# Deer Island effluent characterization and pilot treatment plant studies: June 1993 - November 1994

Massachusetts Water Resources Authority

Environmental Quality Department
Technical Report Series No. 95-7

# Deer Island Effluent Characterization and Pilot Treatment Plant Studies
# June 1993 - November 1994

by

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Environmental Quality Department Technical Report Series 95-7

June 1995

Citation:

Hunt, C.D., D.E. West, and C.S. Peven. 1995. **Deer Island effluent characterization and pilot treatment plant studies: June 1993 - November 1994.** MWRA Enviro. Quality Dept. Tech. Rpt. Series No. 95-7. Massachusetts Water Resources Authority, Boston, MA. 140 pp.

# ACKNOWLEDGEMENTS

A number of institutions and individuals performed the sample collection and analysis for the effluent characterization studies. The MWRA TRAC personnel were responsible for sample collections and quickly learned the requirements for on-site nutrient processing. Mr. Maury Hall and Ms. Nancy Ettele of MWRA were responsible for coordinating sample collection and delivery of samples to the analytical laboratories. Dr. Peter Doering of the University of Rhode Island assisted in planning for the nutrient analyses; Ms. Laura Reed of the University of Rhode Island performed the nutrient analyses. Ms. Gerri Miceli of Biological Analytical Laboratory, Inc. conducted the *Clostridium perfringens* analysis. Stable isotope analyses were conducted by Ms. Kris Tholke of the Marine Biological Laboratory. The chemistry department of Battelle Ocean Sciences worked diligently to complete the organic contaminant and trace metals analyses.

# EXECUTIVE SUMMARY

Concentrations of selected nutrients, trace metals, and anthropogenic organic compounds were monitored in the effluent of the Massachusetts Water Resources Authority (MWRA) Deer Island Wastewater Treatment Plant as well as in the influent and effluents of the new Deer Island Pilot Wastewater Treatment Plant as part of the MWRA Harbor and Outfall Monitoring Project.

Bimonthly 24-h composite samples of the Deer Island effluent were collected between June 1993 and November 1994. The samples collected between June 1993 and November 1993 were analyzed for Ag, Cd, Cr, Cu, Hg, Ni, Pb, and Zn; an extended list of 40 polynuclear aromatic hydrocarbons (PAHs); $C_{10}$ to $C_{14}$ linear alkyl benzenes (LABs); 20 polychlorinated biphenyl (PCB) congeners; and 16 persistent chlorinated pesticides. Starting in December 1993, samples were also analyzed for *Clostridium perfringens*, Mo, and stable isotopes of nitrogen and sulfur. Also beginning in December 1993, discrete grab samples were collected for nutrient analysis. These samples were analyzed for the major forms of nitrogen ($NH_4$, $NO_2$, $NO_3$, total dissolved inorganic nitrogen, particulate organic nitrogen), and phosphorus ($PO_4$, total dissolved phosphorus, and particulate organic phosphorus), plus dissolved silica, biogenic silica, and dissolved and particulate organic carbon.

The pilot plant influent plus the effluents of the primary and secondary treatment channels were sampled during five test events in 1993 and 1994. Sample collections and analyses were carried out as described for the Deer Island effluent measurement program.

The trace metals and organic contaminant analyses were carried out using ultratrace techniques capable of providing detection limits in the low parts-per-trillion (ng/L) for organic compounds and low parts-per-billion (μg/L) for trace metals. Analytical methods that are routinely used for nutrients in seawater and effluents were used.

## Effluent Characterization

***Toxics*** — Concentrations of organic and metal contaminants in the Deer Island effluent were similar in 1994 to concentrations reported in 1993. Contaminant concentrations measured in the effluent between December 1993 and November 1994 ranged as follows: 13–32 μg/L for total PAHs; 17–110 ng/L for total PCBs; 0–74 ng/L for total chlordanes; 2–68 ng/L for lindane; and 7.5–22 μg/L for total LABs. Re-analysis of samples containing high concentrations (>10 ng/L) of dieldrin demonstrated that the high concentrations observed in 1993 were the result of an unknown interferant. Confirmed concentrations of dieldrin were generally <5 μg/L. Concentrations (in μg/L) of metals ranged as follows: 3–8.6 for Ag; 0.4–1.4 for Cd; 1.7–11 for Cr; 48–111 for Cu; 0.1–0.26 for Hg; 5–25 for Mo; 4.6–9 for Ni; 6–26 for Pb; and 70–136 for Zn.

Organic compound concentrations were generally lower than EPA acute aquatic life criteria in the undiluted effluent. Concentrations of p,p'-DDT consistently exceeded the EPA chronic criteria, and dieldrin, endrin and heptachlor occasionally exceeded the criteria. Ag and Cu were consistently higher than the available marine aquatic life criteria in the undiluted effluent. Hg and Pb consistently exceeded the chronic marine criteria, while Zn was occasionally in excess. Based on the effluent dilution that will occur at the diffuser, it is expected that contaminants now exceeding the marine criteria will be diluted well below the applicable criteria within a few hundred meters of the diffuser.

Thus, violations of aquatic life criteria are not expected when the discharge is relocated to Massachusetts Bay.

Concentrations of total nitrogen, ammonia, nitrate plus nitrite, total phosphorus, and phosphate concentrations in the Deer Island primary treatment plant effluents in 1994 were similar to concentrations previously reported. The concentrations (in μM/L) ranged as follows: 750–1750 for total nitrogen; 650–1500 for dissolved nitrogen; 600–1300 for ammonia; and 220–270 for particulate nitrogen. Ammonia contributed the largest fraction (50–70%) to total nitrogen and comprised 70–90% of the total dissolved nitrogen. Phosphate concentrations were also similar to those reported previously and ranged (in μg/L) as follows: 50–160 for total phosphorus; 25–140 for total dissolved phosphorus; 20–85 for phosphate; and 12–25 for particulate phosphate. Total and dissolve phosphorus increased during the late half of 1994 and particulate phosphorus was relatively constant during the sampling period. The increases in late 1994 were thus due to dissolved forms, primarily increases in the dissolved organic phosphorus concentrations. Dissolved Si concentrations were relatively constant, although decreases were evident in the summer months. Biogenic Si concentrations were low (<21 μM) and contributed <10% to the total biologically available Si concentrations in the effluents. The concentrations of dissolved and particulate organic carbon were about equal in the effluent; the dissolved form consistently comprised about 60% of the total organic carbon in the effluents.

Daily and monthly variability in the treatment plant effluents was evident as reported previously in Uhler *et al.* (1994). The daily and monthly variability was not sufficient to mask seasonal trends, particularly for the nutrients. Seasonal trends were evident for PAHs, chlorinated pesticides such as DDTs and lindane, and PCBs. PAH concentrations were highest in the winter/spring period and PCB concentrations were low in the summer and early fall. When detected, the concentrations of chlorinated pesticides were relatively constant, but showed occasional spikes that were 5–10 times higher than the typical concentrations measured in the effluent. Seasonal trends in the metals data were not evident, although Mo increased from 10 to 20 μg/L between March and July. Cu, while not showing a distinct seasonal trend, did consistently increase in concentration between June 1993 and November 1994. The concentrations of nutrients were generally higher in the summer when the flow in system was lower. Si concentrations generally decreased in the summer when effluent flows were lower.

***Loading*** — The estimated input of contaminants and nutrients to the Boston Harbor/Massachusetts Bay system is consistent with estimates developed in 1993 by Alber and Chan (1994) and by Shea (1993a). Because of relatively higher concentrations in the effluents, on a mass basis, nutrients contributed the largest loading. Inputs ranged from 32 metric tons (mtons) nitrite/year to 8220 mtons total nitrogen/year. Other estimates of loading were 1230 mtons phosphorus/year; 2250 mtons dissolved silicate/year, and 27,000 mtons total organic carbon/year. Nutrient loadings estimated for 1994 are at the lower end of the range provided in Alber and Chan (1994).

Organic contaminant inputs ranged from <10 Kg total chlordanes and lindane/year to 11,000 Kg PAHs/year. The latter is more than twice what Shea (1993a) estimated for 1993. LAB was discharged at about 7990 Kg/Yr. Dieldrin loading was about 1 Kg/year and PCBs were discharged at about 26 Kg/year.

Of the metals, Cu and Zn were discharged at the highest rate, 38 and 44 mtons/year, respectively. All other metals were discharged at <7500 Kg/year; Cd was discharged at 370 Kg/year. Hg loading was estimated to be 75 Kg/year, a rate about three times less than previous estimates, and is directly related to the implementation of clean metals sampling protocols and methods with appropriately low method detection limits. The Cu loading is about 25% higher than estimated for 1993. Other than these two elements, loading of metals is similar to the previous recent estimates.

*Effluent Tracers* — Principal component analysis was used to determine that the PAHs in the effluent were primarily petrogenic in nature, as reported previously in Uhler *et al.* (1994). The principal component analysis indicated that these compounds grouped very tightly except in the November/December time periods and were dominated by low-molecular-weight compounds similar to refined petroleum products. The LABs were similar in composition throughout the 18 months, even though the concentration systematically declined from 30 to 15 $\mu$g/L between mid 1993 and mid 1994. The N/P ratio in the effluents, typically 16, is consistent with the terrestrial source of the organic material. Similarly, the stable isotope nitrogen and sulfur isotope ratios of particulate matter filtered from the effluent are typical of terrestrial sources. The $\delta^{15}$N ranged from 0 to 2‰ (average=1.1 ~~2.5~~‰) and the $\delta^{24}$S ranged from 4 to 8‰ (average=5.8‰). In terms of effluent tracers, the sulfur isotopes probably can be used more effectively than nitrogen due to the larger difference in the ratio relative to seawater, and the fact that the ratio appears to respond less to productivity and bacteria degradation. *Clostridium perfringens* spores in the effluent were also measured and ranged between 1 and 4 x $10^4$ spores/100 mL.

### Pilot Treatment Plant

*Treatment Plant Effectiveness* — The preliminary tests of the secondary biological treatment process conducted in 1994 showed that the removal efficiency of the primary and secondary treatment process was variable. Removal efficiencies appear to depend on the concentrations in the influent, the operational status of the treatment plant, and specific contaminant or nutrient species. Even though there is significant variability among the various tests, the results are encouraging in that the concentrations of several toxic contaminants (*i.e.*, Hg, Cu, PCBs, PAHs, organic carbon [by extension cBOD]) that are of concern in the receiving waters of Massachusetts Bay will be substantially reduced through secondary treatment. Other contaminants (*i.e.*, total nitrogen, certain pesticides, and Mo) will not be substantially reduced through secondary treatment. Because the operational aspects of the pilot treatment plant were still being optimized in 1994, evaluations to confirm the findings from 1994 should continue, with the specific objectives to optimize the treatment process, and to quantify the variability in treatment efficiency and relationship to operation conditions.

Relative to the primary effluent, the biological secondary treatment in the pilot plant was found to have very high removal efficiency (>85%) for total PAHs, total PCBs, Cu, Pb, and particulate organic carbon. High removal efficiencies (70–85%) were evident for total LABs, total DDTs, Ag, Hg, Zn, total phosphorus, and dissolved organic carbon. Chlordane, Cd, Cr, and Ni showed intermediate (20–70%) removal efficiency, while lindane, Mo, total nitrogen, dissolved Si, and biogenic Si were inefficiently (<20%) removed by the secondary treatment. A single test of the Chemical Enhanced Primary Treatment (CEPT) process in December 1993 suggests that the relatively high removal efficiencies for many of the chemical contaminants could be obtained using this process. Further tests are required to provide definitive conclusions regarding the efficiency of this treatment relative to the primary and full secondary treatment. These preliminary pilot plant data are consistent with, if not slightly better than, the removal efficiencies used in the EPA Supplemental Environmental Impact Statement for the MWRA Massachusetts Bay outfall to make predictions of impact.

***Loading*** — The preliminary removal efficiencies identified from the pilot plant secondary treatment process suggest that toxic contaminant loading to Massachusetts Bay will be substantially reduced. Relative to the 1994 loading estimates, contaminant reductions approximating the removal efficiencies listed above can be expected. Of special note is the very high removal efficiency of dissolved and particulate organic carbon (~90% relative to the present primary effluent). This reduction is expected to have significant impacts on the cBOD in the effluent and thus oxygen demand in the receiving waters. The significant reductions in loading that are expected from full secondary treatment must also be considered relative to monitoring the sediments for contaminants. Because of the reduced loading rate and the expected dilution of the effluent by the diffuser, it may take several years before significant changes in the contaminant concentrations are detected in the sediments. It is questionable whether extensive annual nearfield or bay-wide sediment monitoring will detect significant changes over short time scales. Thus, annual measurements of contaminants in the sediments should be considered a low priority. Sufficient information on inputs of contaminants could be realized through a more focused sample collection at stations very near the diffuser.

