbor with separated stormwater systems was estimated by Metcalf and Eddy for the CSO planning project (Metcalf and Eddy 1994). The total area in their estimate for those sub-basins that drain directly to the Harbor (Lower Mystic, Chelsea Creek, Constitution Beach, Inner Harbor, Fort Point Channel, Reserved Channel, and Dorchester Bay) was 36 km^2. This is close to the estimate of 33 km^2 provided by the CH2M Hill Team for a similar set of sub-basins as part of the CSO facilities plan (MWRA 1989a,b,c). Note that these estimates do not include Logan Airport, which is evaluated separately below.

Stormwater flow was estimated by multiplying average annual rainfall (average annual rainfall measured at Logan Airport between 1961 and 1991 was 41.6 inches, BWSC 1993) times the drainage area times a runoff coefficient (that proportion of the rainfall hitting an area that runs off into the storm drains). Estimates are summarized in Table 2.4-1.

For the South Harbor, runoff coefficient was estimated based on EPA methodology, using the following formula:

runoff coefficient = 0.009 x % impervious surface + 0.05 (BWSC 1993).

To apply this formula, we used the compilation of land use types in the South Harbor drainage area done by Menzie *et al.* (1991). The percent impervious surface for each land use type as given by the Federal Highway Association (cited in BWSC 1993) was used to calculate average run-off coefficient. These coefficients were then used to calculate runoff. Since not all rainfall events actually generate runoff, these estimates were adjusted downward by 10%, according to EPA guidance. After accounting for this adjustment, the runoff coefficient actually used in the South Harbor was 0.26.

For the North Harbor, runoff coefficient was estimated three ways. First, Rizzo Associates and Sullivan and Worcester conducted a field study for BWSC as part of BWSC's stormwater permit application, where they empirically estimated a runoff coefficient of 0.23 (BWSC 1993). Second, BWSC applied the EPA methodology described above to their drainage area, which generated an average runoff coefficient (after adjustment) of 0.34. Third, we applied the EPA methodology, based on the land usage compiled by Menzie *et al.* (1991) (adjusted to reflect the area with separate storm drains). This resulted in a runoff coefficient of 0.43. The difference between the second and third estimates reflects a larger percentage of residential area (with less impervious surface and consequently lower runoff) in the BWSC study area.

Metcalf and Eddy (1994) estimated runoff in the North Harbor for a typical year as 3,597 million gallons, which falls in the range of our estimate (between 2,330 and 4,359 mgal).

2.4.2 Metals

Concentrations--BWSC sampled stormwater runoff at five locations in the city of Boston during four storms in 1992. Although they routinely looked for all eight metals we are tracking (Table 1.1-1), only chromium, copper, and zinc met our criteria for inclusion. Method detection limits for the other metals were as follows: cadmium (0.01 mg/l), lead (0.07 mg/l), mercury (0.0005 mg/l), nickel (0.04 mg/l) and silver (0.007 mg/l). Average concentrations are in Table 2.4-2.

Loads--Stormwater loads were calculated as described above for CSOs. The overall average concentration of each metal was multiplied by the average of the two flow estimates to get an average loading estimate. The high loading estimate is the product of the average concentration plus the s.d. times the high flow estimate, and the low loading estimate is the product of the average concentration minus the s.d. times the low flow estimate (Table 2.4-3)

2.4.3 PAHs

Concentrations--PAHs in stormwater that drains into the Harbor was measured at four locations during three storms in 1992 and at a fifth location during three storms in 1993 as part of the PAH study being conducted by Menzie-Cura and Associates for the Massachusetts Bays Program. Average concentrations of the three PAH compounds are reported in Table 2.4-4.

Loads--PAH loads were calculated as described above for metals (Table 2.4-5).

2.4.4 Nutrients

Concentrations--BWSC analyzed for nutrients as part of the sampling program described above for metals (BWSC 1993). Average concentrations are in Table 2.4-6.

Loads--Nutrient loads were calculated as described above for metals (Table 2.4-7).

2.4.5 Conventional pollutants

Concentrations--BWSC analyzed for conventional contaminants as part of their sampling program (BWSC 1993). Menzie-Cura and Associates have also measured TSS as part of their PAH sampling program. Average concentrations are included in Table 2.4-3.

Loads--Loads were calculated as described above for metals (Table 2.4-4).

2.4.6 Comparison with previous estimates

The previous estimates of stormwater runoff used by Menzie *et al.* (1991) were done using National Urban Runoff Program (NURP) methodology. Their estimate did not distinguish between areas with separate storm drains and those with combined systems, and because it is calculated based on a larger area, their estimates of flow are greater than the present estimate (Table 2.4-8). Adding our estimate of CSO flow (section 2.3.1) to stormwater increases the estimated flow range to 0.77 - 1.08 m^3/sec, which is more in keeping with the NURP estimate.

While the estimated concentrations of copper and zinc have not changed, lead concentrations have decreased compared with those used previously. In fact, BWSC were unable to detect lead in any of their 15 samples. The shift in recent years to the use of unleaded gasoline may be the cause of decreased lead concentrations in stormwater runoff as well as in other sources, as a decrease in lead concentrations was observed in several data sets.

Table 2.4-1. Stormwater flow estimates.
Calculations are described in Section 2.4.1.
Note that 8,336 x m3/sec = mgal/yr.

	Low (m3/sec)	Mean (m3/sec)	High (m3/sec)
North Harbor	0.279	0.416	0.523
South Harbor	0.319	0.319	0.319
Total	0.598	0.734	0.842

Table 2.4-2. Stormwater metal and conventional contaminant concentrations.
Calculations are described in Sections 2.4.2 and 2.4.5.

	Chromium (mg/l)	Copper (mg/l)	Zinc (mg/l)	TSS (mg/l)	BOD5 (mg/l)
Total Mean	0.013	0.047	0.278	28	17.7
Std Deviation	0.009	0.035	0.172	21.3	15.9
No. Samples	15	15	15	15	15

Table 2.4-3. Stormwater and metal conventional contaminant loads.
Calculations are described in Sections 2.4.2 and 2.4.5.

	Chromium (kg/yr)	Copper (kg/yr)	Zinc (kg/yr)	TSS (mton/yr)	BOD5 (mton/yr)
North Harbor Mean	174	619	3,651	368	232
Low	37	107	940	59	15
High	369	1,358	7,431	815	555
South Harbor Mean	134	475	2,801	282	178
Low	42	122	1,072	67	17
High	225	828	4,530	835	338
Total Mean	308	1,094	6,452	650	410
Low	79	229	2,012	126	33
High	594	2,185	11,961	1,650	893

Table 2.4-4. Stormwater PAH Concentrations.
Calculations are described in Section 2.4.3.

	2-methylnaphthalene (ng/l)	pyrene (ng/l)	benzo(a)pyrene (ng/l)
Mean	216	592	205
Std Deviation	257	914	438
No. Samples	18	18	18

Table 2.4-5. Stormwater PAH Loads.
Calculations are described in Section 2.4.3.

	2-methylnaphthalene (kg/yr)	pyrene (kg/yr)	benzo(a)pyrene (kg/yr)
North Harbor Mean	3	8	3
Low estimate	0	0	0
High estimate	8	25	11
South Harbor Mean	2	6	2
Low estimate	0	0	0
High estimate	5	15	6

Table 2.4-6. Stormwater nutrient concentrations.
Calculations are described in Section 2.4.4.

	TKN (mg/l)	NH4 (mg/l)	NO2 & NO3 (mg/l)	Phosphorus (mg/l)
Total Mean	4.99	2.38	0.56	0.55
Std Deviation	3.24	2.40	0.66	0.47
No. Samples	15	15	15	15

Table 2.4-7. Stormwater nutrient loads.
Calculations are described in Section 2.4.4.

	TKN (mton/yr)	Ammonia (mton/yr)	NO2 & NO3 (mton/yr)	Phosphorus (mton/yr)
North Harbor Mean	65.47	31.27	7.37	7.20
Low	15.42	0.00	0.00	0.73
High	135.91	79.03	20.21	16.76
South Harbor Mean	50.21	23.99	5.65	5.52
Low	17.58	0.00	0.00	0.83
High	82.84	48.17	12.32	10.21
Total Mean	115.68	55.26	13.03	12.73
Low	33.00	0.00	0.00	1.57
High	218.76	127.21	32.53	26.97

Table 2.4-8. Comparison of present and previous estimates of stormwater runoff.

Calculated as described in Section 1.3.4. If change is positive or negative, the current estimate is significantly greater or less than the previous estimate ($p<0.05$). If change is zero, the current estimate is not significantly different from the previous estimate. n.d. = not determined.
In those cases where means were not estimated a range of values is given.

	Previous	Mean	std err	Change
Flow (m3/sec)	0.97	0.60-0.85		n.d.
Metals (ug/l)				
Cr		13	2	n.d.
Cu	37	47	9	o
Pb	175	<70		-
Zn	225	278	44	o
Nutrients (mg/l)				
NH4		2.4	0.6	n.d.
NO3+NO2		0.6	0.2	n.d.
TKN		5.0	0.8	n.d.
TN	2.2			n.d.
TP	0.3	0.5	0.1	o
Conventional (mg/l)				
BOD	82	18	4	-
TSS	159	28	6	-

2.5 Airport

Runoff from Logan Airport was evaluated separately from the rest of the Harbor (Fig. 1.0-1). A revised estimate of loading was possible based on the NPDES stormwater permit application prepared for the Massachusetts Highway Department by Rizzo Associates in 1992 (Massport 1992). The airport was divided into three sites chosen to represent a range of land uses and runoff characteristics: north outfall, west combination outfall, and airfield outfall. Total airport drainage area was estimated as 7 km^2.

2.5.1 Flow

Stormwater flow was measured at up to three sites during five storms in March, May and June of 1991, resulting in a total of 13 sampling events (Massport 1992) and runoff coefficient was estimated. Runoff coefficient varied with rainfall intensity and land use characteristics at each site. Total runoff was estimated based on an analysis of rainfall duration and frequency during 1991, estimated runoff coefficients, and land use patterns in the area (Massport 1992). These calculations resulted in an annual flow estimate of 1,165 million gallons (our low estimate).

We did a second estimate of flow, based on the land use patterns described by Massport, using the EPA standard formula for runoff coefficient described above in section 2.4.1. This resulted in an estimated annual flow of 1,485 million gallons (our high estimate). Low and high estimates of flow are summarized in Table 2.5-1.

2.5.2 Metals

Concentrations--Massport measured metal concentrations during each of the storm sampling events (Massport 1992). Of the eight metals, only copper and zinc were detected frequently enough to warrant inclusion in our analysis (Table 2.5-2). Lead was detected once, and the remaining metals were never detected. Detection limits were as follows: cadmium (0.005 mg/l), chromium (0.01 mg/l), lead (0.05 mg/l), mercury (0.0005 mg/l), nickel (0.025 mg/l), and silver (0.01 mg/l).

Loads--Airport runoff loads were calculated as described above for CSOs. The overall average concentration of each metal was multiplied by the average of the two flow estimates to get an average loading estimate. The high loading estimate is the product of the average concentration plus the s.d. times the high flow estimate; the low loading estimate is the product of the average concentration minus the s.d. times the low flow estimate (Table 2.5-3).

2.5.3 PAHs

Concentrations--Massport analyzed for the entire list of priority pollutants during each sampling event (Massport 1992). Detection limits for PAHs generally ranged from 5 to 10 μg/l. 2-methylnaphthalene (detection limit = 1.8 μg/l) was detected in 3 out of 5 samples at the North Airfield, and in 1 of 5 samples in the West area. Although the compound was observed in less than half the cases, it is included here for completeness of the overall budget (Table 2.5-2). Spills of substances such as jet fuel are monitored at the airport. These can contain PAHs and other harmful compounds. However, very few of these spills reach the drainage system (Massport 1992).

Loads--2-methylnaphthalene load was calculated as described above for metals (Table 2.5-3).

2.5.4 Nutrients

Concentrations--Massport measure nutrients during each sampling event (Table 2.5-4).

Loads--Nutrient loads were calculated as described above for metals (Table 2.5-5).

2.5.5 Conventional pollutants

Concentrations--Massport measured conventional pollutants during each sampling event (Massport 1992). Data are included in Table 2.5-2.

Loads--Conventional pollutant loads, estimated as described above for metals, are included in Table 2.5-3. The chemicals used for deicing planes and runways (ethylene or propylene glycol) have a high oxygen demand (BOD). As part of their study, Massport (1992) estimated the total amount of glycol added to the Harbor as a result of deicing activity at the airport. We used this information to estimate the BOD load from winter deicing events, as follows. The total estimated load of deicing solution for the 1990-91 season was 490,000 gallons. Assuming that deicing solution is 50% propylene glycol and 50% water, that 50% of the solution reaches the drainage system, that 1.7 pounds of oxygen is required to oxidize 1 pound of propylene glycol, and that 65% of the oxygen is consumed over a period of five days, the resultant load of BOD_5 is approximately 534 metric tons. This additional load is included in the total given in Table 2.5-3.

2.5.6 Comparison with previous estimates

The previous estimate of airport runoff was based on National Urban Runoff Program methodology (Menzie *et al.* 1991). Although the current estimate of flow is not different from the previous one, the current estimates of lead, zinc, and TSS concentrations represent large decreases from the previous estimate (Table 2.5-6). The decrease in lead is probably due to a real source reduction, as a result of the shift to unleaded fuels noted earlier. Most of the jet fuel currently used at the airport does not contain lead (Massport 1992). Zinc loading estimates have also decreased, although it is unclear whether this is because the NURP methodology provides an overestimate or whether there has been a reduction in zinc concentrations in runoff. The very large decrease in TSS concentration may be the result of increased accuracy in estimating percent impervious and pervious surfaces. In the previous analysis it was assumed that the airport was approximately half open space and half paved runway. In the land use assessment done by Massport (1992) the percent impervious surface in each drainage area was evaluated; the overall total was 60% impervious surface. Since the previous estimate did not consider deicing activity, the BOD concentrations given in Table 2.5-6 only consider standard airport runoff. When deicing activity is included the average BOD concentration in the present estimate increases substantially, to approximately 140 mg/l.