***Effluent Quality*** — The pilot plant results suggest that the quality of the effluent will be excellent, especially with regard to priority pollutants. Only a few metals or organic compounds will exceed EPA marine water quality criteria within the secondary effluent prior to discharge. The contaminants (Cu, Hg) that exceed the criteria will be diluted within 10s to 100s of meters of the diffuser to concentrations well below their applicable aquatic life water quality criteria. Because the contaminant concentrations in the effluent are expected to be low and the dilution rate is expected to be high, increases in the concentrations of the organic and metal contaminants in the water column will be very difficult to detect. Because of this, the outfall monitoring program should focus on confirming the plume dynamics and verifying the predicted dilutions. Chemical measurements in the effluents and use of validated dilution models should be the standard for this program rather than a focus on measuring concentrations in the receiving waters. Furthermore, measurements in the sediments and biota in the vicinity of the diffuser will be the most cost-effective method of evaluating fate and the potential for impact.

***Secondary Effluent Characteristics*** — In addition to reducing contaminant concentrations in the effluent, there will probably be other benefits of secondary treatment. The ratio of nitrogen to phosphorus (N/P), for example, will likely increase from about 16 to as much as 30 when, relative to nitrogen, phosphorus is more efficiently removed from the effluent. As a result of this differential removal, the quality of the MWRA sewage sludge as fertilizer will likely increase as more phosphorus is transferred to the sludge. The altered N/P ratio is expected to have little effect on the productivity of receiving waters because the system is clearly nitrogen limited. In contrast, more efficient removal of toxic compounds may degrade the quality of the sludge, although increases in the amount of sludge produced by the secondary treatment will likely ameliorate the magnitude of such increases. Regardless, any adverse changes should be detected by the MWRA sludge monitoring program.

Furthermore, the data from the secondary treatment process suggest that this treatment is likely to change the characteristic fingerprints of the LAB and PAH analytes relative to the present primary discharge. Principal component analysis of the data demonstrates a clear separation of the secondary effluents from the pilot plant influent and primary effluents. Such changes in source characteristics may enable the signature of the secondary effluent to be traced more effectively within the receiving environment. Characterizations must therefore continue to ensure that the signature is adequately determined.

*Monitoring* — The anticipated low concentrations of contaminants in the secondary effluent clearly suggests that the monitoring program focus on the effluent quality rather than on the receiving water quality. Because of the predicted low concentrations of contaminants and the expected dilution rates, detecting toxic contaminants in the water column will become extremely difficult, except in the plume immediately adjacent to the diffuser, and the ability to measure changes in the sediments and biota, particularly in the farfield, will decrease. Reductions in organic carbon loading will substantially reduce oxygen demand in the receiving waters but, as projected from ongoing water column studies, nutrient loading to the system will not change much.

# Table of Contents

## List of Tables

## List of Tables (Continued)

# List of Figures

## List of Figures (Continued)

# 1.0 INTRODUCTION

Wastewater from the greater Boston metropolitan area is treated at two primary treatment plants located on Deer Island and Nut Island in Boston Harbor. The sewage effluent from both plants is presently discharged near the mouth of the Harbor just off the Deer Island facility (Figure 1). As part of the Boston Harbor cleanup, the Massachusetts Water Resources Authority (MWRA) is upgrading these treatment facilities through improvements to the primary treatment facilities at both Deer Island and Nut Island (completed in 1990), and through construction of a new primary and secondary treatment facility at Deer Island that will treat both the Deer and Nut Island flows. When completed, these upgrades are expected to significantly improve the quality of the effluent that will be discharged from these treatment facilities at the present Deer Island outfall and from the new ocean outfall located in Massachusetts Bay.

As part of the Harbor and Outfall Monitoring Project comprehensive baseline assessment, in 1993 and 1994, the MWRA conducted bi-monthly monitoring of the effluent from the Deer Island plant and evaluations of the effluent from the MWRA 1 MGD pilot treatment plant that became operational near the end of 1993. The former study was designed to characterize the nature of the primary effluent being discharged into the Harbor and Massachusetts Bay; the latter study was designed to evaluate removal efficiencies and improvements to effluent quality that can be expected when the new Deer Island primary and secondary treatment plants become operational. This report summarizes the monthly effluent characterization samples that were collected between June 1993 and November 1994, and presents the results of pilot treatment plant studies that were completed in December 1993 and in June and July 1994.

The objectives of the effluent characterization monitoring were to evaluate

- *Selected trace metal and persistent anthropogenic organic contaminant concentrations in the effluent.* The trace metal and organic contaminants of particular concern in the MWRA effluent are listed in Table 1; these compounds are of interest because established EPA Water Quality Criteria exist for them or they have been detected in the MWRA effluent or otherwise found in receiving waters or sediments of Boston Harbor and Massachusetts Bay or can serve as tracers of sewage effluents.

- *Effluent nutrient concentrations plus other parameters related to eutrophication issues.* Discharge of nutrients in general, and nitrogen in particular, can influence the primary productivity of coastal ecosystems and can lead to eutrophic conditions in the receiving

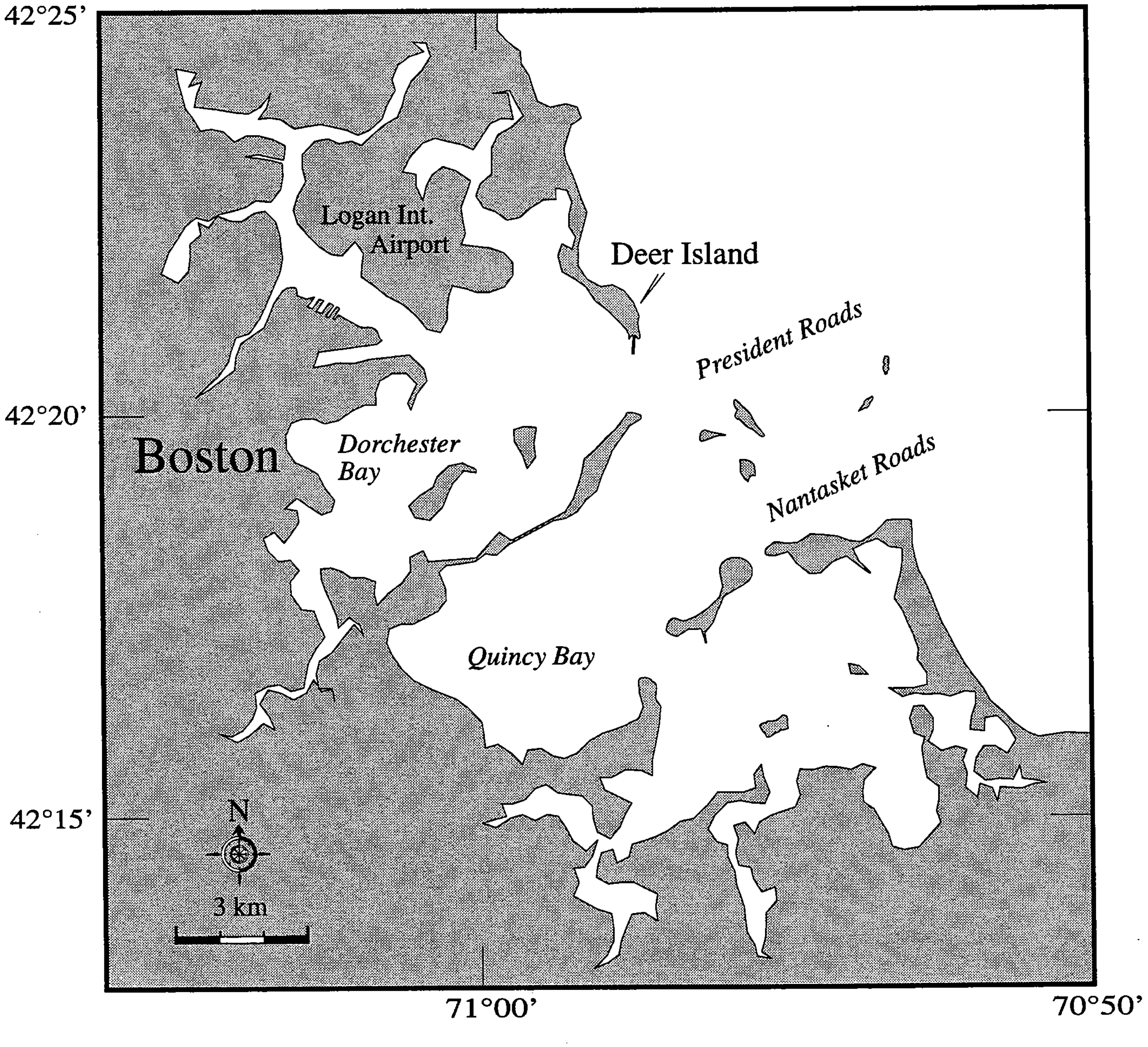


**Figure 1. Location of Deer Island in Boston Harbor.**

**Table 1. Organic and trace metal analytes for the Deer Island effluent characterization task.**

***Polynuclear Aromatic Hydrocarbons***
Naphthalene (N)
$C_1$-$C_4$ naphthalene
Biphenyl (BI)
Acenaphthylene (AE)
Acenaphthene (AC)
Fluorene (F)
$C_1$-$C_3$ fluorenes
Phenanthrene (P)
Anthracene (A)
$C_1$-$C_4$ phenanthrene/anthracenes
Fluoranthene (FL)
Pyrene (PY)
$C_1$-fluoranthene/pyrene (FP1)
Dibenzothiophene (D)
$C_1$-$C_4$ dibenzothiophenes
Benz[*a*]anthracene (B)
Chyrsene (C)
$C_1$-$C_4$ chyrsenes
Benzo[*b*]fluoranthene (BB)
Benzo[*k*]fluoranthene (BK)
Benzo[*e*]pyrene (BE)
Benzo[*a*]pyrene (BA)
Perylene (PER)
Indeno[1,2,3-*c,d*]pyrene (IP)
Dibenz[*a,h*]anthracene (DA)
Benzo[*g,h,i*]perylene (BP)

***Linear Alkyl Benzenes***
Phenyl decanes ($C_{10}$)
Phenyl undecanes ($C_{11}$)
Phenyl dodecanes ($C_{12}$)
Phenyl tridecanes ($C_{13}$)
Phenyl tetradecanes ($C_{14}$)

***Pesticides***
Hexachlorobenzene
Lindane
Heptachlor
Aldrin
Heptachlorepoxide
cis-Chlordane
trans-Nonachlor
Dieldrin
Endrin
Mirex
2,4'-DDD
4,4'-DDD
2,4'-DDE
4,4'-DDE
2,4'-DDT
4,4'-DDT

***Polychlorinated Biphenyls***
2,4,-$C_{12}$(8)
2,2',5-$C_{13}$(18)
2,4,4'-$C_{13}$(28)
2,2',3,5'-$C_{14}$(44)
2,2',5,5'-$C_{14}$(52)
2,3',4,4'-$C_{14}$(66)
3,3',4,4'-$C_{14}$(77)
2,2',4,5,5'-$C_{15}$(101)
2,3,3',4,4'-$C_{15}$(105)
2,3',4,4',5-$C_{15}$(118)
3,3',4,4',5-$C_{15}$(126)
2,2',3,3',4,4'-$C_{16}$(128)
2,2',3,4,4',5'-$C_{16}$(138)
2,2',4,4',5,5'-$C_{16}$(153)
2,2',3,3',4,4',5-$C_{17}$(170)
2,2',3,4,4',5,5'-$C_{17}$(180)
2,2',3,4,5,5',6-$C_{17}$(187)
2,2',3,3',4,4',5,6-$C_{18}$(195)
2,2',3,3',4,4',5,5',6-$C_{19}$(206)
Decachlorobiphenyl-$C_{110}$(209)

***Trace Metals***
Silver (Ag)
Cadmium (Cd)
Chromium (Cr)
Copper (Cu)
Mercury (Hg)
Molybdenum (Mo)
Nickel (Ni)
Lead (Pb)
Zinc (Zn)

***Nutrients***
Dissolved inorganic nutrients
    ($NH_3$, $NO_2$, $NO_3$, $PO_4$, Si)
Dissolved organic nutrients
    (N, P)
Dissolved organic carbon (DOC)
Particulate organic carbon (POC)
Particulate organic nitrogen (PON)
Particulate organic phosphorous (POP)
Biogenic silica

***Stable Isotopes***
$\delta^{15}N$
$\delta^{34}S$

***Clostridium perfringens***

waters if discharged in excess. Available effluent nutrient data were limited to selected measurements of dissolved inorganic forms (ammonia, nitrate, nitrite, and orthophosphate), total Kjeldahl nitrogen, and total phosphorus concentrations (Alber and Chan, 1994). These measurements were not sufficient for the water quality model being developed by MWRA. Thus, beginning in December 1993, MWRA initiated bi-monthly monitoring of the Deer Island effluent for all major nutrient forms (Table 1) and selected other parameters (*e.g.*, *Clostridium perfringens* spores and stable isotopes of nitrogen and sulfur) that provide additional information on the transfer of effluents throughout the receiving environment or into organisms.

- *Short-term (e.g., 2-3 day) variability in the concentrations of effluent contaminants and nutrients.* Two-day interval, twenty-four hour composite bi-monthly samples of Deer Island effluent were collected each month beginning in June 1993. The objective of this effort was to monitor for short-term fluctuations in the concentrations of the target metals, organic compounds, nutrients, and the tracers in the waste stream. Short-term fluctuations could indicate episodic inputs of contaminants that might otherwise be overlooked using a one-time sampling strategy. Changes in nutrient forms could also be evaluated.

- *Long-term (e.g., monthly and seasonal) changes in the concentrations of effluent contaminants and nutrients.* Monthly sampling of effluent was conducted to determine if the composition of the effluent was seasonally influenced. For example, certain organic compounds such as pesticides might be used more frequently during certain months of the year, possibly resulting in seasonally elevated concentrations of such compounds in the effluent.

- *Monthly and annual contaminant-specific loading to Massachusetts Bay.* Effluent flow data (measured by MWRA), coupled with the contaminant and nutrient concentration data, provide a means for calculating loadings of contaminants and nutrients into the Harbor and Bay. These data provide one type of long-term gauge for measuring change in inputs to the Harbor/Bay system as waste stream treatment practices change.

- *Possible chemical "fingerprints" that might be unique to the effluent or suggest potential sources of the contaminants in the effluent and changes that may occur as a result of the secondary treatment process.* The presence and distribution of metals and organic compounds in the effluent, if unique, can be useful for tracking the fate of the discharge plume and some of the contaminants in the aquatic environment. Similarly, a characteristic pattern in the distribution of certain contaminants might suggest a source or type of source for the effluent. For example, the distribution of polynuclear aromatic hydrocarbons (PAHs) reveals the predominant type of petroleum hydrocarbons in the waste stream which, in turn, could be linked to a source or source type. Changes in these signatures may occur as treatment processes or treatment levels are modified. Thus, an understanding of the effect of such changes on the source signals is needed.

- *Comparability of the results of effluent analysis between ultra-trace metal and organic contaminant techniques, and standard methods used to support National Pollutant Discharge Elimination System (NPDES) methods.* This objective was addressed in the 1993 annual effluent characterization study (Uhler *et al.*, 1994) and is not elaborated in this 1994 report.

The MWRA pilot treatment plant was constructed to enable MWRA to conduct evaluations of the operational characteristics of new primary and secondary treatment plants, and to evaluate other treatment alternatives such as Chemically Enhanced Primary Treatment (CEPT) to ensure that MWRA achieves the highest effluent quality from the Deer Island treatment plant. The pilot plant was designed to mimic the new primary plant and secondary plant. Its two treatment channels allow the evaluation of different operational modes, for example CEPT and also the biological secondary treatment processes. The CEPT capability was completed in late 1993 and the secondary capability was completed in the spring of 1994. Details of the treatment plant design and operations can be found in the draft report CP-201 Pilot Plant One Year Operations Plan (MWRA, 1993).

Understanding how well the various treatment processes perform is central to the utility of the pilot treatment plant. Thus, the objectives of pilot treatment plant studies were to

- *Evaluate the effectiveness of the pilot treatment plant primary and secondary treatment for removal of metals, organic contaminants, and nutrients.*
- *Estimate the effluent quality that will be achieved when full secondary treatment is implemented.*

Meeting these objectives required that the influent to the pilot plant, as well as the effluents from the various treatments, be sampled and analyzed. Because sampling in support of the pilot treatment plant's operations was undertaken in concert with the plant shakedown, operational and facility interruptions were experienced during the sampling period. For example, between March and July 1994, during shakedown of the secondary treatment plant, BOD and total suspended solids data suggested that full secondary treatment was not being achieved. Further evaluation determined that the aerators and impellers were not operating as expected. Plant improvements were thus implemented and completed in late 1994 (M. Hall, MWRA, personal communication, February 1995). Because of the small number of tests completed, estimates of removal efficiencies presented in this report must be considered preliminary and may not fully reflect the improvements in effluent quality that will be achieved when the new primary and secondary treatment plants are fully operational.

# 2.0 METHODS

## 2.1 Sample Collection

### 2.1.1 Deer Island Effluent

Beginning in June 1993 and continuing through November 1994, effluent samples from the Deer Island treatment plant were collected each month by MWRA personnel. Twenty-four-hour composite samples were collected using Isco automated samplers. Each month, two composite samples were collected two days apart. The composite effluents were subsampled as follows:

- 2 L for trace organic analysis (PAHs, pesticides, PCBs)
- 500 mL for trace metal analysis (Ag, Cd, Cr, Cu, Ni, Pb, Zn); Mo analysis was added in December 1993
- 500 mL for Hg analysis
- *Clostridium perfringens* (added in November 1993)

Beginning in December 1993, discrete grab samples were collected for analysis of nutrients, stable nitrogen and sulfur isotopes. Additional effluent was also collected for use as matrix spike quality control samples. The composite samples for contaminant analysis were stored on ice and shipped by courier to the Battelle Ocean Sciences laboratory. The nutrient samples and other effluent tracer samples were filtered as necessary immediately after collection, the aqueous phase was preserved with chloroform, and the samples were shipped at ambient temperature to the University of Rhode Island. *Clostridium perfringens* samples were shipped on ice to Biological Analytical Laboratory, Inc. in North Kingston, RI. Particulate matter for stable isotope analysis was collected on a filter and frozen. Samples were dried at Battelle, then transferred to the Marine Biological Laboratory (MBL) for analysis.

All bottles for the trace metals and the Hg analyses were rigorously cleaned in dilute, high-purity acids to ensure that extraneous contaminants were not added to the samples. For the metals, acids used to preserve the samples were included in the bottles when they were transferred to the control of MWRA. Samples for organics analysis were collected in 2-L amber-glass I-Chem bottles. Liquid phases for nutrient analysis were stored in polyethylene or glass, as appropriate to the parameter of interest. *Clostridium perfringens* samples were collected in 250-mL polypropylene bottles that contained sodium thiosulfate, a chlorine neutralizer.

The composite samples were processed and analyzed for total metals (Ag, Cd, Cr, Cu, Hg, Mo, Ni, Pb, and Zn), an extended list of 40 PAHs, $C_{10}$ to $C_{14}$ LABs, 20 PCB congeners, 16 chlorinated pesticides (Table 1), and subsamples for *Clostridium perfringens* spores. Grab samples were collected on the day that the Isco samplers were deployed for measurement of nutrients. Duplicate samples for all nutrient forms were collected. The grab samples were processed for measurement of dissolved and particulate organic carbon (DOC and POC, respectively); the major forms of nitrogen (particulate nitrogen, $NH_3$, $NO_2$, $NO_3$, total dissolved nitrogen, and dissolved organic nitrogen [by difference]); phosphate (dissolved $PO_4$, total dissolved phosphorus, dissolved organic phosphorus [by difference], and particulate organic phosphorus), and two forms of silicate (dissolved and biogenic). Dissolved inorganic nutrients and total dissolved nitrogen and phosphorus were filtered through 0.4-$\mu$m Nuclepore filters; DOC and POC/PON samples were filtered through Whatman GF/F glass-fiber filters (details of the filtration steps can be found in the appendices to West and Doering (1994). Biogenic silica samples were filtered through poretic filters. The samples for metals, organic contaminants, and *Clostridium perfringens* analysis were iced and shipped to the analytical laboratories for final processing, analysis, or archival. Samples for *Clostridium perfringens* analysis were delivered to BAL within 24 h of collection. Samples for metals and organic compounds were shipped on the second day of collection. Samples for nutrients were either shipped within 24 h or on the second day of collection. Once received, processing required to meet EPA holding times and to otherwise ensure the integrity of the measurements was completed (*e.g.*, samples for organic compounds were extracted within 14 days and Hg was analyzed within 30 days).

### 2.1.2 Pilot Treatment Plant

Table 2 summarizes the sample collection dates, sample types, and number of samples collected for these studies. The first study was conducted in December 1993 and was designed to examine the efficiency of contaminant removal using CEPT. During this experiment, MWRA added 30% ferric chloride, a byproduct of titanium oxide production. Pilot plant sampling continued during the

Table 2. Sample collection dates, type, and number for the pilot treatment plant studies.

| Date | Sample Type | MWRA Sample ID | Organic | Metals | Mercury | Nutrients (Grab samples)[1] | *Clostridium perfringens* |
|---|---|---|---|---|---|---|---|
| 12/7/93 | Influent | NA[2] | 1 | 1 | 1 | NR[3] | 1 |
| 12/7/93 | 1° Effluent | NA | 1 | 1 | 1 | NR | 1 |
| 12/7/93 | CEPT[4] | NA | 1 | 1 | 1 | NR | 1 |
| | | | | | | | |
| 6/1/94 | Influent | 39405853 | 1 | 1 | 1 | NR | NR |
| 6/1/94 | 1° Effluent | 39405739 | 1 | 1 | 1 | 2 | NR |
| 6/1/94 | 2° Effluent | 39405743 | 1 | 1 | 1 | 2 | NR |
| | | | | | | | |
| 6/3/94 | Influent | 39405854 | 1 | 1 | 1 | NR | NR |
| 6/3/94 | 1° Effluent | 39405740 | 1 | 1 | 1 | 2 | NR |
| 6/3/94 | 2° Effluent | 39405844 | 1 | 1 | 1 | 2 | NR |
| | | | | | | | |
| 7/15/94 | Influent | 39407263 | 1 | 1 | 1 | 2 | NR |
| 7/15/94 | 1° Effluent | 39407265 | 1 | 1 | 1 | 2 | NR |
| 7/15/94 | 2° Effluent | 39407267 | 1 | 1 | 1 | 2 | NR |
| | | | | | | | |
| 7/29/94 | Influent | 39407918 | 1 | 1 | 1 | 2 | NR |
| 7/29/94 | 1° Effluent | 39407920 | 1 | 1 | 1 | 2 | NR |
| 7/29/94 | 2° Effluent | 39407922 | 1 | 1 | 1 | 2 | NR |

[1] Separate Ids were assigned to each grab sample
[2] Not assigned
[3] Not requested
[4] Chemically Enhanced Primary Treatment

summer of 1994, with four sampling events of the biological secondary process being completed in June/July. No additional sampling events were conducted in 1994 because the pilot plant was undergoing modifications. MWRA did not request nutrient analysis of influent samples for the two June 1994 studies.

During each sampling event, automated Isco samplers were used to collect 24-h composite samples from the pilot plant influent (except as noted in Table 2) plus the effluents of the primary and secondary treatment channels. The MWRA TRAC personnel collected all samples and performed the sample filtration for all dissolved nutrient samples. The composite samples were processed and analyzed for the same metals, PAHs, $C_{10}$ to $C_{14}$ LABs, PCB congeners, chlorinated pesticides, nutrients, and effluent tracers that were measured in the effluent samples. Sample processing and storage bottles were the same as described for the effluent samples. No samples were processed for stable nitrogen and sulfur isotope analysis during the pilot plant studies. Only three samples were collected (December 1993) for *Clostridium perfringens* spore enumeration.

## 2.2 Sample Analysis

The methods used to analyze the samples are described in detail in Shea (1993b), Albro *et al.* (1993), and West and Doering (1994). The methods are briefly summarized below and the method detection limits (MDLs) are listed in Table 3. The interested reader is referred to the above-referenced Combined Work/Quality Assurance Project Plans (available from MWRA upon request) for additional details on the sample analysis.

***Metals and Organic Contaminants*** — Because the concentrations of most target metals and anthropogenic organic compounds in the MWRA effluent are known to be in the low nanogram-per-liter range for organics and in the low microgram-per-liter range for metals (Uhler *et al.*, 1994), samples were analyzed using methods that have been specially modified for measurement of ultra-trace levels of contaminants in fresh and marine water matrices. These concentration ranges were consistently achieved during the analytical program, although selected organic analytes fell below the listed MDLs.

## Table 3. Method Detection Limit (MDL) goals.

| Parameter | MDL Goal | NPDES MDL[1] |
|---|---|---|
| *Metals* | (μg/L) | (μg/L) |
| Ag (silver) | 0.50 | 10.0 |
| Cd (cadmium) | 0.50 | 4.0 |
| Cu (copper) | 0.50 | 10.0 |
| Cr (chromium) | 1.0 | 10.0 |
| Hg (mercury) | 0.005 | 0.2 |
| Mo (molybdenum) | 0.50 | 80.0 |
| Ni (nickel) | 1.00 | 10.0 |
| Pb (lead) | 0.50 | 1.0 |
| Zn (zinc) | 2.00 | 6.0 |
| *Organic Analytes* | (ng/L) | (ng/L) |
| Polychlorinated biphenyls (PCB) (as congeners) | 1 | 500 |
| Linear alkyl benzenes (LAB) | 50 | NA |
| Polynuclear aromatic hydrocarbons (PAH) | 10 | 10,000 |
| Pesticides | 1 | 50-100 |
| **Nutrients** | (μM) | (μM) |
| Dissolved $NH_3$ | 0.04 | NA |
| Dissolved $NO_2$ | 0.02 | NA |
| Dissolved $NO_3$ | 0.02 | NA |
| Dissolved $PO_4$ | 0.02 | NA |
| Dissolved Si | 0.04 | NA |
| Dissolved organic carbon | 30 | NA |
| Dissolved organic nitrogen | 2 | NA |
| Particulate organic phosphorous | 0.6 | NA |
| Particulate organic carbon | 4 | NA |
| Particulate organic nitrogen | 3 | NA |
| Particulate organic phosphorous | 0.02 | NA |
| Biogenic Si | 0.04 | NA |

[1] NPDES contaminant MDLs are typical MDLs reported by MWRA in their NPDES monitoring
reports; the listed contaminant MDLs meet the EPA Contract Laboratory Program (CLP) requirements.