Table 2.5-1. Airport flow estimates.
Calculations are described in Section 2.5.1.
Note that 8,336 x m3/sec = mgal/yr.

	Low (m3/sec)	Mean (m3/sec)	High (m3/sec)
North Outfall	0.014	0.016	0.018
West Combo Outfall	0.066	0.073	0.080
Airfield Outfall	0.059	0.070	0.081
Total	0.140	0.159	0.178

Table 2.5-2. Airport metal, PAH, and conventional contaminant concentrations.
Calculations are described in Sections 2.5.2, 2.5.3, and 2.5.5.

	Copper (mg/l)	Zinc (mg/l)	2-Methyl-naphthalene (ug/l)	TSS (mg/l)	BOD5 (mg/l)
North Mean	0.06	0.15	21.1	29	46
Std Deviation	0.02	0.03	35.8	39	47
No. Samples	5	5	5	5	5
West Combo Mean	0.10	0.14	2.0	18	55
Std Deviation	0.06	0.02	2.6	8	79
No. Samples	6	6	6	6	6
Airfield Mean	0.03	0.09	0.90	11	12
Std Deviation	0.02	0.02	0.00	7	11
No. Samples	3	3	3	3	3
Total Mean	0.07	0.13	8.6	20	42
Std Deviation	0.05	0.03	22.1	23	58
No. Samples	14	14	14	14	14

Table 2.5-3. Airport metal, PAH, and conventional contaminant loads
Calculations are described in Sections 2.5.2, 2.5.3, and 2.5.5.

	Copper (kg/yr)	Zinc (kg/yr)	2-Methyl-naphthalene (kg/yr)	TSS (mton/yr)	BOD5 (mton/yr)	BOD5 with deicing (mton/yr)
North Mean	32	77	11	15	23	
Low	19	54	0	0	0	
High	49	103	32	38	52	
West Combo Mean	227	311	5	42	126	
Low	85	243	0	21	0	
High	393	388	12	65	335	
Airfield Mean	55	207	2	25	27	
Low	4	132	2	8	1	
High	122	297	2	46	59	
Total Mean	314	595	17	81	175	709
Low	108	429	2	29	1	535
High	564	788	46	149	446	980

Table 2.5-4. Airport nutrient concentrations.
Calculations are described in Section 2.5.4.

	Ammonia (mg/l)	Nitrate (mg/l)	TKN (mg/l)	Phosphate (mg/l)
North Mean	0.72	0.48	2.40	0.31
Std Deviation	0.38	0.23	0.39	0.11
No. Samples	5	5	4	3
West Combo Mean	0.97	0.67	2.52	0.25
Std Deviation	0.57	0.27	0.66	0.06
No. Samples	6	6	5	4
Airfield Mean	0.42	0.60	1.87	0.05
Std Deviation	0.35	0.10	0.31	0.01
No. Samples	3	3	3	2
Total Mean	0.76	0.59	2.32	0.22
Std Deviation	0.49	0.23	0.54	0.12
No. Samples	14	14	12	9

Table 2.5-5. Airport nutrient loads.
Calculations are described in Section 2.5.4.

	Ammonia (mton/yr)	Nitrate (mton/yr)	TKN (mton/yr)	Phosphate (mton/yr)
North Low	0.36	0.24	1.21	0.15
Mean	0.15	0.11	0.91	0.09
High	0.61	0.40	1.56	0.23
West Combo Low	2.24	1.54	6	0.56
Mean	0.83	0.82	3.89	0.38
High	3.90	2.37	8.0	0.77
Airfield Low	0.92	1.33	4.13	0.10
Mean	0.12	0.94	2.93	0.07
High	1.96	1.79	5.54	0.13
Total Low	3.52	3.11	11.15	0.82
Mean	1.11	1.87	7.7	0.54
High	6.46	4.55	15.1	1.14

Table 2.5-6. Comparison of present and previous estimates of airport runoff.

Calculated as described in Section 1.3.4. If change is positive or negative, the current estimate is significantly greater or less than the previous estimate ($p<0.05$). If change is zero, the current estimate is not significantly different from the previous estimate. n.d. = not determined.
In those cases where means were not estimated a range of values is given.

	Previous	Mean	std err	Change
Flow (m3/sec)	0.1	0.14-0.18		n.d.
Metals (ug/l)				
Cu	64	70	13	o
Pb	466	<50		-
Zn	409	132	9	-
Nutrients (mg/l)				
NH4		0.8	0.1	n.d.
NO3		0.6	0.1	n.d.
TKN		2.3	0.2	n.d.
TN	3.2			n.d.
PO4		0.2	0.0	n.d.
TP	0.5			n.d.
Conventional (mg/l)				
BOD	56	42	16	o
TSS	251	20	6	-

2.6 Tributaries

Three rivers drain into the North Harbor (the Charles, Mystic, and Neponset), and three smaller rivers into the South Harbor (Weymouth Fore, Weymouth Back, and Weir) (see Fig. 1.0-1). Since the Weir River is located entirely within the sub-basin that drains to the Harbor, its discharge is not included in the present estimate. It should be noted that stormwater, groundwater and atmospheric deposition all affect the concentration of contaminants in rivers. In addition, CSOs along the rivers in the North Harbor also contribute contaminants. Although some of the contaminants added to the rivers either break down or settle out before the water flows into the Harbor, many of them do not. In order to account for the contributions of all of these sources, we sought estimates of contaminant concentrations in water samples from the mouths of the rivers, just as they enter the Harbor. For the purposes of this estimate, the mouth of the Charles and Mystic rivers were described as the sites of the Charles River and Amelia Earhart dams, respectively.

2.6.1 Flows

Flow at each of the North Harbor rivers as well as the Weymouth Back River are recorded daily at USGS gaging stations (USGS 1990, 1991, 1992). Flow at the Weymouth Fore River and Weir River are measured at partial-record stations. (Note that estimates of discharge from the Weir River are presented here for completeness but it is not included in load calculations.) We used the average annual flow reported during the last three water years (October 1989 through Sept 1992) at the gage station closest to the mouth of each river (Table 2.6-1). Measured flow was adjusted to account for the area of the entire drainage area by the following formula:

total flow = flow at gage x (total drainage area/drainage area above gage).

Note that this formula was applied by Menzie-Cura and Associates (1991) in their estimate of river flow into Massachusetts Bay, but the adjustment was not done in their estimates for Boston Harbor (Menzie *et al.* 1991). This adjustment results in a large increase in estimated river discharge.

Flow estimates are summarized in Table 2.6-2. Low and high estimates are the average of three years of adjusted flow plus or minus the standard deviation. The average flows during the three years used in the present estimate were greater than the long-term averages reported for these rivers. For example, the average (unadjusted) gage flow reported in the Charles River between 1931 and 1992 was 8.6 m^3/sec, whereas the flow used in the present estimate was 9.7 m^3/sec.

2.6.2 Metals

Concentrations--There is very little new information on concentrations of metals in river water. Menzie-Cura and Associates (1991) estimated ranges for various metal concentrations in rivers based on a survey of the literature. Copper concentration in rivers was estimated as 10 µg/l, and lead and zinc were estimated as ranging from 1 to 30 µg/l. We have modified these estimates based on data of Dr. Gordon Wallace and Elva Romanow at UMass/Boston, who made measurements of Charles River dissolved metal concentrations in samples taken in June 1983 and December 1991, and total (dissolved and particulate) metals in samples taken in August 1991.

The ranges and average concentrations used in the present estimate were as follows:

copper: 1 µg/l to 10 µg/l, average: 4.2 µg/l

lead: 1 µg/l to 10 µg/l, average: 3.4 µg/l, and

zinc: 1 µg/l to 20 µg/l, average: 3.3 µg/l.

Average estimates used here are based on total metal concentrations measured in August 1991. High and low estimates envelope the average concentrations of metals measured in a study of 13 east coast rivers (Windom et al. 1991) as well as observations of metal concentrations in tributaries to New York Harbor (Battelle 1992). In addition, Windom et al. (1991) found that an average of 60% of Cu, 10% of Pb, and 20% of Zn were found in dissolved form. Applying these percentages to the dissolved data of Wallace and Romanow generates concentration estimates that fall within the above ranges.

Loads--Low estimates of loading were calculated as the product of the low flow estimate times the low concentration estimate. High estimates were calculated as the product of high flow times high concentration. Average estimates are the product of the average flow times the average concentration estimate. Loading estimates are in Table 2.6-3.

2.6.3 PAHs

Concentrations--PAH concentrations at stations at the mouth of the Charles and Mystic Rivers were measured by Menzie-Cura and Associates in March, April, and October 1992 as part of their Massachusetts Bays Program study. Concentrations of the three PAH compounds are in Table 2.6-4.

Loads--Average loading estimates were calculated as the product of average concentration times average flow. High and low estimates were calculated as the product of high and low concentration estimates times high and low flow estimates, respectively. Loading estimates are in Table 2.6-5.

2.6.4 Nutrients

Concentrations--There is very little new information on concentrations of nutrients in river water. Menzie-Cura and Associates (1991) estimated ranges for nutrient concentrations in rivers based on Department of Environmental Quality Engineering (DEQE, now Department of Environmental Protection, DEP) surveys between 1982 and 1990. In the Menzie *et al.* (1991) estimate, total nitrogen concentration in rivers entering Boston Harbor ranged from 1.4 mg/l to 1.8 mg/l, and total phosphorus from 0.08 mg/l to 0.19 mg/l. We have used their estimated range for phosphorus concentration, and modified the nitrogen range based on a very limited amount of nutrient data collected by Metcalf and Eddy for the MWRA CSO Program, which collected samples at the mouth of the Charles River in November 1992 (MWRA 1993). Since the Metcalf and Eddy data ranged from 0.9 mg/l to 1.7 mg/l, we modified the range of nitrogen concentrations to reflect the lower value, and estimated nitrogen ranged from a low of 0.9 mg/l to a high of 1.8 mg/l.

Loads--Loading estimates were calculated as described above for metals (Table 2.6-6).

2.6.5 Conventional pollutants

Concentrations--Menzie-Cura and Associates (1991) estimated ranges for conventional contaminant concentrations in rivers based on DEQE (now DEP) surveys between 1982 and 1990. In their estimate, TSS concentration in rivers entering Boston Harbor ranged from 5.6 mg/l to 21.9 mg/l, and BOD from 3.0 mg/l to 4.6 mg/l. We have modified these ranges based on measurements made by Metcalf and Eddy at stations in the mouth of the Charles and Mystic Rivers during two storms in November 1992 (MWRA 1993). They observed TSS concentrations averaging 5.7 mg/l (s.d=2.9 mg/l, n=38), and BOD_5 concentrations averaging 11.8 mg/l (s.d.=27.5, n=24). We modified the range of TSS concentration to represent the average concentration observed by Metcalf and Eddy plus or minus the standard deviation (2.8 mg/l to 8.6 mg/l). BOD_5 concentration was modified to extend from 3.0 mg/l up to 11.8 mg/l.

Loads--Loading estimates were calculated as described above for metals (Table 2.6-7).

2.6.6 Comparison with previous estimates

The major change in estimated contaminant loading from tributaries results from the adjusted flow calculations done in the present estimate. This adjustment more than doubled the flow estimate (Table 2.6-8), resulting in a large increase in estimated load.

Due to the fact that there is very little new data on contaminant concentrations, the contribution of contaminants from rivers is one of the largest uncertainties in the present estimate.

Table 2.6-1. Boston Harbor river gage information and drainage areas. Calculations are described in Section 2.6.1.

	Gage location	Gage #	Drainage at gage (km2)	Total drainage (km2)
Mystic River	Winchester	2500	62	162
Charles River	Waltham	4500	588	744
Neponset River	Norwood	5000	90	303
Weymouth Fore River	Holbrook	5568	71	93
Weymouth Back River	S. Weymouth	5600	12	45
Weir River	Hingham	5640	38	67

Table 2.6-2. River flow estimates

Calculations are described in Section 2.6.1.

Note that total does not include the Weir River.

	Low (m3/sec)	Mean (m3/sec)	High (m3/sec)
North Harbor			
Mystic River	1.3	2.4	3.4
Charles River	6.5	12.3	18.0
Neponset River	3.3	5.3	7.4
South Harbor			
Weymouth Fore River	0.0	0.0	0.1
Weymouth Back River	0.3	0.9	1.5
Weir River	0.0	0.1	0.1
North Harbor	11.1	20.0	28.8
South Harbor	0.4	1.0	1.6
Total	11.5	20.9	30.4

Table 2.6-3. River metal loads.

Calculations are described in Section 2.6.2.

	Copper (kg/yr)			Lead (kg/yr)			Zinc (kg/yr)		
	Low	Mean	High	Low	Mean	High	Low	Mean	High
South Mean	30	126	301	30	102	301	30	99	601
Low	11	47	111	11	38	111	11	37	222
High	49	206	490	49	167	490	49	162	980
North Mean	631	2,651	6,313	631	2,146	6,313	631	2,083	12,625
Low	352	1,477	3,517	352	1,196	3,517	352	1,161	7,034
High	911	3,825	9,108	911	3,097	9,108	911	3,006	18,216
Total Mean	661	2,778	6,613	661	2,248	6,613	661	2,182	13,226
Low	363	1,524	3,628	363	1,234	3,628	363	1,197	7,256
High	960	4,031	9,598	960	3,263	9,598	960	3,167	19,196

Table 2.6-4. River PAH Concentrations.