The extraction techniques for organic contaminant analysis followed EPA Method 3510; sample cleanup and instrumental analysis techniques—modifications or derivations of several standard EPA methods—are those from the National Oceanic and Atmospheric Administration (NOAA) National Status and Trends (NS&T) Program (Table 3). Over the last eight years, these methods have been developed and refined by Battelle, NOAA, and the National Institute of Standards and Testing (NIST) scientists to support the low-level contaminant measurement requirements of the NS&T program, and they have become the methods of choice for many monitoring programs.

Methods for the determination of trace metals in effluent are standard EPA techniques modified for ultra-clean analysis. Total recoverable metals were determined following modified EPA 600-01-79-020m Section 4.1.4; Ag, Cd, Cu, Ni, Pb, and Zn were determined by graphite furnace atomic absorption spectrometry (GFAAS). Total recoverable Mo was determined using modified EPA Method 246.2 techniques while Hg was measured using cold vapor atomic absorption spectroscopy (CVAAS). Required MDLs for the effluents were consistently met and no nondetectable results were obtained.

***Nutrients —*** Albro *et al.* (1993) describe the analytical methods used to measure the nutrients that were common with the MWRA Harbor and Outfall Monitoring Project 1992-1994 baseline water quality monitoring program. The major change in using these methods for influent and effluent sampling was the sample dilution required to bring many of the analytes into the linear working range of the method. Analytical methods for parameters that were not measured as part of the 1992-1994 water quality monitoring program are described in detail in West and Doering (1994). Method detection limits, which were consistently met during the effluent analysis program, are shown in Table 3.

### 2.2.1 Trace Organic Contaminants

Influent and effluent samples were serially extracted for PAHs, LABs, chlorinated pesticides, and PCBs following EPA Method 3510. Each 2-L effluent sample was transferred to a 3-L separatory funnel. The sample bottle was rinsed with dichloromethane (DCM) and the rinseate was added to the separatory funnel to ensure that any organic compounds adhering to the wall of the bottle were scavenged. The appropriate chlorinated hydrocarbon, PAH, and LAB surrogate internal standards were added to the sample, and the sample was serially extracted three times with 120-mL portions of DCM. The first phase of extract cleanup was accomplished following modified EPA Method 3610. The extract was passed through a 20-g alumina column and eluted with 50 mL of DCM. The filtrate was reduced in volume to about 1 mL using Kuderna-Danish and nitrogen concentration techniques; the concentrated extract was further cleaned using size-exclusion (gel permeation) high-performance liquid chromatography (HPLC) (modified EPA Method 3640). The gel permeation HPLC cleanup removes common biogenic contaminants that can interfere with low-level instrumental analysis. The post-HPLC extract was concentrated to approximately 0.5 mL under nitrogen, recovery internal standards were added, and the final extract was split for analysis: one half for PAH and LAB analysis; the other half was solvent-exchanged with isooctane and used for PCB and pesticide analysis.

Sample extracts were analyzed for PAH and LAB compounds by selected ion monitoring (SIM) gas chromatography mass spectrometry (GC/MS) following a modification of EPA Method 8270. PAH compounds were determined by monitoring for the most intense parent ion plus one confirmation ion for each target compound. LAB compounds were determined as five separate LAB groups (those with alkyl chains containing 10, 11, 12, 13, and 14 carbon atoms) by monitoring the characteristic LAB m/z 91 molecular ion during the GC/MS analysis and summing the structural homologues within each group (Eganhouse *et al.*, 1983). Pesticides and PCB congeners were analyzed by capillary gas chromatography with electron capture detection (GC/ECD) using EPA Method 8080, modified to include additional analytes. All analytes were quantified using the internal standard method.

***Note on the 1993 Dieldrin Analysis*** — The 1993 dieldrin results (Uhler *et al.*, 1994) and analyses completed through mid 1994 suggested the presence of surprisingly high levels of dieldrin in some samples. To resolve whether the determined concentrations were indeed due to dieldrin, or to some unknown interferant, confirmatory analysis was conducted on one set of sample extracts collected and analyzed during 1994 (Table 4). The samples were selected on the basis of the reported concentrations of dieldrin (*i.e.*, concentrations >10 ng dieldrin/L) and over the seasons that the apparently high dieldrin concentrations were reported. Eight samples from the winter (January and February) and late spring/summer (May through August) of 1994 were analyzed. Both samples

**Table 4. Summary of Dieldrin Data Determined by GC/ECD, November 1994.**

| | Determined Dieldrin Concentration (ng/L) | | | |
|---|---|---|---|---|
| | Original Analysis | | Re-Analysis | |
| Sample Month | Rep#1 | Rep #2 | Rep #1 | Rep #2 |
| 1-94 | 54 | 46 | 2.5 | Not analyzed |
| 2-94 | 26 | 30 | 2.1 | Not analyzed |
| 5-94 | 19 | 20 | 2.2 | Not analyzed |
| 6-94[a] | 49 | 36 | 3.1 | Not analyzed |
| 7-94 (early) | 53 | 56 | 1.6 | Not analyzed |
| 7-94 (late) | 66 | 87 | 4.0 | Not analyzed |
| 8-94 | 53 | 49 | 3.7 | 5.0 |

[a] Replicate 1 is the pilot treatment plant influent; Replicate 2 is Deer Island effluent.

collected in August 1994 were reanalyzed. No spring or fall samples were analyzed because the reported dieldrin concentrations for those samples were low.

Samples were analyzed by simultaneous dual-column gas chromatography with electron capture detection (GC/ECD). In this analysis, the injected sample is automatically split between two GC columns of different retention characteristics (a DB-5 and a DB-1701 phase column), and the data for the two columns/analyses are compared. Confirmation of dieldrin is achieved if similar results are obtained on both columns (*e.g.*, dieldrin identified and quantified at similar levels). Dissimilar data (*e.g.*, significant concentrations of dieldrin identified on the DB-5, but not on the DB-1701) would indicate that the concentration determined in the primary analysis (with the DB-5 column) was not due to the target analyte, but instead was due to some unknown compound having the same primary GC column retention time as the target analyte.

The results of the original 1994 analyses and those from the re-analyses are reported in Table 4. These data are for the primary (DB-5) column analyses. As can be seen in this table, different values were determined in the re-analyses than in the original analyses, even with same type of column. The large peak that had originally been identified as dieldrin was, in the re-analysis, resolved from where dieldrin elutes and, therefore, was not identified as dieldrin. Improved identification and quantification of dieldrin was achieved on this re-analysis than previously experienced. However, daily and weekly operating variability in the instruments is such that the ability to separate the dieldrin from the interfering peak may not always be achieved. Thus, confirmatory analysis should be a standard operating procedure for this analyte. Confirmatory analysis for dieldrin was conducted on all other 1994 samples.

The high concentrations of dieldrin reported in the 1993 Effluent Characterization Report (Uhler *et al.*, 1994) should not be used when evaluating the baseline data for the MWRA Deer Island effluent. Because the high 1993 values are suspect, only the 1994 data are evaluated in this present report.

Selected pilot plant samples (an influent, primary effluent, and secondary effluent) were also re-analyzed. As observed with the Deer Island effluent samples, the re-analysis did not confirm high dieldrin concentrations and did not identify dieldrin these samples. As a result, all dieldrin results for the pilot plant were considered suspect and the data are not reported here.

### 2.2.2 Trace Metals

The sample preparation procedures defined by EPA (Section 4.1.4 of 600-01-79-020, March 1983) for determining total recoverable metals were used for the metals analysis of the effluent. For all metals except Hg, 100 mL of the sample was spiked with 5 mL of hydrochloric acid and the sample was reduced in volume by evaporation to ~10-20 mL. The solution was then filtered through a Nuclepore 0.4-μm membrane. To increase sensitivity, the filtrate was not diluted back to 100 mL. To reduce sample contamination, all sample preparation was performed in a Class-100 clean room, and all sample containers and sample preparation equipment were rigorously cleaned according to the procedures of Patterson and Settle (1976). All effluent samples were directly analyzed by GFAAS for Ag, Cd, Cr, Cu, Mo, Ni, Pb, and Zn. Mo was analyzed by EPA Method 246.2.

A modification of EPA Method 245.1 was used for Hg analysis. The samples were prepared by digesting approximately 50 mL of sample with $KMnO_4$ and $K_2S_2O_8$ and reduced to elemental Hg with $SnCl_2$. Hg measurements were made using CVAAS.

### 2.2.3 Nutrients

***Dissolved Inorganic Nutrients*** — Concentrations of dissolved inorganic nutrients were determined on samples that were passed through a 0.4-μm Nuclepore membrane filter. The concentrations of ammonia, nitrate, nitrite, silicate, and phosphate were measured colorimetrically on a Technicon II Autoanalyzer which simply automates standard manual techniques for the analysis of nutrients. The analysis of ammonia was based on the technique of Solorzano (1969) whereby absorbance of an indophenol blue complex is measured at 630 nm. Nitrite was measured by the method of Bendschneider and Robinson (1952). The total of nitrate and nitrite was determined by reducing all nitrate in the sample to nitrite and analyzing for nitrite as above. The concentration of nitrate was obtained by difference. The reduction is accomplished using a cadmium column (Morris and Riley, 1963). The analysis of phosphate was based on the molybdate blue procedure of Murphy and Riley (1962). The colorimetric analysis of silicate was based on that of Brewer and Riley (1966).

***Particulate Carbon and Nitrogen*** — Particulate matter was collected on a Whatman GF/F glass-fiber filter. The organic carbon and nitrogen content of the particulate matter on the filters was determined by igniting the filter at high temperature (1050°C) in a Carlo Erba Model-1106 CHN elemental analyzer. The combustion releases carbon and nitrogen in gaseous forms which are then quantified using gas chromatography with a thermal conductivity detector.

***Dissolved Organic Nitrogen and Phosphorus*** — The concentration of dissolved organic nitrogen or phosphorus can not be measured directly. The dissolved organic concentration of these parameters is currently determined as the difference between the total dissolved concentration and total dissolved inorganic concentration in the sample. The procedures by which the concentrations of dissolved inorganic nitrogen and phosphorus are obtained are describe above. The method of Valderrama (1981) was used to determine the concentrations of total dissolved nitrogen and phosphorus. This wet-chemical technique utilizes persulphate to oxidize organic nitrogen and phosphorus to nitrate and phosphate. The concentrations of the latter were then determined colorimetrically on a Technicon Autoanalyzer, as described above.

***Dissolved Organic Carbon*** — Dissolved organic carbon was determined by persulphate digestion (Lambert and Oviatt, 1986) using an O.I. Model-700 TOC Analyzer. Some doubt concerning the accuracy of this method has been voiced in the literature and recent work suggests that the higher concentrations obtained by high-temperature combustion more nearly reflect true levels of DOC in nature (Sugimura and Suzuki, 1988). The method that was used for the analysis of effluents was intercalibrated with an Ionics high-temperature combustion instrument. This study demonstrated that both fresh- and salt-water samples agreed to within 6%. Thus, bias is not suspected in these effluent samples and internal consistency with the water column monitoring program is retained.

***Particulate Phosphate*** — Methods used to measure particulate phosphate were modified from Solorzano and Sharp (1980). The filter containing the particles was placed in a scintillation vial, 2 mL of 0.017 M $MgSO_4$ was added, the sample was dried and baked at 450°C. HCl was then added and the phosphorus in the sample was determined colorimetrically as described for the inorganic phosphate analysis.

***Biogenic Silica*** — Particulate matter for determination of biogenic silica was extracted using a wet alkaline digestion (Knauss *et al.*, 1983). Particulates retained on a 0.4-$\mu$m Poretics membrane filter were digested with 0.2 N NaOH and neutralized with 0.2 N HCl. The silica dissolved by this procedure was measured colorimetrically using a Technicon II Autoanalyzer and biogenic silica concentrations were calculated.

### 2.2.4 *Clostridium perfringens*

*Clostridium perfringens* spores were enumerated by membrane filtration, using serial half-log dilutions of the effluent, according to the procedure developed by Bisson and Cabelli (1979). The effluent was filtered using sterile filtration apparatus and membrane filters that had been rinsed with sterile phosphate-buffered saline (PBS). The filters were incubated for 18-24 h at 44.5°C, exposed to ammonium hydroxide, and the *C. perfringens* colonies counted and recorded.

### 2.2.5 Stable Isotopes

All effluent samples were filtered with glass-fiber filters (Whatman GF/F, nominal pore size 0.7 $\mu$m). After acidification to remove carbonate and desiccation in scintillation vials at 60°C, stable isotopes of particulate nitrogen ($^{15}$N) retained on the filters were analyzed by mass spectrometry. The samples were then flash-combusted at 1800°C in an evacuated gas manifold and the resulting gases were routed via a helium carrier flow to a cryogenic trap to separate the water, carbon dioxide, and nitrogen gases. $^{15}$N was analyzed using a Finnigan Delta-S mass spectrometer and the excess $^{15}$N in each sample was detected by comparing the $^{15}$N/$^{14}$N against an air reference.

Sulfur isotope ($^{34}$S) measurements were made on a separate sample, which was dried and combusted in a sealed tube with potassium nitrate to oxidize sulfur species to sulfate salts. The sulfate salts were digested in an acid solution, which was filtered and to which 10% barium chloride solution was added to precipitate sulfate as barium sulfate. The barium sulfate was recovered by filtering the solution through ash-less filters which are subsequently combusted in crucibles. Finally, the residual barium sulfate ash was treated with vanadium pentoxide and elemental copper, and transferred to a vacuum apparatus. Upon heating, sulfur dioxide is released, cryogenically trapped on the vacuum line, and analyzed for $^{34}S$ using a Finnigan MAT 251 isotope ratio mass spectrometer. The excess $^{34}S$ in each sample was determined by comparing the $^{34}S/^{32}S$ against a Canyon Diablo Triolite meteorite reference.

## 2.3 Data Treatments

### 2.3.1 Effluent Data

Effluent data were treated as described in Uhler *et al.* (1994). Individual sample and monthly mean contaminant and nutrient concentrations plus effluent flow were plotted as a function of sampling month to evaluate temporal trends. Monthly loading estimates from the Deer Island treatment plant were estimated by multiplying the mean monthly contaminant or nutrient concentration times the mean flow rate for the two sample collections each month. The calculated monthly inputs between December 1993 and November 1994 were used to estimate the annual loading of the various contaminants and nutrients from the Deer Island treatment plant. The most recent 12-month period was chosen for this calculation because it represents the most recent information on this effluent and is not biased by including an unbalanced set of seasonal data (*i.e.*, from two summer periods and one winter period).

The annual loading of contaminants from the Deer Island facility was estimated using the following assumptions:

- The average of the two effluent flow measurements taken at the time of effluent sampling is representative of that entire month.
- The average concentration of contaminants measured in the effluent for a given month is representative of the entire month.

The annual loading for each contaminant of interest was calculated from the equation

$$L_i \text{ (Kg)} = [\Sigma \ (C_{i,m} \times F_m)]$$

where

$L_i$ is the annual loading of contaminant in kilograms

$C_{i,m}$ is the average concentration of contaminant *i* in the effluent measured in month *m* in Kg/gal; *m* ranges from December to November

$F_m$ is the average effluent flow at Deer Island in millions of gallons per day (MGD) for the days that the effluent samples were collected for analysis in month *m*

This simple calculation allows a first-order estimate of the inputs of anthropogenic contaminants to the Harbor and Bay, and provides a basis for comparison of contaminant loadings that have been estimated by other investigators.

Estimates of 1994 effluent loading to the Massachusetts Bay/Boston Harbor system were compared to previous estimates (Alber and Chan, 1994; Shea, 1993a) by assuming that effluent concentrations in the Nut Island effluent were the same as those from Deer Island. The effluent flow to the Boston Harbor/Massachusetts Bay system was then proportioned between the two treatment facilities based on the running 12-month flow average of 255 and 128 MGD reported by MWRA for Deer Island and Nut Island, respectively (MWRA NPDES NEWS, November 1994). Based on these assumptions, the Deer Island effluent loading estimates were increased by a factor of 1.5 to account for the total loading from both facilities.

### 2.3.2 Pilot Treatment Plant Data

Results from the pilot treatment plant study are reported as concentrations in the influent and effluents. The focus of the data treatment was on estimating removal efficiencies for the various parameters during primary and secondary treatment, and on examining conversions among the various nutrient forms. Preliminary estimates of contaminants and nutrient loading to Massachusetts Bay, after the secondary treatment becomes operational, were also made based on the 1994 loading estimates and the removal efficiencies of the secondary treatment relative to primary treatment.

The efficiency of the contaminant and nutrient removal process was examined using the following formula:

$$R_e = ((C_i - C_e)/C_i) \times 100$$

where

$R_e$ is the removal efficiency
$C_i$ is the influent concentration
$C_e$ is the effluent concentration (either primary or secondary)
the constant 100 expresses the ratio as a percentage

The same formula was used to estimate remove efficiencies between the primary and secondary treatment trains of the pilot treatment plant.

### 2.3.3 Principal Components Analysis

Principal components analysis (PCA) is a multivariate data analysis tool for creating data matrices that distinguish similarities/differences in patterns (analyte distributions) between individual samples, and that determine the influence each variable (analyte) or set of variables has on that pattern. PCA is especially useful for uncovering underlying patterns that may not be obvious from a visual analysis of the data. This technique helps determine how samples may be related and which characteristics of the samples define their relationship. The Ein*Sight (Infometrix, Inc.) pattern-recognition software package was used to perform PCA analysis of the PAH and LAB data from the effluent samples. Initially, the effluent data (PAH) from June 1993 through November 1994, as well data from the analysis of several common fuel products, were explored with PCA. The PAH and LAB data from the pilot plant study were then included with the effluent data to emphasize any potential differences in the analyte distributions that may be attributed to the treatment processes.

# 3.0 RESULTS AND DISCUSSION

## 3.1 Effluent

### 3.1.1 Flow

The daily effluent flow rate from the Deer Island treatment facility is characterized by base flows overlain with periodic high flow events (Figure 2). The base flow exhibits seasonal behavior, with lower flows occurring in the summer and higher flows in the winter/spring. Careful examination of the sample collection dates in 1993 and 1994 shows that the base flows from the Deer Island facility were well represented. In addition, a number of high-flow events were sampled, although no samples were collected during the periodic major increases in flow that are apparent from the data.

The flow data for the sampling periods are shown in Figure 3. The results show that the flows in the winter/spring period were generally higher than in the summer/fall period. The ratio (1.32) of the average flows for the sample collection dates between December 1993 and May 1993, and June through November 1994 shows that the winter/spring flow was ~1.5 times the flow during the summer/fall period.

### 3.1.2 Trace Organic Contaminants

The temporal variability of the organic compounds measured between June 1993 and November 1994 are considered in this section.

***PAHs* —** PAHs in the environment have two primary sources. The lighter weight, more volatile 2- and 3-ring petrogenic PAHs result from spills or chronic input of refined and unrefined petroleum products. The heavier pyrogenic 4-, 5-, and 6-ring PAHs are derived from the combustion of fossil fuels. The total PAH concentrations (sum of all PAHs listed in Table 1) in the Deer Island effluent samples is presented in Figure 4.

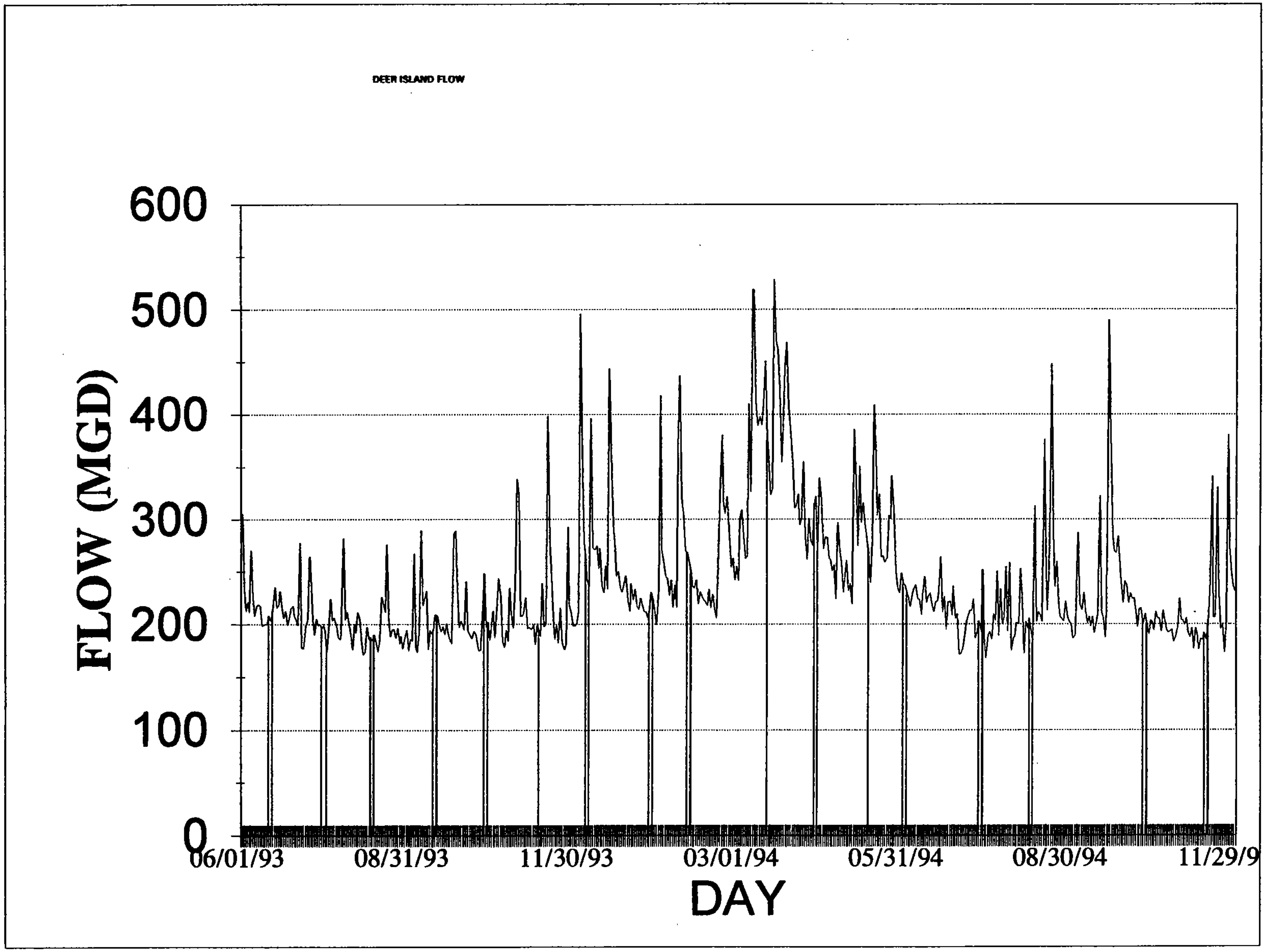


Figure 2. Daily flow rates from Deer Island Treatment plant June 1993 through November 1994. Sample collection dates are shown by the lines descending from the flow data.

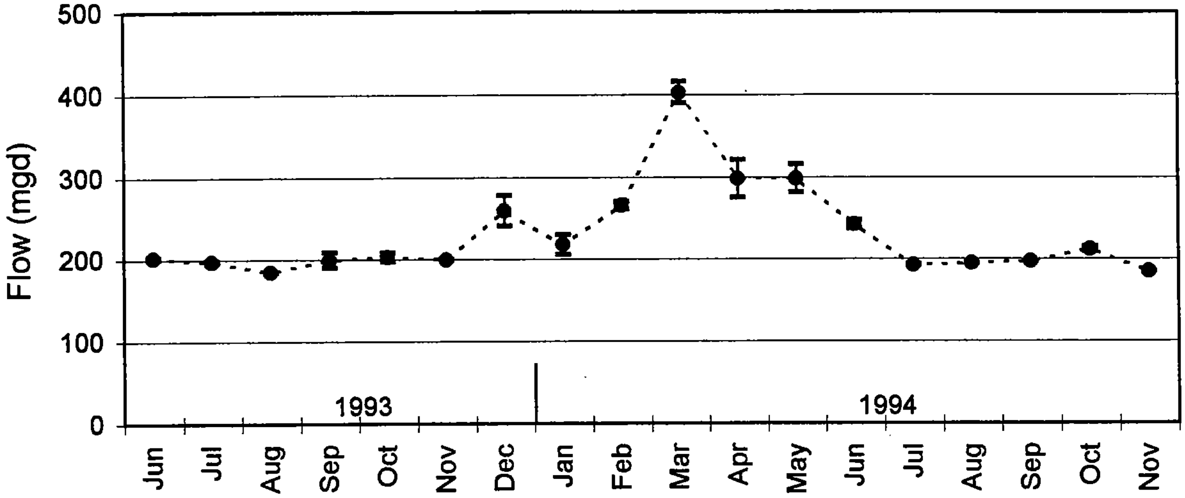
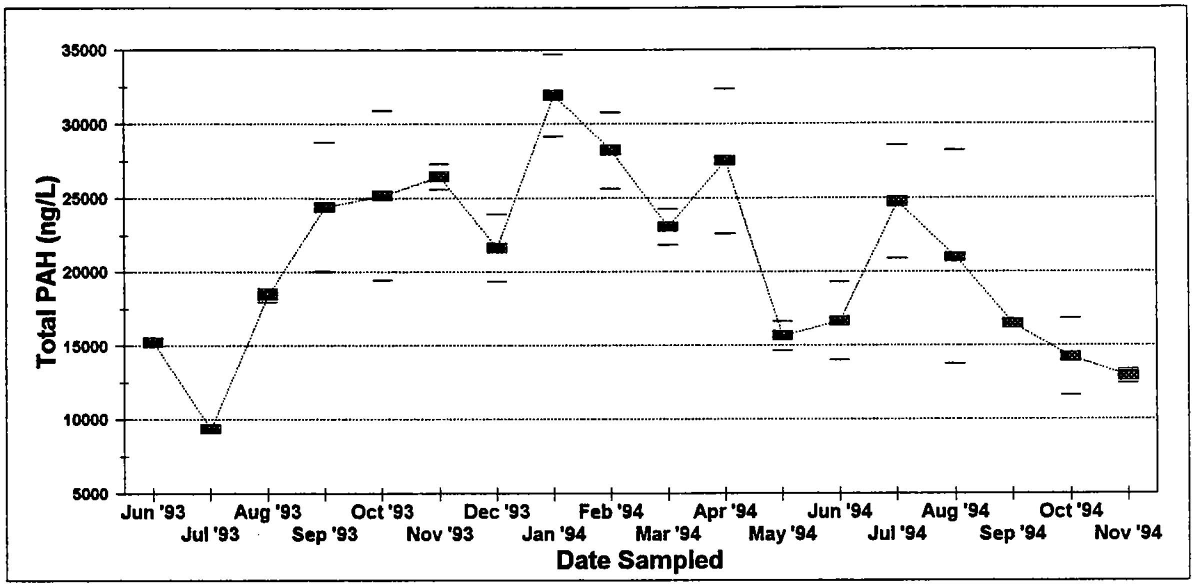


Figure 3. Deer Island flow rates on the days that the effluent samples were collected.