Calculations are described in Section 2.6.3.

	2-methylnaphthalene (ng/l)	pyrene (ng/l)	benzo(a)pyrene (ng/l)
Mean	124	168	12
Std Deviation	165	169	5
No. Samples	6	6	6

Table 2.6-5. River PAH Loads.

Calculations are described in Section 2.6.3.

	2-methylnaphthalene (kg/yr)	pyrene (kg/yr)	benzo(a)pyrene (kg/yr)
North Harbor Mean	78	106	7
Low estimate	0	0	2
High estimate	263	307	15
South Harbor Mean	4	5	0
Low estimate	0	0	0
High estimate	14	17	1

Table 2.6-6. River nutrient loads.

Calculations are described in Section 2.6.4.

	Total N (mton/yr)		Total P (mton/yr)	
	Low	High	Low	High
South Mean	27	54	2	6
Low	10	20	1	2
High	44	88	4	9
North Mean	568	1,136	51	120
Low	317	633	28	67
High	820	1,639	73	173
Total Mean	595	1,190	53	126
Low	327	653	29	69
High	864	1,728	77	182

Table 2.6-7. River conventional contaminant loads.
Calculations are described in Section 2.6.5.

	TSS (mton/yr)		BOD (mton/yr)	
	Low	High	Low	High
South Mean	84	258	90	355
Low	31	95	33	131
High	137	422	147	578
North Mean	1,768	5,429	1,894	7,449
Low	985	3,025	1,055	4,150
High	2,550	7,833	2,732	10,747
Total Mean	1,852	5,687	1,984	7,804
Low	1,016	3,120	1,088	4,281
High	2,687	8,254	2,879	11,326

Table 2.6-8. Comparison of present and previous estimates of river discharge.

	Previous	Present
Flow (m3/sec)	12	21
Metals (ug/l)		
Cu	10	1-10
Pb	1-30	1-10
Zn	1-30	1-20
Nutrients (mg/l)		
TN	1.4-1.8	0.9-1.8
TP	0.08-0.19	0.08-0.19
Conventional (mg/l)		
BOD	2-5	3-11.8
TSS	6-22	2.8-8.6

2.7 Atmospheric Sources

Investigators at UMass/Lowell (Dan Golomb, David Ryan, and Jeffrey Underhill) are currently working on a project for the Massachusetts Bays Program to estimate atmospheric deposition of contaminants onto Massachusetts and Cape Cod Bays. The following estimates of atmospheric deposition should be viewed as preliminary: complete data and final estimates will be available in their final report, which will be available in late 1994 (also, see Underhill, 1994).

Atmospheric contaminants enter the Harbor via both wetfall (*e.g.* rain) and dryfall (*e.g.* deposition of dust). In the sections below, the deposition rate and load of each contaminant is presented. Deposition rate is calculated as the concentration measured in samples from both wet and dry collectors, divided by the area of the collectors and the length of the sampling period (units are kg/km^2y). Annual loads are calculated by multiplying the deposition rate times the area of the North Harbor (51 km^2), or South Harbor (57 km^2).

2.7.1 Metals

Deposition rates--As part of the Massachusetts Bays Program project, metal concentrations were analyzed in samples collected in both wet and dry collectors at a station in Nahant and one in Truro from July 1992 through September 1993. For the present estimate, we used information from samples collected in Nahant since it is closest to Boston. Preliminary analyses by J. Underhill, based on approximately six months of data, yield an estimated deposition rate of 1.8 kg/km^2y for copper, 4.9 kg/km^2y for lead, and 8.8 kg/km^2y for zinc (see Table 2.7-1). These estimates are based on assumptions about the solubility of the different metals. The average and range of solubility coefficients (Underhill, 1994) results in the range of deposition rates given in Table 2.7-1.

Menzie-Cura and Associates (1991) estimated metal deposition based on literature values. They estimated that copper deposition was 5.0 kg/km^2y, lead was 58 kg/km^2y, and zinc ranged from 1.4-22.8 kg/km^2 y.

Loads--Loads of each metal are calculated as deposition rate times area (Table 2.7-2).

2.7.2 PAH

Deposition rates--PAH deposition rates used in the present estimate are from samples collected in wet and dry collectors at the Nahant station by the UMass/Lowell investigators. Data are from samples collected biweekly over a six week period (September 30 to November 10, 1992). Deposition rate of 2-methylnaphthalene was 40.8 g/km^2y, that of pyrene was 40.1 g/km^2y, and that of benzo(a)pyrene was 22 g/km^2y.

Loads--Loads were calculated as described above for atmospheric deposition of metals (Table 2.7-3).

2.7.3 Nutrients

Deposition rates--We have used the estimate of phosphorus deposition done by Menzie-Cura and Associates (1991), as there is no new data for atmospheric phosphorus deposition. They estimated that wet deposition ranged from 2.2 to 12.8 kg/km^2y, whereas dry deposition equalled 1.2 kg/km^2y. We used their low or high wet deposition plus dry deposition to calculate low (3.2 kg/km^2y) and high (14.0 kg/km^2y) deposition rates of phosphorus.

Atmospheric deposition of nitrogen was estimated for the Massachusetts Bays Program project by Dr. Steve Zemba of Cambridge Environmental (Zemba 1993). Wet and dry deposition were estimated independently. Wet deposition measurements of NO_3 and NH_4 are based on data taken as part of the National Acid Deposition Program (NADP), which collects wet deposition samples on a weekly basis. Data from 1990 and 1991 at the NADP site in Waltham, the site closest to Boston, were used (Table 2.7-3).

Zemba (1993) estimated dry deposition of gases and aerosols (particle-bound N) separately. Dry deposition was calculated according to the formula:

$D = C \times V \times g$, where

D is the rate of dry deposition of nitrogen (kg $N/km^2/yr$),

C is the concentration of nitrogen-containing species in air (ppb N),

V is the deposition velocity (cm/s), and

g is a units conversion factor of 181 (kg N s/ppb N-cm-km^2-y).

[$g = 0.573\ \mu g\ N\ m^{-3}/ppb\ N \times 1\ kg/10^9\ \mu g \times 1\ m/10^2\ cm \times 10^6\ m^2/km^2 \times 3.16 \times 10^7\ s/yr$]

Two forms of nitrogen-containing trace gases, NO_x (includes NO, NO_2, HNO_3, and organic nitrate species) and NH_3 were considered, using a deposition velocity of 0.4 cm/sec for both gases (Zemba, 1993).

According to data given in Zemba (1993), the concentration of NO_x in urban areas is 25 ppb, whereas the concentration in seabreeze is 2.9 ppb. Zemba presents an analysis of wind direction at Logan Airport, which shows that winds blow from the east (0 to 180 degrees) one third of the time, and from the west (180 to 360 degrees) the remaining two thirds of the time. We used this information to make two estimates of the dry deposition of NO_x. In the first, we assumed that winds from the east had the concentration of seabreeze whereas those from the west had the concentration measured in urban areas. In the second, we assumed that all the wind had the concentration measured in urban areas.

NH_3 concentrations range from 1-5 ppb in the eastern United States (Zemba 1993). Zemba used a value of approximately 2 ppb for his estimate of NH_3-N loading to Massachusetts and Cape Cod Bays. We used Zemba's estimate for our average concentration, and the high of 5 ppb for our high concentration.

For the deposition of N-containing aerosols, we again followed Zemba (1993) and used a deposition velocity of 0.3 cm/s for NO_3, and one of 0.1 cm/s for NH_4. The concentration of NO_3 for coastal locations along the eastern seaboard was estimated as 0.51 ppb, and for NH_4 we used an average concentration of 1.2 ppb.

The total estimated deposition rates are summarized in Table 2.7-4. The average deposition was estimated as the sum of the average estimates of wet and dry deposition, plus aerosols. The high estimate is the sum of the average wet deposition plus the s.d., plus the high case estimate of dry deposition, plus aerosols. The low estimate is the sum of the average wet deposition minus the s.d., plus the low case estimate of dry deposition, plus aerosols.

Loads---High and low phosphorus loads were calculated by multiplying high or low deposition rates times the area of the Harbor. Average load is the average of the high and low estimates. Nitrogen loads were calculated by multiplying average, low or high deposition rates (Table 2.7-4) times the area of the Harbor. Estimates are in Table 2.7-5.

2.7.4 Conventional pollutants

Not applicable to atmospheric deposition.

2.7.5 Comparison with previous estimates

The estimates of both lead and zinc load due to atmospheric deposition have decreased considerably (Table 2.7-6). The Menzie-Cura estimates are based on data from 1985, and there has been a substantial decrease in atmospheric lead concentrations since that time. For example, the Department of Environmental Protection division of air quality control data (Lane *et al.* 1992) shows a long-term decrease in atmospheric lead concentrations in their Boston and Springfield monitoring sites, from approximately 0.53 $\mu g/m^3$ in 1983 to less than 0.01 $\mu g/m^3$ in 1992, with at least a ten-fold drop in concentration between 1985 and 1992. It is unclear why the estimate of zinc deposition has decreased, although this may reflect improved analytical capability. However, the decrease in lead deposition provides additional evidence that the shift to unleaded gasoline has resulted in decreased lead loading to the Harbor.

The phosphorus estimates decreased as a result of differences in the estimate used in the Boston Harbor loadings (Menzie *et al.* 1991) and the revised numbers used for the Massachusetts Bay estimates (Menzie-Cura and Associates 1991). However, it should be kept in mind that there are no new data on phosphorus deposition. Nitrogen estimates in the present estimate are greater than the upper-end estimate derived by Menzie *et al.* (1991) (Table 2.7-7). This is largely due to an increase in the estimation of dry deposition.

Table 2.7-1. Metal atmospheric deposition rates.
Calculations are described in Section 2.7.1.

	Copper (kg/km2yr)	Lead (kg/km2yr)	Zinc (kg/km2yr)
Dry	1.29	3.11	6.34
Wet	0.53	1.80	2.51
Total Mean	1.81	4.91	8.85
Low	1.50	4.12	7.31
High	2.24	6.08	12.57

Table 2.7-2. Atmospheric metal loads.
Calculations are described in Section 2.7.

	Copper (kg/yr)	Lead (kg/yr)	Zinc (kg/yr)
North Harbor Mean	92	250	451
Low	77	210	373
High	114	310	641
South Harbor Mean	103	280	504
Low	86	235	417
High	128	346	717
Total Mean	196	530	955
Low	162	445	790
High	242	656	1,358

Table 2.7-3. Atmospheric PAH loads.
Calculations are described in Section 2.7.2.

	2-methylnaphthalene (kg/yr)	pyrene (kg/yr)	benzo(a)pyrene (kg/yr)
North Harbor	2.08	2.05	1.12
South Harbor	2.32	2.29	1.25
Total	4.40	4.34	2.38

Table 2.7-4. Atmospheric nitrogen deposition rates.
Calculations are described in Section 2.7.3.

	NH4 (kg/km2yr)	NO3 (kg/km2yr)	NH3 (kg/km2yr)	NOx (kg/km2yr)	Total (kg/km2yr)
Wet deposition					
Average	158	1,210			
Std dev	70	354			
Dry deposition					
Average	22	27	145	1,281	
High			362	1,810	
Average estimate	180	1,237	145	1,281	2,842
Low estimate	109	882	145	1,281	2,418
High estimate	250	1,591	362	1,810	4,012

Table 2.7-5. Atmospheric nutrient loads.
Calculations are described in Section 2.7.3.

	Total N (mton/yr)	Total P (mton/yr)
North Harbor Mean	145	0.44
Low	123	0.17
High	205	0.71
South Harbor Mean	162	0.50
Low	138	0.19
High	229	0.80
Total Mean	307	0.94
Low	261	0.37
High	433	1.51

Table 2.7-6. Comparison of present and prevous estimates of atmospheric deposition.

	Previous	Present
Metals (mg/m2yr)		
Cu	4.6	1.2-5
Pb	53	0.5-58
Zn	14-68	1.4-23
Nutrients (kg/m2yr)		
TN	500	2,418-4,012
TP	12-70	3.4-14

2.8 Groundwater

We did not have new information on the concentration of contaminants in groundwater that enters Boston Harbor. For the purposes of this estimate, the area of the Harbor receiving direct groundwater input to the Harbor was assumed to be the same area that contributes runoff to storm drains or CSOs. This is the area of the closest sub-basin to the Harbor (see Fig. 1.0-1), which is in keeping with the assumption made by Menzie *et al.* (1991). Estimated area (Massachusetts Geographic Information System) of the South Harbor drainage basin is 34 km^2 and of the North Harbor is 64 km^2 (including the airport and areas with both separate and combined stormwater systems). These areas were used in the present estimate of groundwater flow. Menzie *et al.* (1991) estimated that the South Harbor drainage area totals 36 km^2 and the North Harbor totals 48 km^2. Adjusting their North Harbor estimate upward to account for the added sub-basin (see section 1.2) brings this to 55 km^2. A higher estimate of the North Harbor drainage basin (68 km^2) was made by the CH2M Hill Team as part of the CSO facilities plan (MWRA 1989 b,c).

2.8.1 Flows

Groundwater flow was assumed to be half of the rainfall that does not run off directly (Menzie *et al.* 1991, USGS, pers. comm). Since we assumed that between 25 and 35% of the rainfall is stormwater runoff, that means approximately 35% of the rainfall enters the Harbor as groundwater. Assuming an annual average rainfall of 1.1 m (BWSC 1993), flow equals 35% x 1.1m/yr x area. This equals 0.75 m3/s for the North Harbor, and 0.40 m^3/s for the South Harbor.