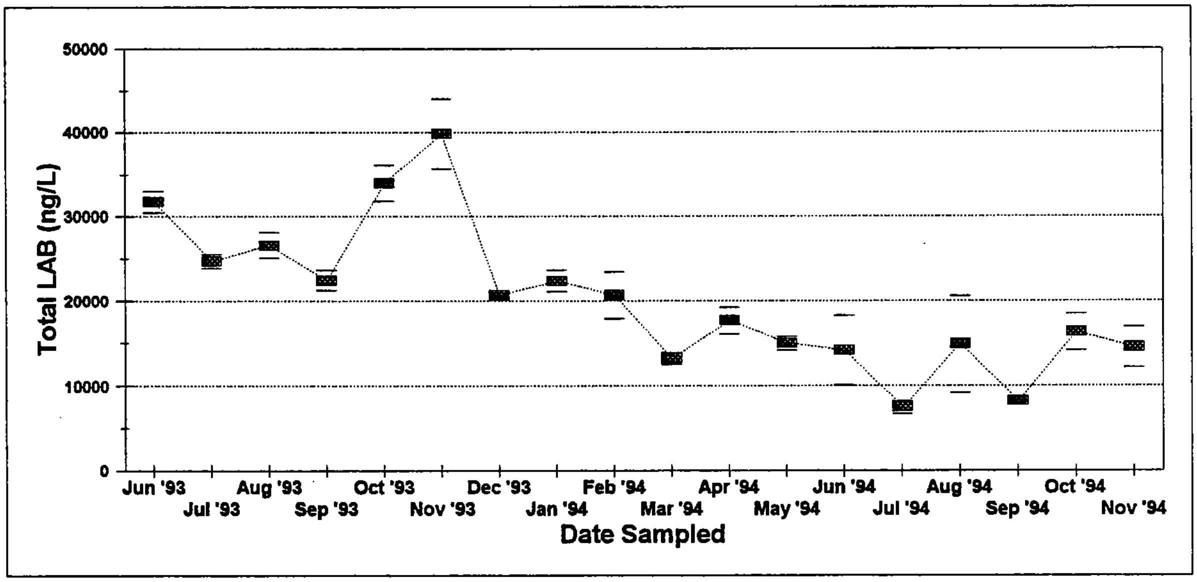


**Figure 4.** Temporal response in PAH (upper) and LAB (lower) concentrations in Deer Island effluent from June 1993 to November 1994. Mean concentration (rectangle) and the range of concentrations between the two sampling days for each month are shown.

The highest total PAH concentrations were measured in January and February 1994, averaging 30 μg/L. During the first nine sampling events (*i.e.*, June 1993 through February 1994), variability in PAH concentrations was more pronounced than during the second nine months (March–November 1994). Despite variabilities in concentration, the distribution of the individual PAH compounds was relatively consistent between samples (Figure 5). In each case, the low-molecular-weight petrogenic PAHs dominate the distribution. The presence of these compounds in the effluent is probably related to the input of refined fuel products. The major pyrogenic PAHs are also present in the effluent, but at lower concentrations.

To help distinguish differences in analyte distribution among the samples, PAH data were subjected to PCA. PAH data for a variety of fuel products were included with the effluent data to determine whether the analyte distributions for the field samples resembled the distributions for common fuel products. To minimize variability based solely on differences in concentration, all data were normalized to the analyte having the highest concentration in each sample. The PCA analysis of PAHs separated the samples into two distinct clusters (Figure 6). Some seasonal variability was detected in these analyses, including the separation of the 1993 October and the 1993 and 1994 November samples from most of the other data points. Additionally, the August/September/October samples generally fall along the periphery of the tightly clustered group of samples. Subtle differences in analyte distributions may be caused by variations in input to the system which may be related to seasonal lifestyle changes. The petroleum products most closely related to the samples are all representative of mid range distillates (e.g., fuel oil, fuel oil #2 and #4, residual fuel oil, and marine diesel fuel).

***LABs*** — LABs are precursors used in the production of linear alkylbenzene sulphonate surfactants (LAS), common in domestic detergents (Eganhouse *et al.*, 1983; Takada and Ishiwatari, 1990; Takada and Ishiwatari, 1991. Unreacted LABs remain in the detergent product as impurities or result from desulfonation of LAS. LASs are easily oxidized and, therefore, do not persist in the environment. Because LABs are more resistant to oxidation, they are used as a chemical tracer for domestic wastes. Total LAB concentrations are presented in Figure 4. Like the PAHs, the first nine samples had higher concentrations of LABs than the last nine effluent samples collected. Although the concentrations varied over time, they ranged between a high of 40 μg/L in November 1993 to 7.5 μg/L in July 1994. Careful examination of the time trends suggests that LABs systematically

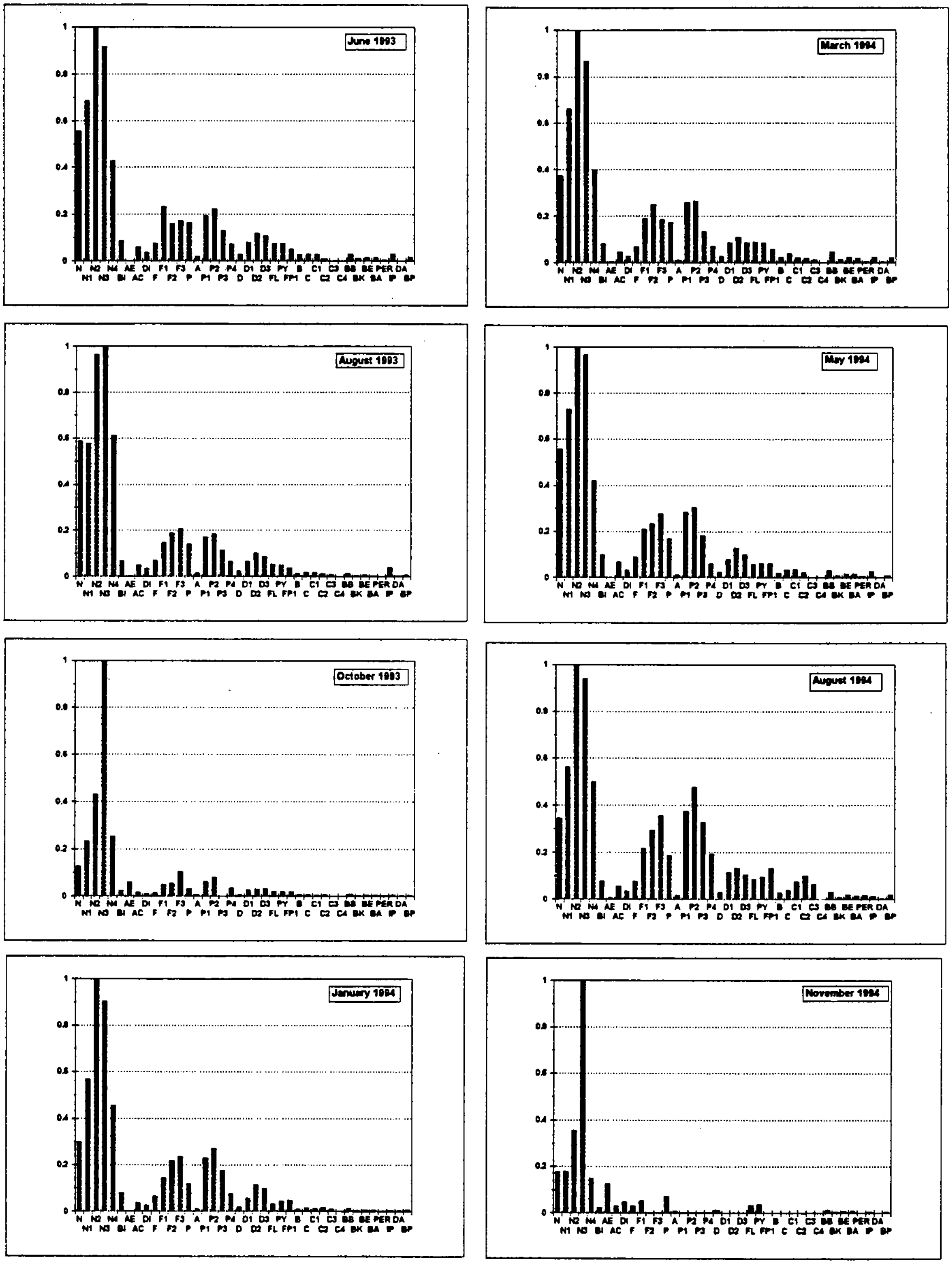


**Figure 5. Relative PAH distributions in selected effluent samples. Data is normalized to the compound of highest concentration in each sample. The compound names in order of presentation are:** **Naphthalene (N), $C_1$-naphthalenes (N1), $C_2$-naphthalenes (N2), $C_3$-naphthalenes (N3), $C_4$-naphthalenes (N4), Biphenyl (DI), Acenaphthylene (AE), Acenaphthene (AC), Fluorene (F), C1-fluorenes (F1), $C_2$-fluorenes (F2), $C_2$-fluorenes (F2), $C_3$-fluorenes (F3), Phenanthrene (P), Anthracene (A), $C_1$-phenanthrene/anthracenes (P1), $C_2$-phenanthrene/anthracenes (P2), $C_3$-phenanthrene/anthracenes (P3), $C_4$-phenanthrene/anthracenes (P4), Fluoranthene (FL), Pyrene (PY), $C_1$-fluoranthene/pyrene (FP1), Dibenzothiophene (D), C1-dibenzothiophenes (D1), $C_2$-dibenzothiophenes (D2), $C_3$-dibenzothiophenes (D3), $C_4$-dibenzothiophenes (D4), Benz[*a*]anthracene (B), Chrysene (C), $C_1$-chrysenes (C1), $C_2$-chrysenes (C2), $C_3$-chrysenes (C3), C4-chrysenes (C4), Benzo[*b*]fluoranthene (BB), Benzo[*k*]fluoranthene (BK), Benzo[*e*]pyrene (BE), Benzo[*a*]pyrene (BA), Perylene (PER), Indeno[1,2,3-*c,d*]pyrene (IP), Dibenz[*a,h*]anthracene (DA), Benzo[*g,h,i*]perylene (BP).**

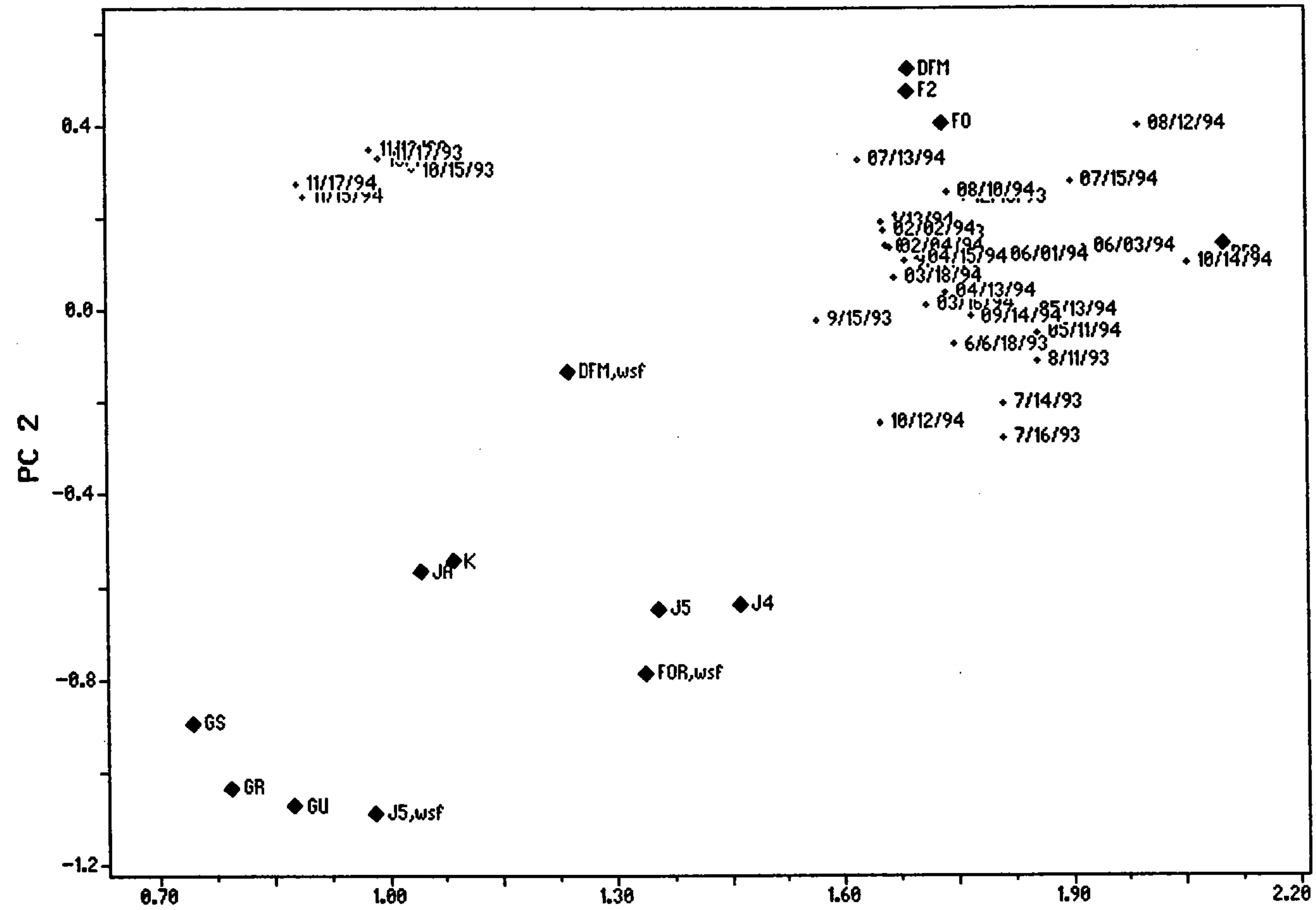


**Figure 6.** **Principal components analysis (PCA) of PAHs in Deer Island effluents and common fuel products.**
Key to fuel product abbreviations: jet fuel A (JA), jet propulsion 4 (J4), jet propulsion 5 (J5), kerosene (K), regular gasoline (GR), unleaded gasoline (GU), premium gasoline (GS), fuel oil (FO), residual fuel oil (RFO), diesel fuel marine (DFM), fuel oil #2 (F2), water soluble fraction of jet propulsion 5 (J5,wsf), water soluble fraction of reclaimed fuel oil (FOR,wsf), water soluble fraction of diesel fuel marine (DFM,wsf).

decreased from about 30 μg/L in mid 1993 to 10–15 μg/L in mid 1994. The concentrations of LABs remained relatively constant over the last half of 1994 (Figure 7).

*Chlorinated Pesticides* — Although the target chlorinated pesticides have been banned in the United States, they are still persistent in the environment, entering waste streams as a result of illegal use or chronic release from old deposits. Figure 8 shows the concentrations of selected chlorinated pesticides in the effluent during the sampling period. Except for May and June 1994 samples, which averaged ~50 ng/L, concentrations of total chlordane (heptachlor + heptachlorepoxide + cis-chlordane + transnonachlor) were relatively constant (<20 ng/L) throughout the sampling period. Concentrations of total DDT (the sum of parent and all breakdown products) ranged from 7 ng/L to 160 ng/L; the highest concentrations were detected in the summer/fall of 1994. During the summer/fall sampling period, the distribution of the individual DDT components changed such that a higher percentage of the total was comprised of the parent compounds 2,4'-DDT and 4,4'-DDT, suggesting that a fresh source of DDT was being introduced to the system. Low concentrations of the pesticide were detected in the November 1994 effluent samples. With the exception of a spike in the September 1994 sample, lindane concentrations were relatively constant, averaging 10–15 ng/L. Hexachlorobenzene was detected sporadically throughout the sampling program, with spikes in June and July 1993, October and November 1993, and September and October 1994.

As discussed previously, the very high dieldrin concentrations in the effluents in 1993 could not be confirmed on reanalysis. Thus, the average dieldrin concentrations in the effluent are much lower than previously reported. Confirmed concentrations in the effluent were generally <5 μg/L and frequently <2 μg/L (Figure 8). A clear seasonal signature was not evident due, in part, to the nondetectable results for several samples.

*PCBs* — This group of commercially produced compounds has a wide range of industrially desirable characteristics, including flame resistance, electrical properties, and chemical stability. Because of their unique properties, the demand for PCBs was once high, and they were manufactured and distributed in large quantities. Despite being banned 20 years ago, PCBs are still found in effluent streams. PCB formulations are made up of various combinations of 209 congeners (biphenyl molecule with chlorine atoms in different positions on the biphenyl rings).

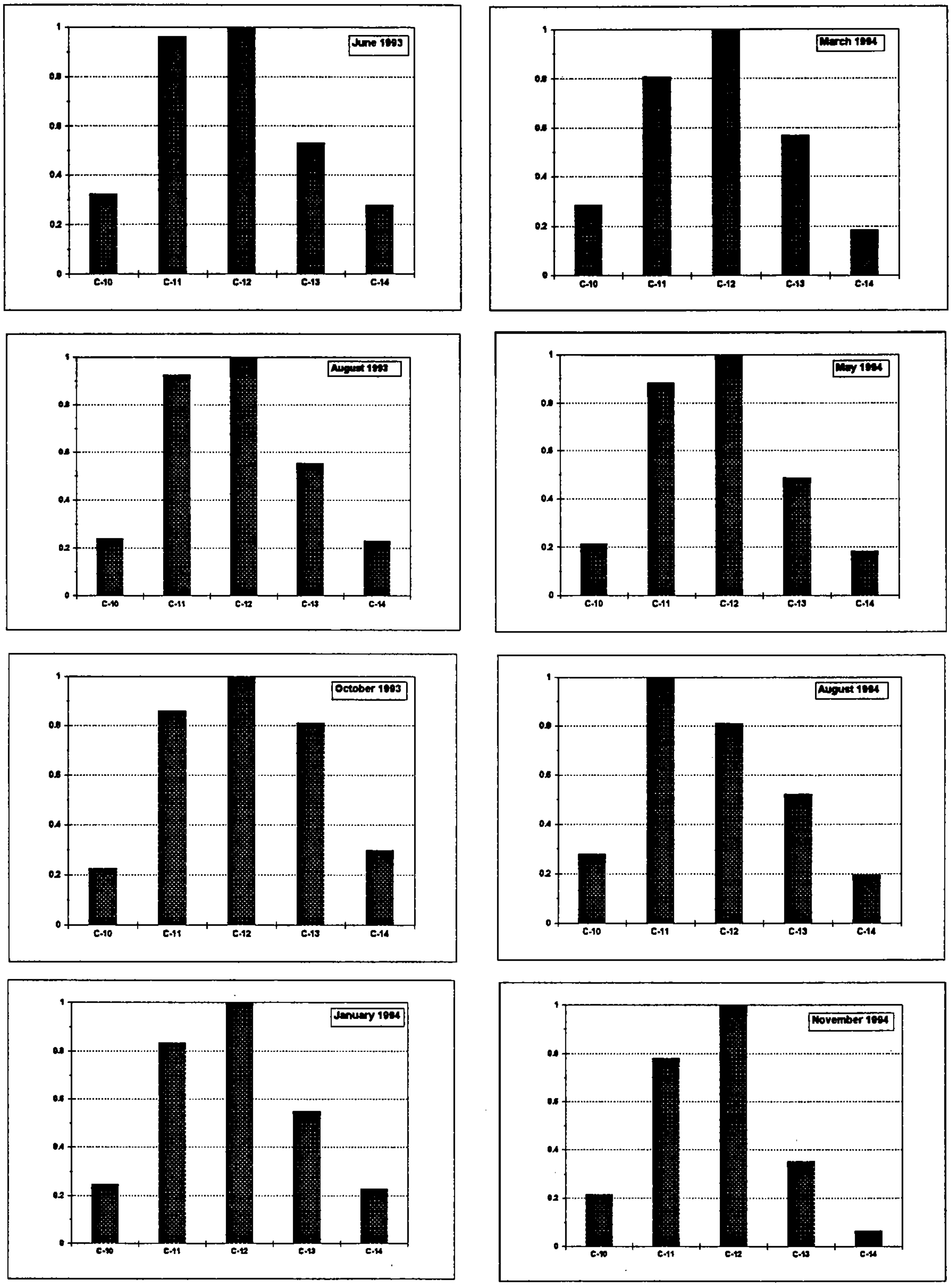


**Figure 7.** Relative LAB distributions in selected effluent samples. Data is normalized to the compound of highest concentration in each sample.

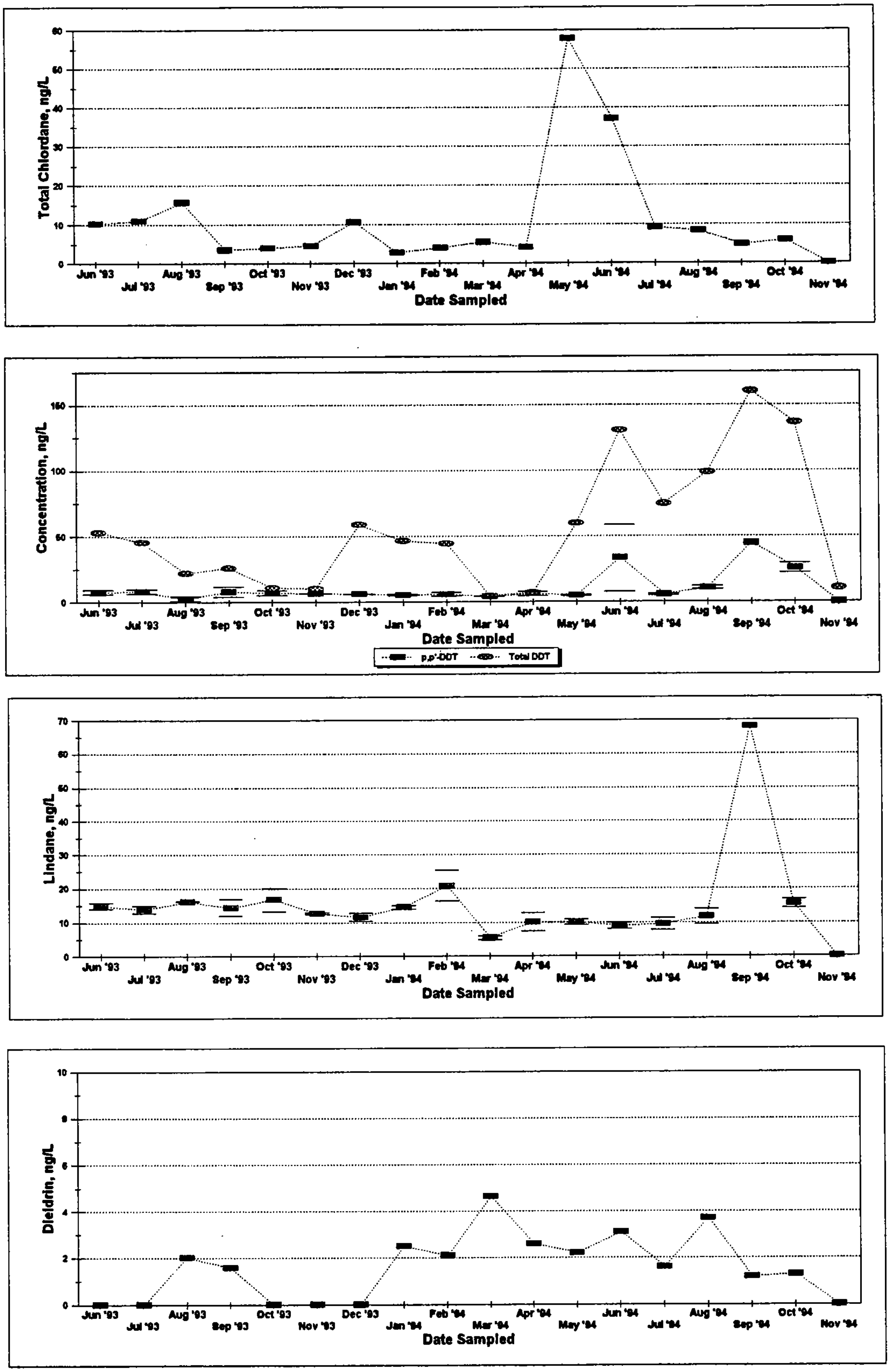


**Figure 8.** Temporal response in p,p'-DDT, lindane, and dieldrin concentrations in Deer Island effluent from June 1993 to November 1994. Mean concentration (solid symbols) and the range of concentrations between the two sampling days for each month are shown.