2.8.2 Metals

Concentrations--Menzie-Cura and Associates (1991) estimated ranges for various metal concentrations in groundwater based on a survey of the literature and results of several older studies in the Boston area. We have revised their estimated ranges for copper and lead based on 146 samples taken in groundwater in Massachusetts. Typical copper concentrations in Massachusetts public-supply wells are about 20 to 30 µg/l; median concentrations ranged from 10 µg/l to 50 µg/l (USGS 1986). Lead concentrations ranged from to 1 to 30 µg/l, with most observations between 1 and 2 µg/l (USGS 1986). The zinc concentration estimate is based on information from the USGS on water quality in public water supplies (Hem 1985). They cite average zinc concentrations in all surface waters as 10 µg/l, in streams as 20 µg/l, and in rivers as ranging from 5 to 45 µg/l (Hem 1985). Note that the zinc concentrations are based on studies done in the 1960s, and so they may not be representative of present conditions. In addition, the analytical techniques used in these older analyses have been called into question (Windom et al. 1991) and are probably overestimates. The estimates used in the present estimate are as follows:

copper: 10 µg/l to 40 µg/l, average = 25 µg/g,

lead: 1 µg/l to 30 µg/l, average = 2 µg/l, and

zinc: 10 µg/l to 30 µg/l, average = 20 µg/l.

Loads--Average loads are the product of average concentration times estimated flow. Low or high loading estimates are calculated as the product of low or high concentration times the estimated flow (Table 2.8-1).

2.8.3 PAH

There are no data on the concentration of specific PAH compounds in groundwater of which we are aware.

2.8.4 Nutrients

Concentrations--We used a concentration range of 0.1 to 5 mg/l for NO_3 and 0.01 to 0.5 mg/l for PO_4, based on the range of concentrations in Valiela *et al.* (1990), who reported nutrient concentrations for groundwater discharge into coastal waters, including groundwater on Cape Cod and that flowing into Buzzards Bay. It should be noted that these sites were mostly unconsolidated sediments, where the concentrations of nutrients might be expected to be higher than in Boston Harbor, which consists of a heterogeneous mixture of fill. In addition, the groundwater in this area may be subject to inputs from septic systems. These estimates may therefore be on the high end. Note also that although these estimates are based on nitrate and phosphate only, these inorganic forms probably represent the major forms of nitrogen and phosphorus present in groundwater.

Loads--High and low loading estimates were calculated as described above for metals (Table 2.8-2). Average loads are the arithmetic average of the low and high loading estimates

2.8.5 Conventional pollutants

Not applicable to groundwater loading.

2.8.6 Comparison with previous estimates

Our metal estimates have decreased substantially compared with the data used by Menzie *et al.* (1991) (Table 2.8-3). However, the concentrations used in the present estimates are still based on data from several years ago and should be used with caution. Note that the present estimate of concentration of phosphorus in groundwater is several orders of magnitude higher than the previous estimate.

Table 2.8-1. Groundwater metal loads.
Calculations are described in Section 2.8.2.

	Copper (kg/yr)	Lead (kg/yr)	Zinc (kg/yr)
North Harbor Mean	593	47	474
Low	237	24	237
High	948	711	711
South Harbor Mean	316	25	253
Low	126	13	126
High	506	379	379
Total Mean	909	73	727
Low	363	36	363
High	1454	1090	1090

Table 2.8-2. Groundwater nutrient loads.
Calculations are described in Section 2.8.4.

	Nitrate (mton/yr)	Phosphate (mton/yr)
North Harbor Mean	60.4	6.0
Low	2.4	0.2
High	118.5	11.9
South Harbor Mean	32.2	3.2
Low	1.3	0.1
High	63.2	6.3
Total Mean	92.7	9.3
Low	3.6	0.4
High	181.7	18.2

Table 2.8-3. Comparison of present and previous estimates of groundwater discharge.

	Previous	Present
Flow (m3/sec)	1	1-1.2
Metals (ug/l)		
Cu	10-100	10-40
Pb	1-100	1-30
Zn	10-100	10-30
Nutrients (ug/l)		
TN	100-1,000	100-5,000
TP	0.01-0.06	10-500

2.9 Other NPDES Discharges

Besides the MWRA, Boston Edison is the only other NPDES permit-holder that discharges contaminants directly to the Harbor. We used monthly discharge data (from NPDES Discharge Monitoring Reports) from January 1990 through May 1993 for the two pipes that discharge treated wastewater to the Harbor: # 002A, and #011A (located in Mystic River just below the Amelia Earhart Dam).

2.9.1 Flows

Average monthly flows measured at each discharge over the 41 month period are in Table 2.9-1.

2.9.2 Metals

Concentrations--Copper, zinc, and nickel are measured monthly at each site. Iron is also measured, although it is not included here because it is not one of the eight metals we are tracking. Average concentration of each metal at each site is in Table 2.9-2.

Loads--Loads are calculated as the monthly concentration times monthly flow for each discharge site. These are added to get total annual discharge. The average and standard deviations of the load from each site, as well as the total combined load, are presented in Table 2.9-3.

2.9.3 PAHs

Not applicable.

2.9.4 Nutrients

Not applicable.

2.9.5 Conventional pollutants

Concentration--TSS is measured each month. Average concentrations are included in Table 2.9-2.

Loads--Total load, calculated as described above for metals, are included in Table 2.9-3.

2.9.6 Comparison with previous estimates

The present estimate represents a decrease in most parameters (Table 2.9-4). The very large decrease in TSS concentration is partially the result of the inclusion by Menzie *et al.* (1991) of two additional sources of TSS, Exxon Oil's outfall, which does not discharge directly into the Harbor, and Boston Edison's outfall #003A, which has since been eliminated. However, even with these additional sources, the concentration in the original report should have been approximately 10 mg/l, rather than the much higher value that was used. This was the result of a transcription error in Menzie *et al.* (1991).

Table 2.9-1. Boston Edison flow estimate.
Calculations are described in Section 2.9.1.

	Flow (m3/sec)
002A Mean	0.018
Std Deviation	0.004
No. Samples	41
011A Mean	0.010
Std Deviation	0.003
No. Samples	41
Total Flow	0.028
Std Deviation	0.005
No. Samples	41

Table 2.9-2. Boston Edison metal and conventional contaminant concentrations

Calculations are described in Section 2.9.2 and 2.9.5.

	Copper (mg/l)	Nickel (mg/l)	Zinc (mg/l)	TSS (mg/l)
002A Mean	0.11	0.09	0.05	4.16
Std Deviation	0.06	0.05	0.05	1.51
No. Samples	41	41	41	41
011A Mean	0.14	0.15	0.04	8.31
Std Deviation	0.10	0.12	0.03	1.91
No. Samples	41	41	41	41
Total Mean	0.12	0.12	0.04	6.24
Std Deviation	0.08	0.10	0.04	2.70
No. Samples	82	82	82	82

Table 2.9-3. Boston Edison metal and conventional contaminant loads.

Calculations are described in Section 2.9.2 and 2.9.5.

	Copper (kg/yr)	Nickel (kg/yr)	Zinc (kg/yr)	TSS (mton/yr)
002A Mean	62.3	47.9	25.8	2.4
Std Deviation	34.8	29.5	28.5	1.1
011A Mean	42.6	45.5	11.1	2.5
Std Deviation	40.3	38.3	9.1	1.0
Total Mean	104.9	93.3	36.9	4.9
Low	29.8	25.6	0.0	2.9
High	180.0	161.1	74.5	7.0

Table 2.9-4. Comparison of present and previous estimates of Boston Edison discharge.

Calculated as described in Section 1.3.4. If change is positive or negative, the current estimate is significantly greater or less than the previous estimate ($p<0.05$). If change is zero, the current estimate is not significantly different from the previous estimate. n.d. = not determined.

	Previous	Present	std err	Change
Flow (m3/sec)	0.05	0.03	0.0	-
Metals (ug/l)				
Cu	40	123	9	+
Ni	468	118	11	-
Zn	109	41	4	-
Conventional (mg/l)				
TSS	241	6	0.3	-

3.0 Summary of Loadings

Figures and tables of summary budgets for those contaminants for which we have complete information are presented on the following pages. The tables summarize the estimated low, average, and high loads associated with each contaminant source to both the North and South portions of the Harbor (see Fig. 1.0-1). The updated estimates of contaminant loading from sludge are included in the North Harbor budgets, because sludge from both plants was discharged through outfall pipes located in the northern part of the Harbor during part of the period covered during the present study. However, since sludge is no longer discharged, it is not included in current estimates of total contaminant loading to the Harbor.

In the figures that follow, the bars represents our estimate of the average annual load of material that enters Boston Harbor from each of the sources considered, with the exception of sludge. The lines through the bars span the range of estimates, from the low to the high. The total amount of material that enters the Harbor each year is in the box on the upper right. The large number in each bar is the percentage of the total accounted for by each source, calculated in terms of the average estimate. Note that the y-axis in all figures is a log scale, which means that very large differences in loads translate to small differences in the height of the bar.

3.1 Flows of Discharges

More flow is discharged into the North Harbor than into the South Harbor (Table 3.1-1). This is both because all three of the major rivers that enter the Harbor enter into the northern section, and because flow from Deer Island accounts for the majority of the effluent discharge. In terms of overall discharge into the Harbor, rivers represent a total of 48% of the flow (Fig. 3.1-1). Effluent contributes most of the remaining flow, accounting for 39%. Note that the atmospheric contribution is calculated on the basis of wet deposition only.

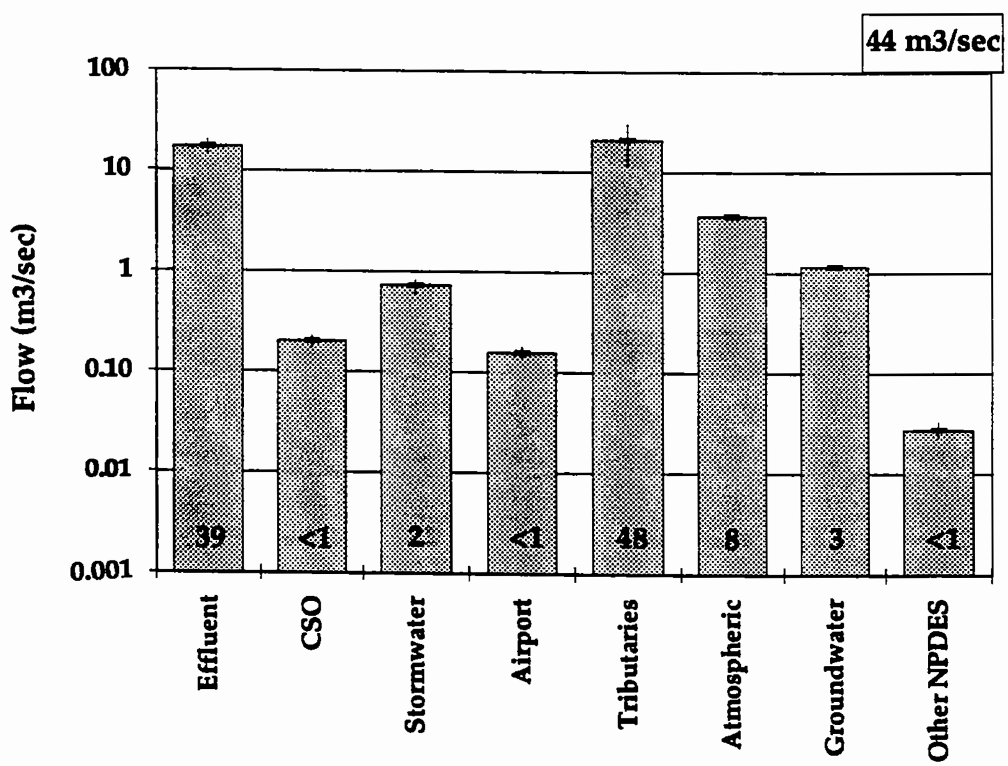
3.1.1 Comparison with previous estimates

The total flow estimated here is 22% greater than the flow estimated by Menzie *et al.* (using NURP values for runoff), largely because of the corrected estimate of river flow (see section 2.6.1).

Table 3.1-1 Budget of flow discharged to Boston Harbor

(m3/sec)	North Harbor Low	North Harbor Mean	North Harbor High	South Harbor Low	South Harbor Mean	South Harbor High	Total Low	Total Mean	Total High
Effluent	10.0	11.6	13.1	4.4	5.7	7.0	14.41	17.26	20.11
CSO	0.18	0.20	0.23	n.a.	n.a.	n.a.	0.18	0.20	0.23
Stormwater	0.28	0.42	0.52	0.3	0.3	0.3	0.60	0.73	0.84
Airport	0.14	0.16	0.18	n.a.	n.a.	n.a.	0.14	0.16	0.18
Tributaries	11.1	20.0	28.8	0.4	1.0	1.7	11.50	21.00	30.50
Atmospheric	1.7	1.7	1.7	1.9	1.9	1.9	3.62	3.62	3.62
Groundwater	0.4	0.4	0.4	0.8	0.8	0.8	1.15	1.15	1.15
Other NPDES	0.023	0.028	0.033	n.a.	n.a.	n.a.	0.03	0.03	0.02
Sludge	0.017	0.020	0.023	n.a.	n.a.	n.a.	0.02	0.02	0.02
Total (minus sludge)	23.9	34.5	45.0	7.7	9.7	11.6	32	44.15	57

Fig. 3.1-1. Flow discharged to Boston Harbor



Each bar represents the estimated average annual load of material that enters Boston Harbor from each of the sources listed. The number in the box on the upper right is the total amount of material that enters the Harbor each year. The numbers within each bar are the percentage of the total accounted for by each source, calculated in terms of the average estimate, and the vertical lines span the range of estimates. Note that the y-axis is a log scale, so very large differences in loads translate to small differences in bar height.

3.2 Metals

Of the eight metals we evaluated (Table 1.1-1), complete data sets were only available for copper, lead, and zinc.

3.2.1 Copper

A total of 38 metric tons of copper are added to Boston Harbor each year. Effluent is the largest source of this material, accounting for 83% of the total (Fig. 3.2-1). Because effluent is such a large source, and because Deer Island is a larger contributor of effluent than Nut Island, approximately 71% of the total load is added to the North Harbor (Table 3.2-1). The next largest source is the rivers, although there is uncertainty in this estimate.

3.2.2 Lead

Although treatment plants are a major source of lead to the Harbor, rivers and non-point sources together account for most of the contaminant load (Fig. 3.2-2). A large portion of the material (77%) enters the North Harbor; the rest enters the South Harbor (Table 3.2-2). The total amount added is 10 metric tons per year.

3.2.3 Zinc

The total amount of zinc added to the Harbor is 56 metric tons annually. Effluent is the largest source of this material, followed by stormwater (Fig. 3.2-3). Approximately 71% of the zinc is added to the North Harbor (Table 3.2-3).

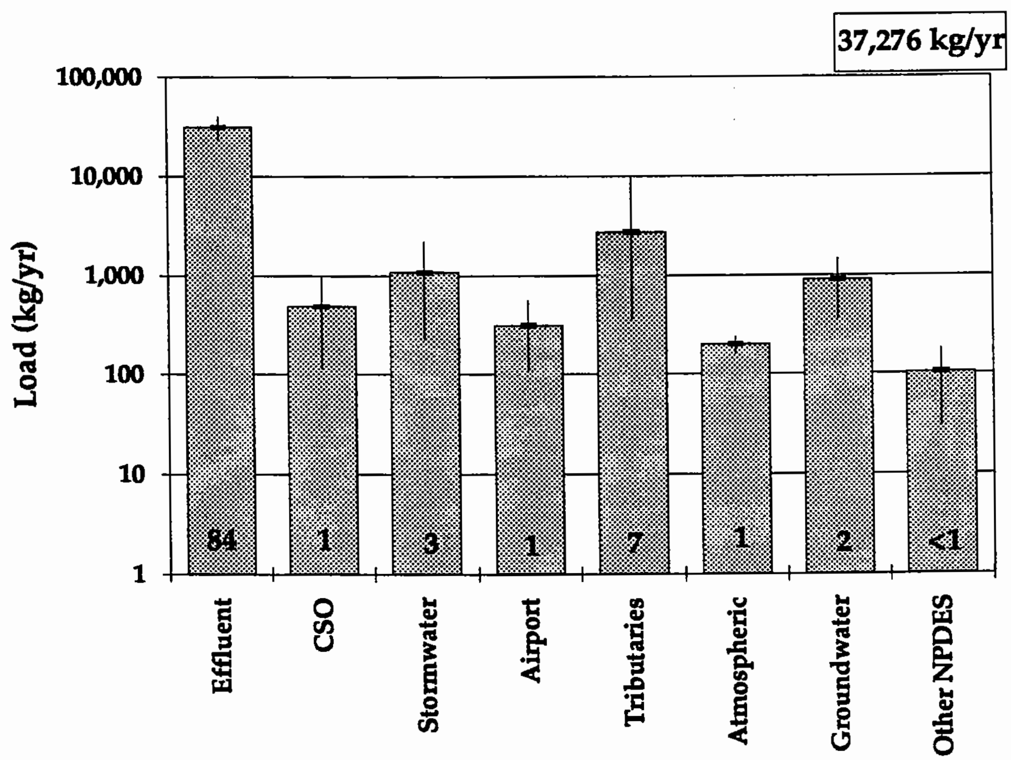
3.2.4 Comparison with previous estimates

Estimated metal loadings have decreased as follows: copper loading estimates have decreased from 73 to 38 metric tons per year, lead loading estimates have decreased from 37 to 10 tons per year, and zinc loading estimates have decreased from 157 to 56 tons per year (Fig. 3.2-4). The removal of sludge accounts for 26-62% of this reduction (sludge accounted for 22 metric tons of copper, 7 metric tons of lead, and 47 metric tons of zinc). The rest of the reduction can be attributed to source reduction and to improved contaminant estimates.

Table 3.2-1 Budget of copper discharged to Boston Harbor

(kg/yr)	North Harbor			South Harbor			Total		
	Low	Mean	High	Low	Mean	High	Low	Mean	High
Effluent	15,526	21,525	27,523	7,792	9,861	11,929	23,318	31,386	39,453
CSO	116	489	959	n.a.	n.a.	n.a.	116	489	959
Stormwater	107	619	1,358	122	475	828	229	1,094	2,185
Airport	108	314	564	n.a.	n.a.	n.a.	108	314	564
Tributaries	352	2,651	9,108	11	126	490	363	2,778	9,598
Atmospheric	77	95	114	86	107	128	162	202	242
Groundwater	237	593	948	126	316	506	363	909	1,454
Other NPDES	30	105	180	n.a.	n.a.	n.a.	30	105	180
Sludge	6,497	10,707	14,916	n.a.	n.a.	n.a.	6,497	10,707	14,916
Total (minus sludge)	16,552	26,391	40,754	8,137	10,884	13,881	24,689	37,276	54,634

Fig. 3.2-1. Copper discharged to Boston Harbor

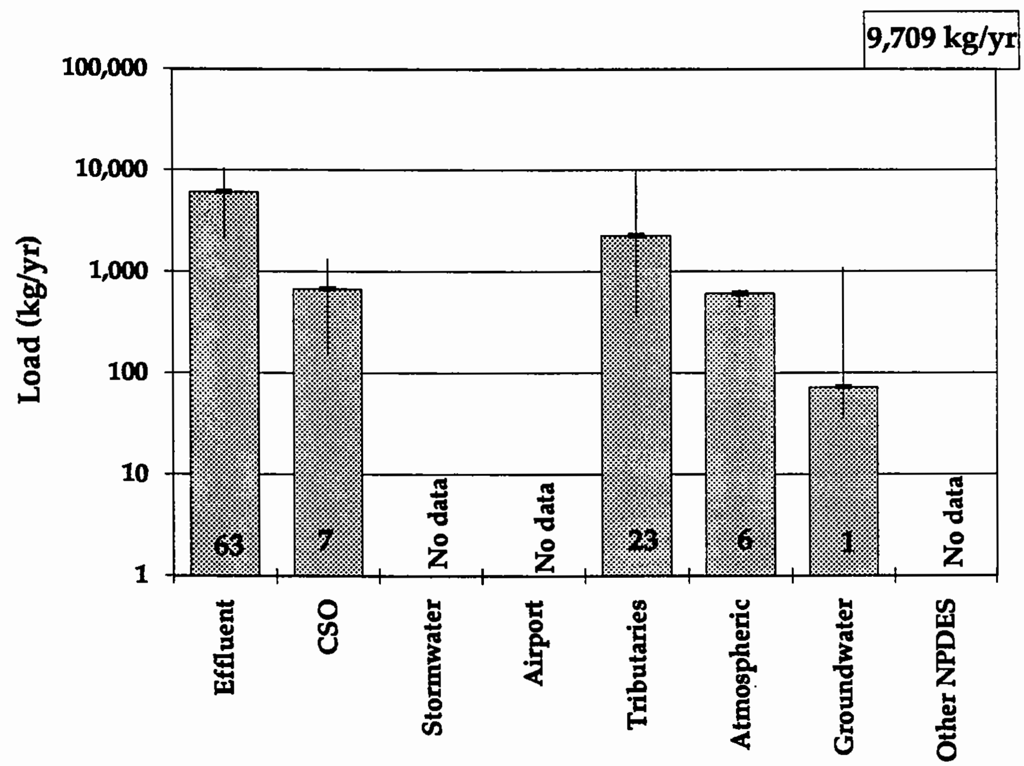


n.a. = not available
For explanation of figure, see Fig. 3.1-1.

Table 3.2-2. Budget of lead discharged to Boston Harbor

(kg/yr)	North Harbor Low	North Harbor Mean	North Harbor High	South Harbor Low	South Harbor Mean	South Harbor High	Total Low	Total Mean	Total High
Effluent	2,105	4,319	6,534	0	1,793	3,804	2,105	6,112	10,338
CSO	149	675	1,338	n.a.	n.a.	n.a.	149	675	1,338
Stormwater	n.a.	n.a.	n.a.	n.a.	n.a.	n.a.	n.a.	n.a.	n.a.
Airport	n.a.	n.a.	n.a.	n.a.	n.a.	n.a.	n.a.	n.a.	n.a.
Tributaries	352	2,146	9,108	11	102	490	363	2,248	9,598
Atmospheric	210	300	310	235	300	346	445	600	656
Groundwater	24	47	711	13	25	379	36	73	1,090
Other NPDES	n.a.	n.a.	n.a.	n.a.	n.a.	n.a.	n.a.	n.a.	n.a.
Sludge	1,815	3,566	5,318	n.a.	n.a.	n.a.	1,815	3,566	5,318
Total (minus sludge)	2,839	7,488	18,001	258	2,220	5,020	3,097	9,709	23,021

Fig. 3.2-2. Lead discharged to Boston Harbor

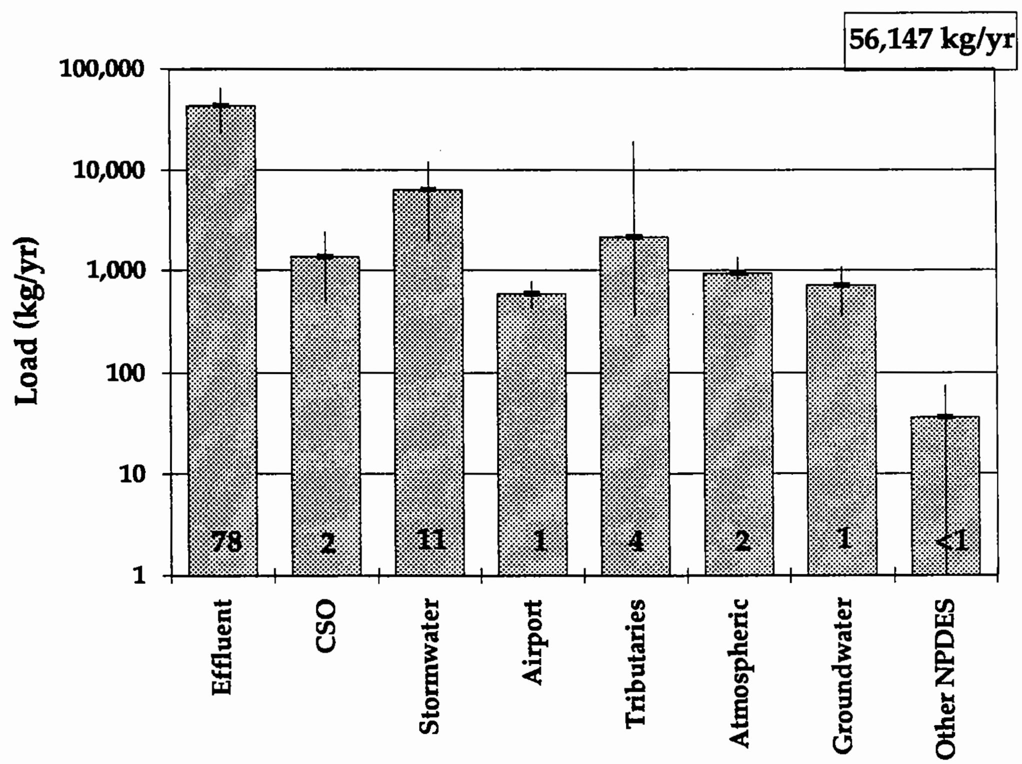


n.a. = not available
For explanation of figure, see Fig. 3.1-1.

Table 3.2-3. Budget of zinc discharged to Boston Harbor

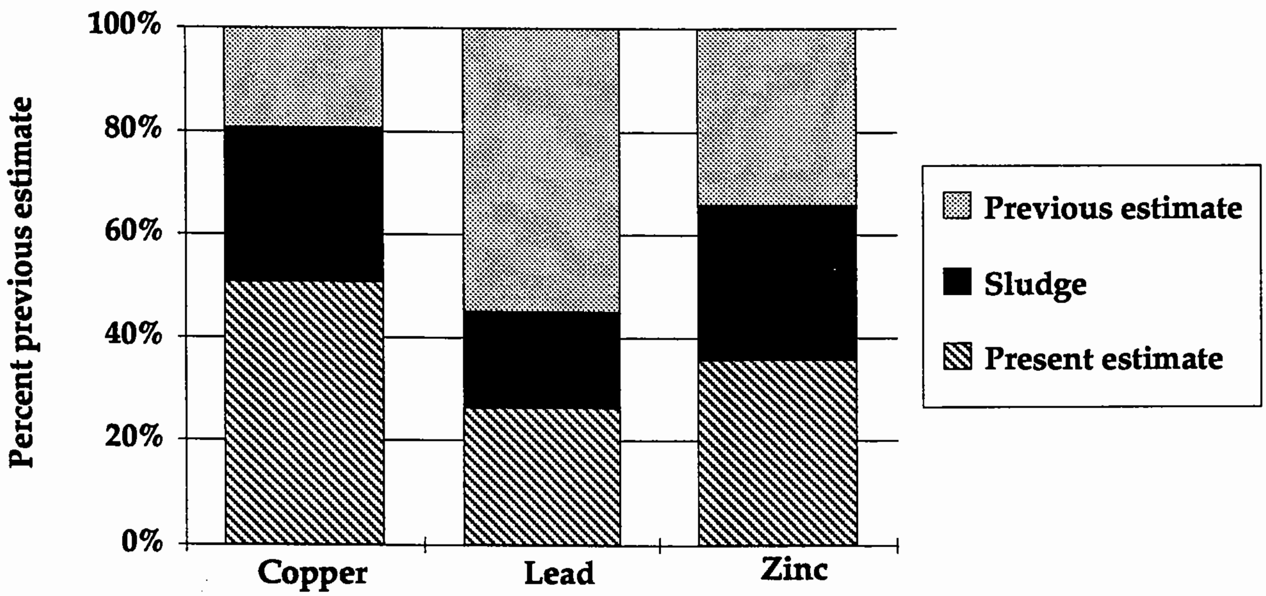
(kg/yr)	North Harbor Low	North Harbor Mean	North Harbor High	South Harbor Low	South Harbor Mean	South Harbor High	Total Low	Total Mean	Total High
Effluent	15,462	31,459	47,456	7,725	12,367	17,008	23,187	43,826	64,465
CSO	489	1,373	2,476	n.a.	n.a.	n.a.	489	1,373	2,476
Stormwater	940	3,651	7,431	1,072	2,801	4,530	2,012	6,452	11,961
Airport	429	595	788	n.a.	n.a.	n.a.	429	595	788
Tributaries	352	2,083	18,216	11	99	980	363	2,182	19,196
Atmospheric	373	451	641	417	504	717	790	955	1,358
Groundwater	237	474	711	126	253	379	363	727	1,090
Other NPDES	0	37	74	n.a.	n.a.	n.a.	0	37	74
Sludge	8,199	14,465	20,730	n.a.	n.a.	n.a.	8,199	14,465	20,730
Total (minus sludge)	18,282	40,124	77,794	9,351	16,024	23,614	27,633	56,147	101,408

Fig. 3.2-3. Zinc discharged to Boston Harbor



n.a. = not available
For explanation of figure, see Fig. 3.1-1.

Fig. 3.2-4. Comparison of current and previous metal loading estimates



In this figure, the present estimate is presented as a proportion of the previous estimate. The previous estimate, including sludge, is from Menzie *et al.* (1991), and is based primarily on information from 1988 and earlier, whereas the present estimate is based primarily on information from 1990 through 1993.

3.3 PAHs

Relatively complete data sets were available for all three of the PAH compounds we evaluated. Note that oil spills are an additional source of PAHs to the water. These are not accounted for in the present estimate, but Shea (1993) estimated that the total PAH input to the Harbor could double if this source were included. In this report we are only looking at sources entering the Harbor. Howevever, Chen (1993) has suggested that flux from in-place sediments could be a major source to the water column.

3.3.1 2-methylnaphthalene

2-methylnaphthalene is the PAH compound most frequently detected in MWRA effluent. Effluent represents 94% of the estimated 1,761 kilograms added to the Harbor each year (Fig. 3.3-1). Approximately 89% of the 2-methylnaphthalene discharged to the Harbor is added to the North Harbor (Table 3.3-1).

3.3.2 Pyrene

Pyrene, an intermediate-weight PAH, has a different distribution than 2-methylnaphthalene (Fig. 3.3-2). It enters the Harbor primarily from tributaries, although the effluent also contributes a large portion of the material. Approximately 88% of the 190 kg pyrene discharged annually to Boston Harbor enters the North Harbor (Table 3.3-2).

3.3.3 Benzo(a)pyrene

Benzo(a)pyrene is discharged to the Harbor through many sources (Table 3.3-3), and considerably less material is added on an annual basis as compared to the above two compounds (22 kg/yr). Benzo(a)pyrene enters the Harbor via rivers, effluent, stormwater runoff, and atmospheric deposition (Fig. 3.3-3). Benzo(a)pyrene is a high molecular weight PAH compound, formed primarily as a combustion product and therefore present as a non-point source pollutant. Approximately 73% of this compound is added to the North Harbor (Table 3.3-3).

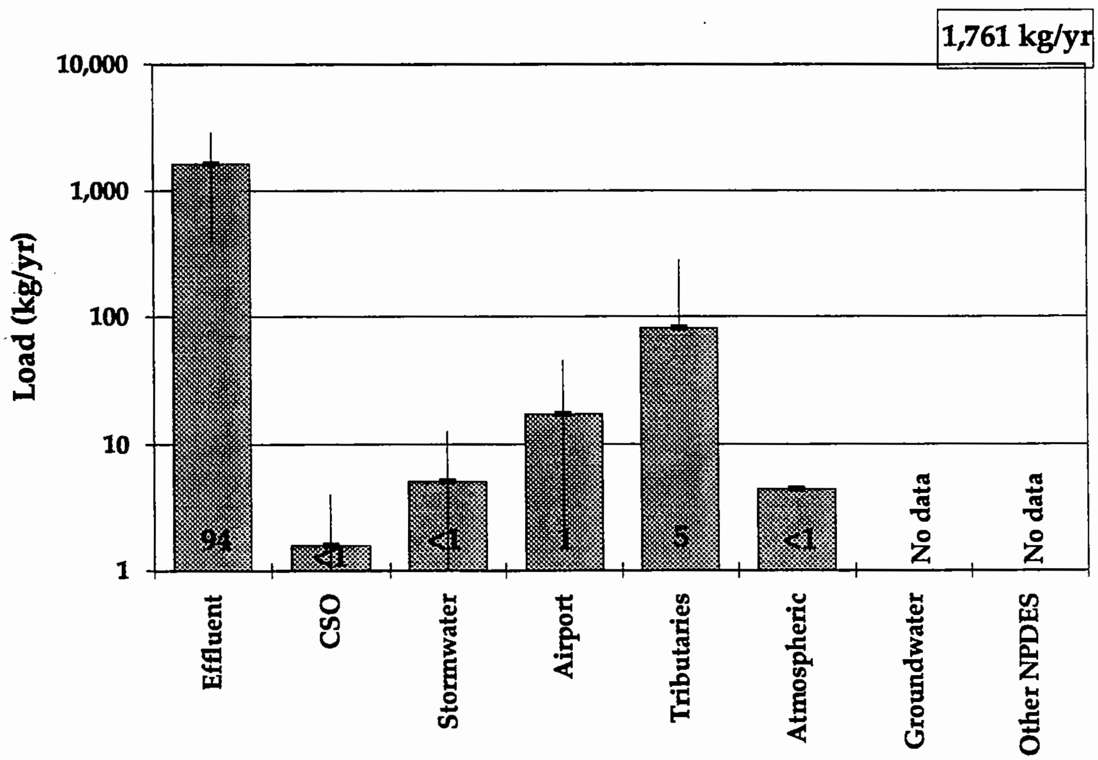
3.3.4 Comparison with previous estimates

The previous estimate could not be broken down into individual species, and so cannot be compared with the present estimate.

Table 3.3-1. Budget of 2-methylnaphthalene discharged to Boston Harbor

(kg/yr)	North Harbor Low	North Harbor Mean	North Harbor High	South Harbor Low	South Harbor Mean	South Harbor High	Total Low	Total Mean	Total High
Effluent	344	1,473	2,601	46	178	310	390	1,651	2,911
CSO	0.0	1.6	4.0	n.a.	n.a.	n.a.	.0	1.6	4.0
Stormwater	0.0	2.8	7.8	0.0	2.2	4.8	0	5.0	12.6
Airport	1.7	17.2	45.6	n.a.	n.a.	n.a.	1.7	17.2	45.6
Tributaries	0.0	78.3	262.8	0.0	3.7	14.1	0.0	82.1	277.0
Atmospheric	2.1	2.1	2.1	2.3	2.3	2.3	4.4	4.4	4.4
Groundwater	n.a.	n.a.	n.a.	n.a.	n.a.	n.a.	n.a.	n.a.	n.a.
Other NPDES	n.a.	n.a.	n.a.	n.a.	n.a.	n.a.	n.a.	n.a.	n.a.
Sludge	5.3	24.4	43.6	n.a.	n.a.	n.a.	5.3	24.4	43.6
Total (minus sludge)	347	1,575	2,924	48	186	331	396	1,761	3,255

Fig. 3.3-1. 2-methylnaphthalene discharged to Boston Harbor

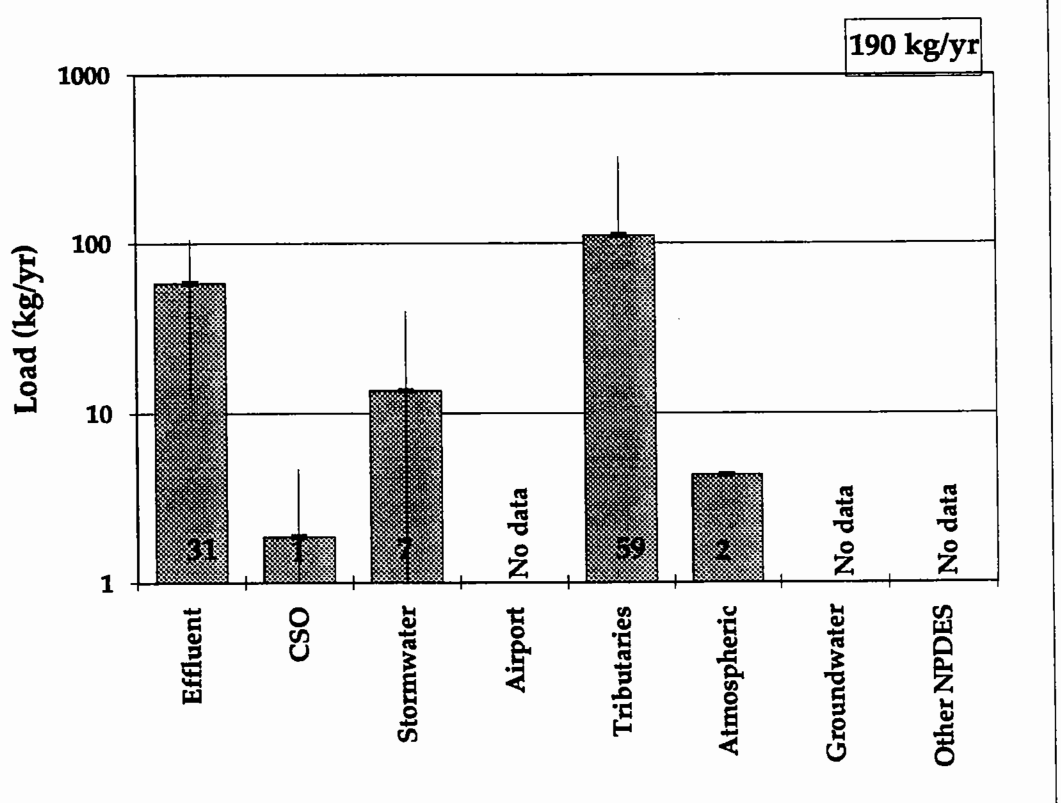


n.a. = not available
For explanation of figure, see Fig. 3.1-1.

Table 3.3-2. Budget of pyrene discharged to Boston Harbor

(kg/yr)	North Harbor			South Harbor			Total		
	Low	Mean	High	Low	Mean	High	Low	Mean	High
Effluent	7.7	48.9	90.2	4.8	9.7	14.7	12.5	58.7	104.9
CSO	0.0	1.9	4.7	n.a.	n.a.	n.a.	.0	1.9	4.7
Stormwater	0.0	7.8	24.9	0.0	6.0	15.2	.0	13.7	40.0
Airport	n.a.	n.a.	n.a.	n.a.	n.a.	n.a.	n.a.	n.a.	n.a.
Tributaries	0.0	106.1	306.7	0.0	5.1	16.5	0.0	111.1	323.2
Atmospheric	2.0	2.0	2.0	2.3	2.3	2.3	4.3	4.3	4.3
Groundwater	n.a.	n.a.	n.a.	n.a.	n.a.	n.a.	n.a.	n.a.	n.a.
Other NPDES	n.a.	n.a.	n.a.	n.a.	n.a.	n.a.	n.a.	n.a.	n.a.
Sludge	2.8	6.7	10.5	n.a.	n.a.	n.a.	2.8	6.7	10.5
Total (minus sludge)	10	167	428	7	23	49	17	190	477

Fig. 3.3-2. Pyrene discharged to Boston Harbor

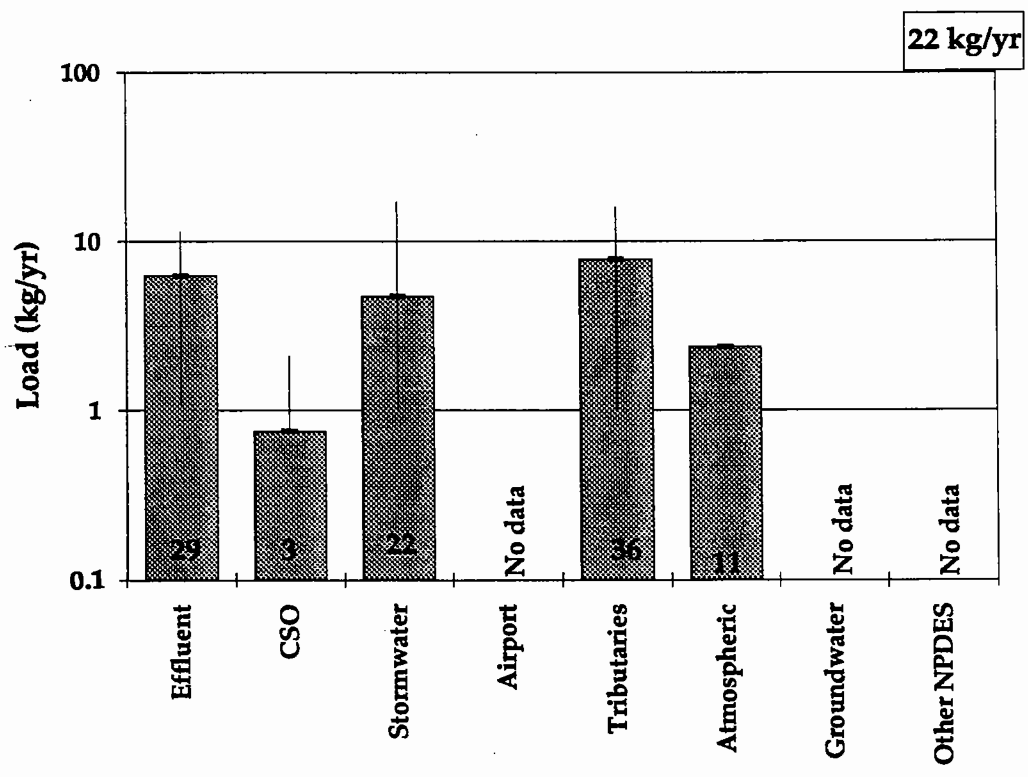


n.a. = not available
For explanation of figure, see Fig. 3.1-1.

Table 3.3-3. Budget of benzo(a)pyrene discharged to Boston Harbor

(kg/yr)	North Harbor Low	North Harbor Mean	North Harbor High	South Harbor Low	South Harbor Mean	South Harbor High	Total Low	Total Mean	Total High
Effluent	0.03	4.09	8.14	1.05	2.20	3.35	1.08	6.28	11.49
CSO	0.00	0.76	2.10	n.a.	n.a.	n.a.	0	0.76	2.10
Stormwater	0.00	2.69	10.63	0.00	2.07	6.48	0	4.76	17.11
Airport	n.a.	n.a.	n.a.	n.a.	n.a.	n.a.	n.a.	n.a.	n.a.
Tributaries	0.00	7.49	15.24	0.00	0.36	0.82	1.00	7.85	16.06
Atmospheric	1.12	1.12	1.12	1.25	1.25	1.25	2.38	2.38	2.38
Groundwater	n.a.	n.a.	n.a.	n.a.	n.a.	n.a.	n.a.	n.a.	n.a.
Other NPDES	n.a.	n.a.	n.a.	n.a.	n.a.	n.a.	n.a.	n.a.	n.a.
Sludge	n.a.	n.a.	n.a.	n.a.	n.a.	n.a.	n.a.	n.a.	n.a.
Total (minus sludge)	1.15	16.15	37.23	2.30	5.87	11.90	3.46	22.02	49.13

Fig. 3.3-3. Benzo(a)pyrene discharged to Boston Harbor



n.a. = not available
For explanation of figure, see Fig. 3.1-1.

3.4 Nutrients

Complete data sets were available for total nitrogen and total phosphorus with a few exceptions, noted below.

3.4.1 Nitrogen

Most of the approximately 13,000 metric tons of nitrogen added to the Harbor each year comes from effluent (Fig. 3.4-1). Rivers are the next largest source, accounting for 7%. As was the case for copper, the combined river and treatment plant sources mean that most of the nitrogen (approximately three-quarters) is added to the North Harbor (Table 3.4-1). Note that the groundwater estimate is based on nitrate only and does not include either ammonia or organic nitrogen, and the sludge estimate is based on TKN only.

3.4.2 Phosphorus

Effluent accounts for 94% of the estimated 2,000 metric tons of phosphorus entering the Harbor each year (Fig. 3.4-2), with most of it added to the North Harbor (Table 3.4-2). Note that both the groundwater and airport estimates are based on phosphate only and do not include organic phosphorus.

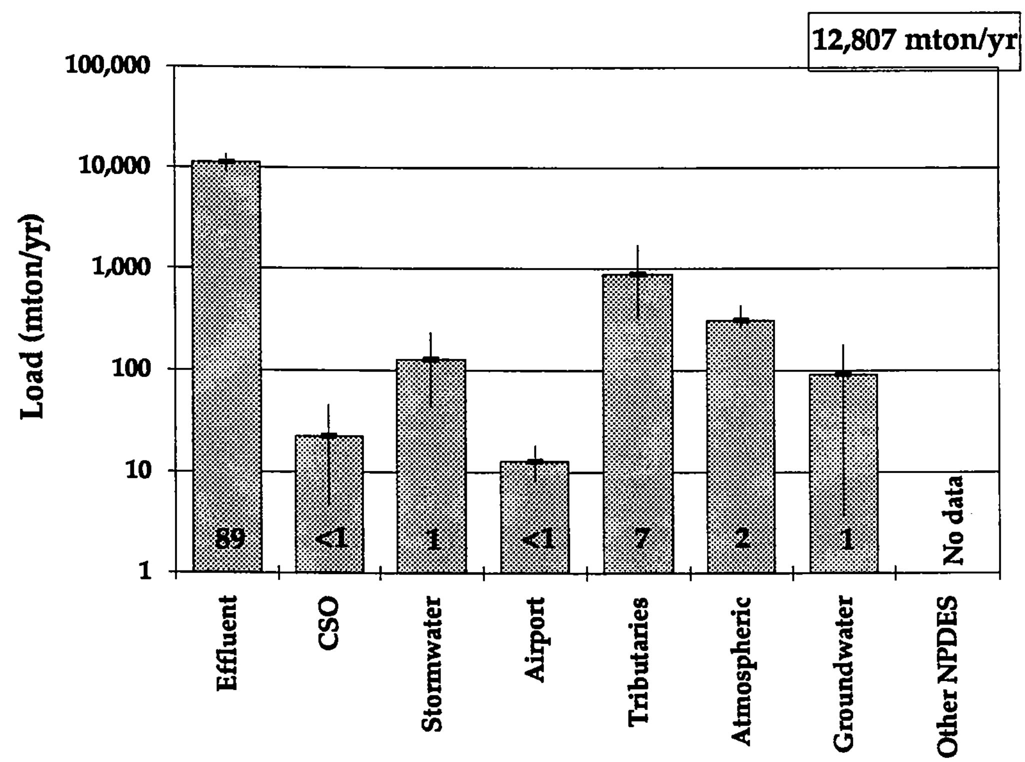
3.4.3 Comparison with previous estimates

Estimates of phosphorus loadings have decreased slightly, from 2,650 to 2,000 metric tons per year, whereas estimates of nitrogen have remained at approximately 13,000 metric tons per year (Fig. 4.1-2). The slight differences in nutrient loading do not necessarily indicate a different trend for nutrients than for other contaminants examined. Rather, we attribute it to the fact that previous estimates were based on only one or two forms of the nutrient in question, whereas the current data set is more complete.

Table 3.4-1. Budget of total nitrogen discharged to Boston Harbor

(mton/yr)	North Harbor			South Harbor			Total		
	Low	Mean	High	Low	Mean	High	Low	Mean	High
Effluent	6,815	8,571	10,326	2,327	2,780	3,173	9,142	11,350	13,499
CSO	5	23	46	n.a.	n.a.	n.a.	5	23	46
Stormwater	21	73	145	24	56	88	44	129	233
Airport	8	13	19	n.a.	n.a.	n.a.	8	13	19
Tributaries	317	852	1,639	10	41	88	327	893	1,728
Atmospheric	123	145	205	138	162	229	261	307	433
Groundwater	2	60	119	1	32	63	4	93	182
Other NPDES	n.a.	n.a.	n.a.	n.a.	n.a.	n.a.	n.a.	n.a.	n.a.
Sludge	615	959	1,303	n.a.	n.a.	n.a.	615	959	1,303
Total (minus sludge)	7,291	9,737	12,498	2,500	3,070	3,641	9,791	12,807	16,140

Fig. 3.4-1. Nitrogen discharged to Boston Harbor



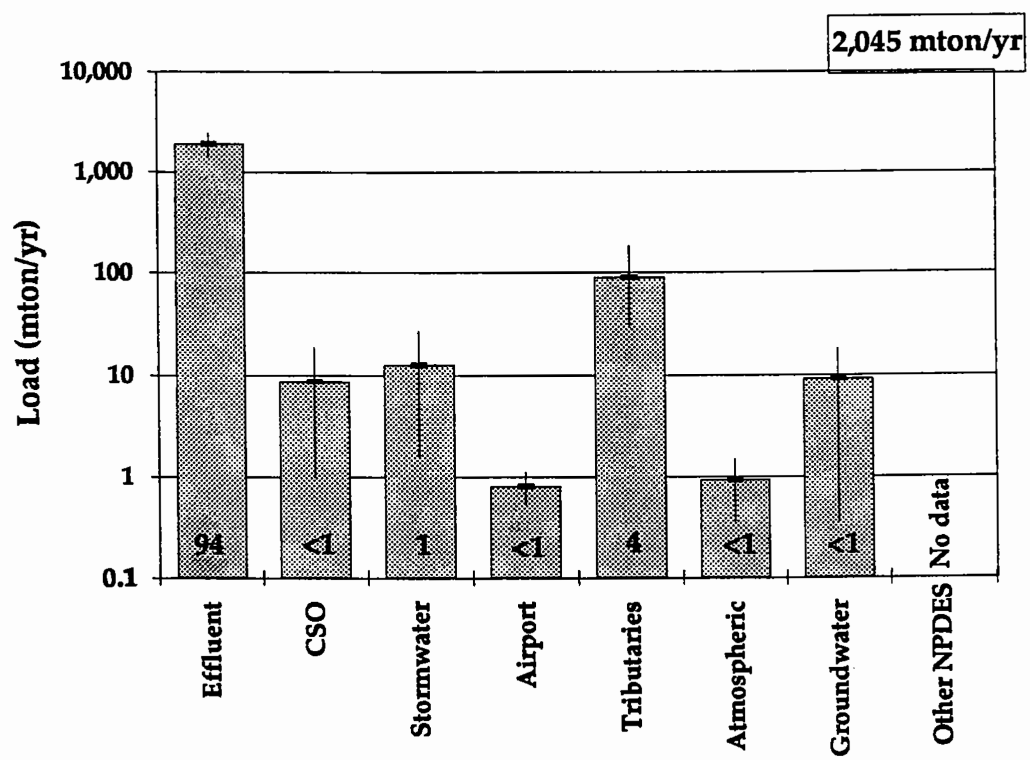
n.a. = not available

For explanation of figure, see Fig. 3.1-1.

Table 3.4-2 Budget of total phosphorus discharged to Boston Harbor

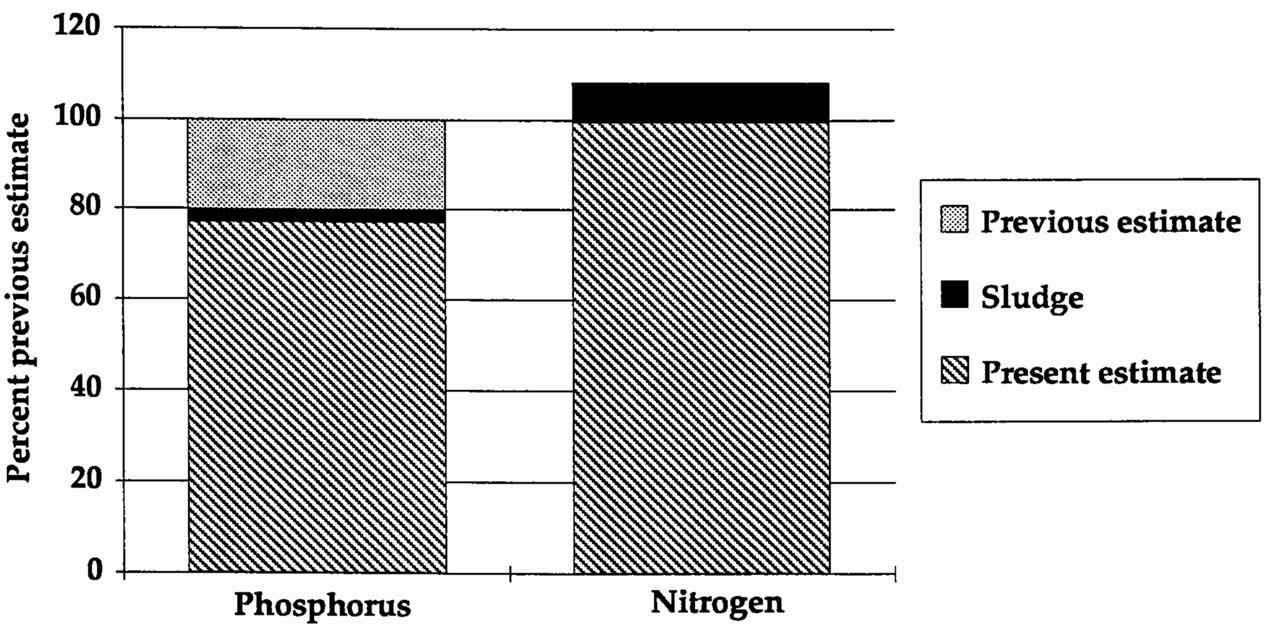
(mton/yr)	North Harbor Low	North Harbor Mean	North Harbor High	South Harbor Low	South Harbor Mean	South Harbor High	Total Low	Total Mean	Total High
Effluent	1,088	1,352	1,616	318	571	825	1,406	1,923	2,441
CSO	1.0	8.7	18.5	n.a.	n.a.	n.a.	1	9	19
Stormwater	0.7	7.2	16.8	0.8	5.5	10.2	2	13	27
Airport	0.5	0.8	1.1	n.a.	n.a.	n.a.	1	1	1
Tributaries	28.1	85.2	173.1	0.9	4.1	9.3	29	89	182
Atmospheric	0.2	0.4	0.7	0.2	0.5	0.8	0	1	2
Groundwater	0.2	6.0	11.9	0.1	3.2	6.3	0	9	18
Other NPDES	n.a.	n.a.	n.a.	n.a.	n.a.	n.a.	n.a.	n.a.	n.a.
Sludge	86	168	251	n.a.	n.a.	n.a.	86	168	251
Total (minus sludge)	1,119	1,460	1,838	320	585	852	1,439	2,045	2,690

Fig. 3.4-2. Phosphorus discharged to Boston Harbor



n.a. = not available
For explanation of figure, see Fig. 3.1-1.

Fig. 3.4-3. Comparison of current and previous nutrient loading estimates



In this figure, the present estimate is presented as a proportion of the previous estimate. The previous estimate, including sludge, is from Menzie *et al.* (1991), and is based primarily on information from 1988 and earlier, whereas the present estimate is based primarily on information from 1990 through 1993.

3.5 Conventional contaminants

We were able to construct budgets for both biochemical oxygen demand and total suspended solids.

3.5.1 BOD_5

The total amount of BOD added annually to the Harbor is 70,000 metric tons. Effluent contributes 91% of the oxygen-demanding material, and rivers contribute 7% (Fig. 3.5-1). Approximately three-quarters of this material enters the North Harbor (Table 3.5-1).

3.5.2 Total suspended solids

Most of the 43,000 metric tons of TSS contributed to the Harbor each year comes from effluent (Fig. 3.5-2). As was true for many of the other contaminants, rivers are the second largest source. As was also true above, approximately three-quarters of the material is added to the North Harbor (Table 3.5-2).

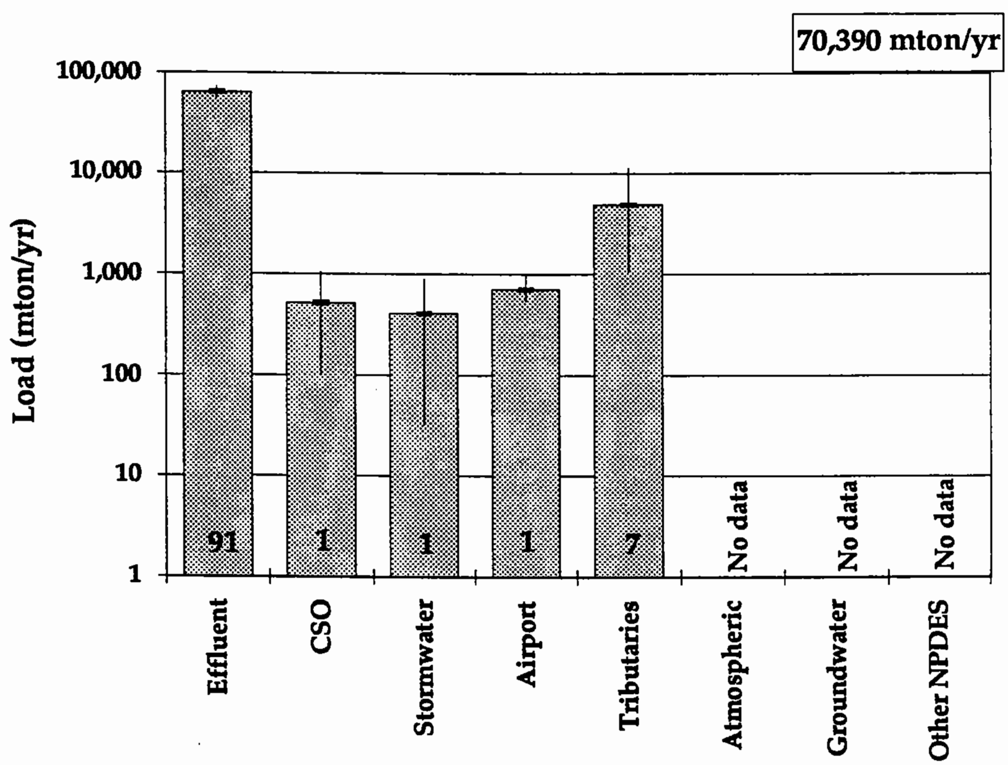
3.5.3 Comparison with previous estimates

Estimates of conventional contaminant annual loadings have decreased substantially, from 96,000 metric tons of both BOD and TSS per year to 70,000 metric tons of BOD, and 43,000 metric tons of TSS (Fig. 4.1-3). Although not estimated in this report, sludge BOD was estimated by Menzie *et al.* (1991). The removal of sludge accounts for 58 and 43% of this reduction, respectively. The rest of the reduction can again be attributed to source reduction and improved estimates.

Table 3.5-1. Budget of BOD discharged to Boston Harbor

(mton/yr)	North Harbor			South Harbor			Total		
	Low	Mean	High	Low	Mean	High	Low	Mean	High
Effluent	41,586	47,596	53,606	14,098	16,265	18,431	55,684	63,860	72,037
CSO	100	516	1,042	n.a.	n.a.	n.a.	100	516	1,042
Stormwater	15	232	555	17	178	338	33	410	893
Airport	535	709	980	n.a.	n.a.	n.a.	535	709	980
Tributaries	1,055	4,671	10,747	33	222	578	1,088	4,894	11,326
Atmospheric	n.a.	n.a.	n.a.	n.a.	n.a.	n.a.	n.a.	n.a.	n.a.
Groundwater	n.a.	n.a.	n.a.	n.a.	n.a.	n.a.	n.a.	n.a.	n.a.
Other NPDES	n.a.	n.a.	n.a.	n.a.	n.a.	n.a.	n.a.	n.a.	n.a.
Sludge	n.a.	n.a.	n.a.	n.a.	n.a.	n.a.	n.a.	n.a.	n.a.
Total (minus sludge)	43,292	53,725	66,930	14,149	16,665	19,348	57,440	70,390	86,278

Fig. 3.5-1. BOD discharged to Boston Harbor

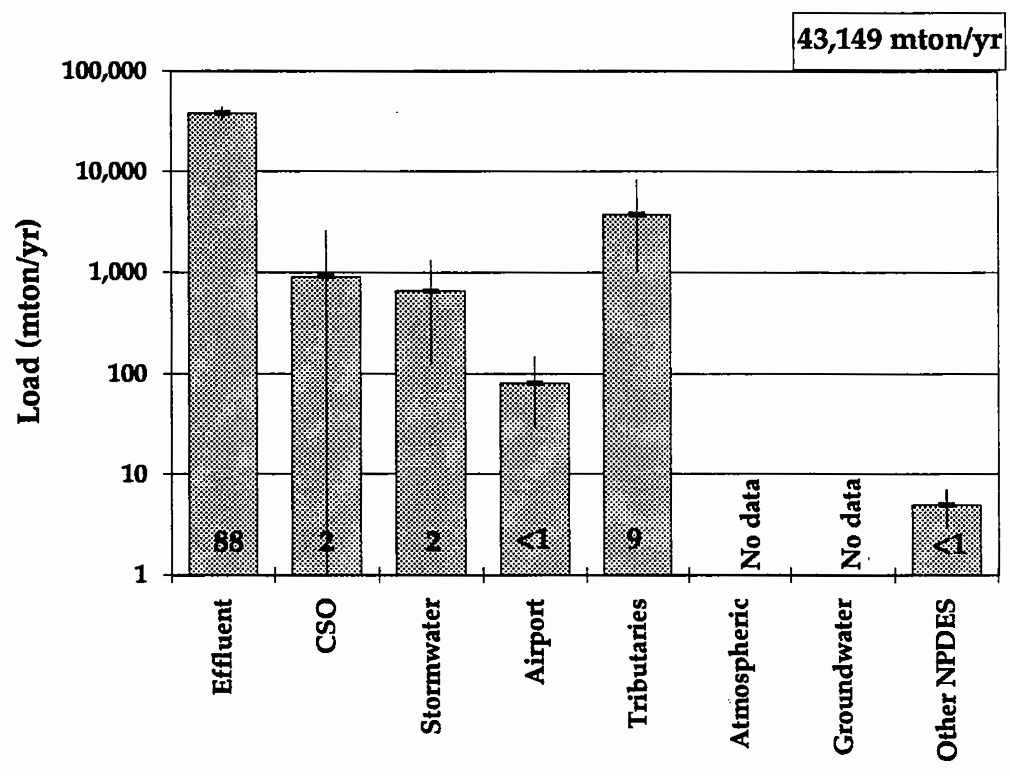


n.a. = not available
For explanation of figure, see Fig. 3.1-1.

Table 3.5-2. Budget of TSS discharged to Boston Harbor

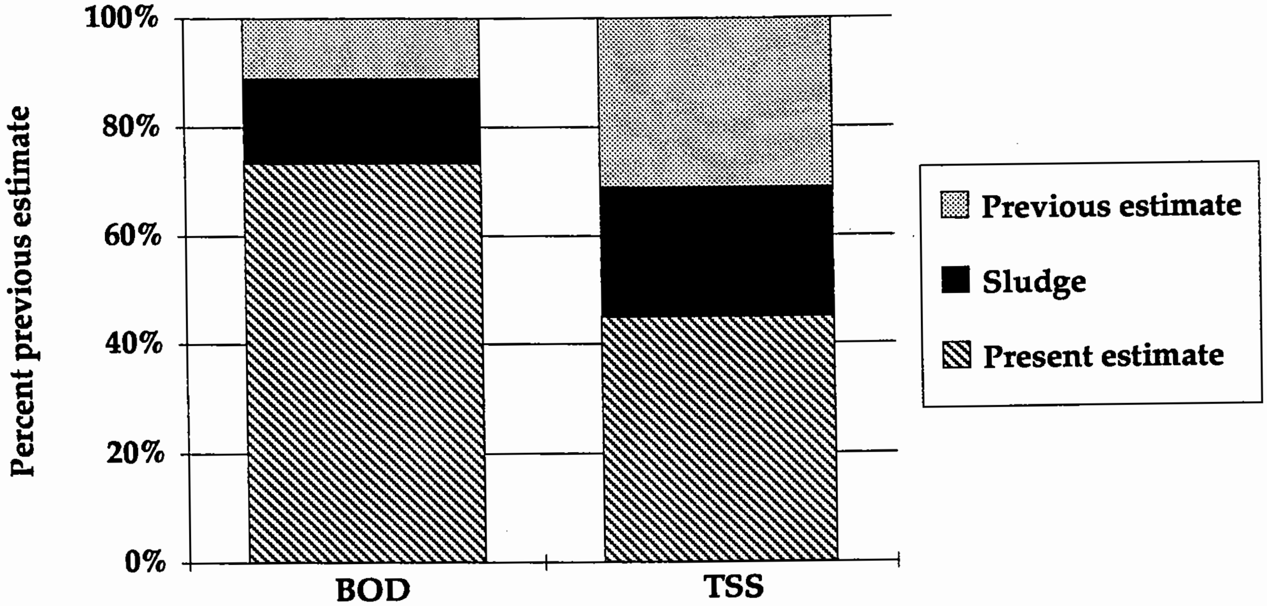
(mton/yr)	North Harbor Low	North Harbor Mean	North Harbor High	South Harbor Low	South Harbor Mean	South Harbor High	Total Low	Total Mean	Total High
Effluent	23,346	27,104	30,862	8,947	10,639	12,330	32,293	37,743	43,193
CSO	0	901	2,568	n.a.	n.a.	n.a.	0	901	2,568
Stormwater	59	368	815	67	282	497	126	650	1,312
Airport	29	81	149	n.a.	n.a.	n.a.	29	81	149
Tributaries	985	3,598	7,833	31	171	422	1,016	3,770	8,254
Atmospheric	n.a.	n.a.	n.a.	n.a.	n.a.	n.a.	n.a.	n.a.	n.a.
Groundwater	n.a.	n.a.	n.a.	n.a.	n.a.	n.a.	n.a.	n.a.	n.a.
Other NPDES	2.9	4.9	7.0	n.a.	n.a.	n.a.	3	5	7
Sludge	11,781	17,588	23,395	n.a.	n.a.	n.a.	11,781	17,588	23,395
Total (minus sludge)	24,422	32,057	42,234	9,046	11,092	13,249	33,467	43,149	55,483

Fig. 3.5-2. TSS discharged to Boston Harbor



n.a. = not available
For explanation of figure, see Fig. 3.1-1.

Fig. 3.5-3. Comparison of current and previous conventional contaminant loading estimates



In this figure, the present estimate is presented as a proportion of the previous estimate. The previous estimate, including sludge, is from Menzie *et al.* (1991), and is based primarily on information from 1988 and earlier, whereas the present estimate is based primarily on information from 1990 through 1993.

4.0. Conclusions

The estimates presented here represent large decreases in loads of sludge, effluent, CSOs, and stormwater as compared to those estimated by Menzie *et al.* (1991). This is partially due to an improvement in discharge quality, and partially due to a better estimate of loads.

The largest decrease in contaminant loading to the Harbor results from reductions in the concentrations of contaminants in the influent to the treatment plants. MWRAs Toxic Reduction and Control Dept. works in concert with other agencies to help reduce toxic discharges into the MWRA sewers by industrial and other dischargers (Industrial Waste Report 1993). This has resulted in decreases in influent metal concentrations over the past ten years (Alber *et al.* 1993).

The elimination of sludge from the Harbor also represented a major reduction in contaminant loading. Since sludge has a high load of solids and many metals are solid-associated, removing sludge led to a reduction in both solid and metal contaminant loads to the Harbor.

Despite the above reductions, effluent discharged from MWRA plants are still a major source of all conventional contaminants, metals, and nutrients examined. The exception is individual PAH compounds, which have large runoff and non-point sources. The next big change in contaminant loading to the Harbor will come once the treatment plant outfall is moved. When the new effluent outfall tunnel is completed, the amount of contaminants entering the Harbor will decrease dramatically. This should result in a major improvement in the water quality of Boston Harbor.

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