Twenty of these congeners were monitored in this effluent study — the same congeners monitored in the NOAA Status and Trends Program.

Total PCB concentrations (sum of 20 congeners) detected in the effluent samples are presented in Figure 9. Concentrations ranged from 20 to 110 ng/L, with the distribution generally favoring the more water-soluble compounds with lower levels of chlorination (Figure 10). The highest concentrations were detected in the summer/fall months while the lowest concentrations occurred in the winter/spring period.

### 3.1.3 Trace Metals

The concentrations of Ag, Cd, Cr, Cu, Hg, Mo, Ni, Pb, and Zn were measured in the Deer Island effluent because they not only reflect anthropogenic inputs and are metals of concern for the receiving waters, but they also represent different potential natural, industrial, and municipal sources to the waste stream or may be used as relatively unique tracers of the effluent in the receiving waters (*e.g.*, Ag [Sanudo-Wllhelmy and Flegal, 1992; Bothner *et al.*, 1994]). Additionally, the U.S. EPA has established marine water quality criteria (acute and, in most cases, chronic) for these metals because of concern for potential ecological impacts due to chronic exposure to these metals.

The concentrations of each trace metal in the effluent stream were relatively constant during the 18-month sampling period (Figures 11a, 11b, and 11c). For each sampling month, the mean concentration for each two-day sampling event is depicted by the mid point of the bar. The bar represents the range (high to low) between the two measurements. During the 1993-1994 sampling period, the concentration ranges for each trace metal in the effluent were: 1.75–8.57 μg/L for Ag; 0.29–1.42 μg/L for Cd (a value of 8.7 μg/L was measured on 6/1/94, but is considered suspect as it is well outside of all other concentrations reported); 1.65–10.9 μg/L for Cr; 48–111 μg/L for Cu; 0.08–0.29 μg/L for Hg; 4.8–25 μg/L for Mo; 3.8–12 μg/L for Ni; 5.8–26 μg/L for Pb; and 67–136 μg/L for Zn. Comparison of the June 1, 1994 date for the two programs found wide disparity.

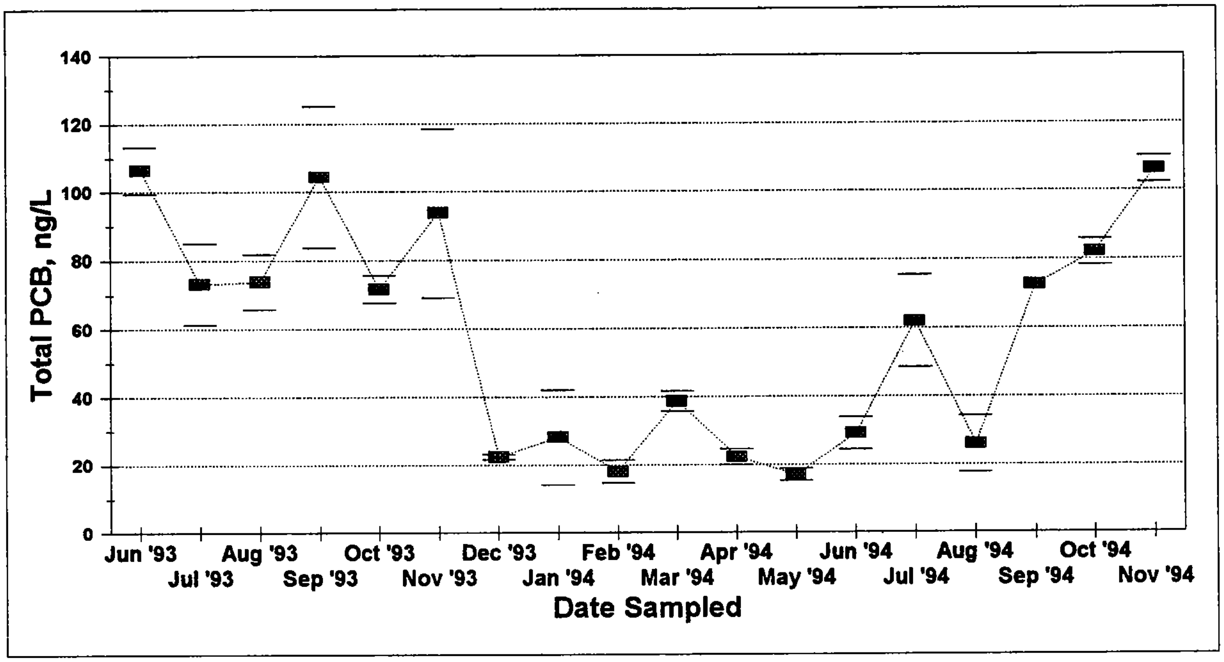


Figure 9. Temporal response in PCB concentrations in Deer Island effluent from June 1993 to November 1994. Mean concentration (rectangle) and the range of concentrations between the two sampling days for each month are shown.

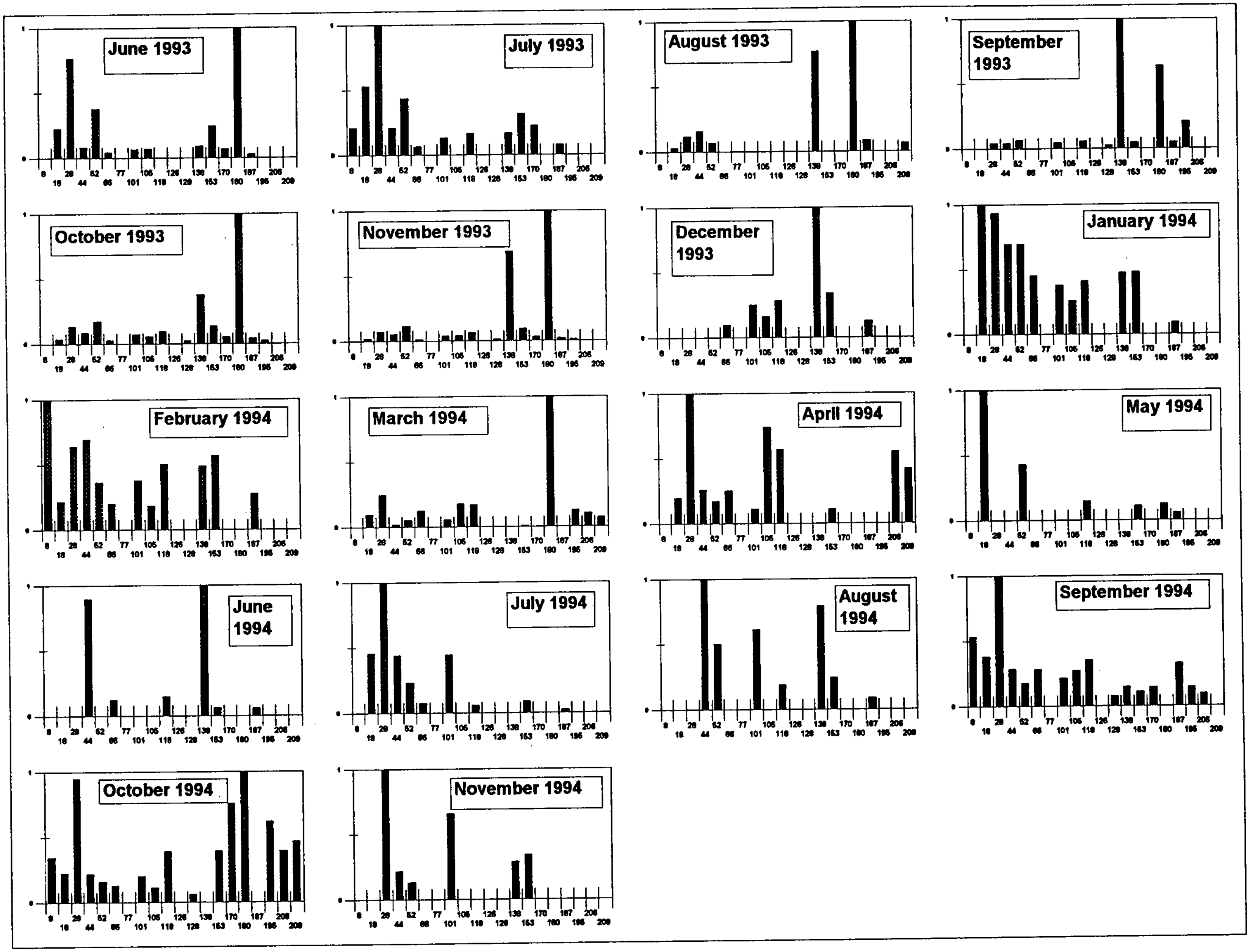


Figure 10. Relative PCB congener distributions in each effluent sample. Data is normalized to the congener of highest concentration in each sample.

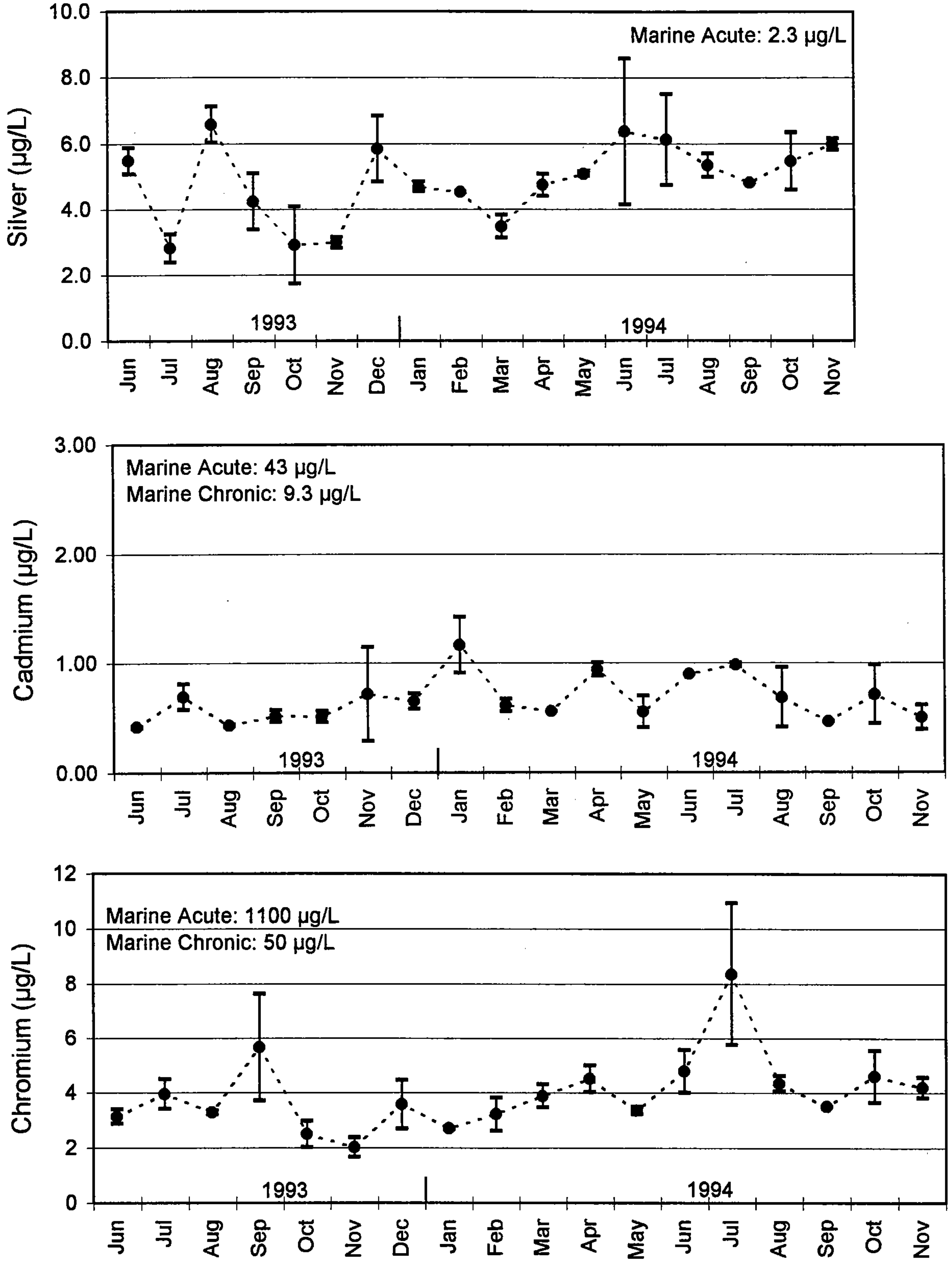


**Figure 11a.** **Temporal response in metals concentrations (Ag, Cd, Cr) in Deer Island effluent from June 1993 to November 1994. Mean concentration (solid symbol) and the range of concentrations between the two sampling days for each month are shown.**

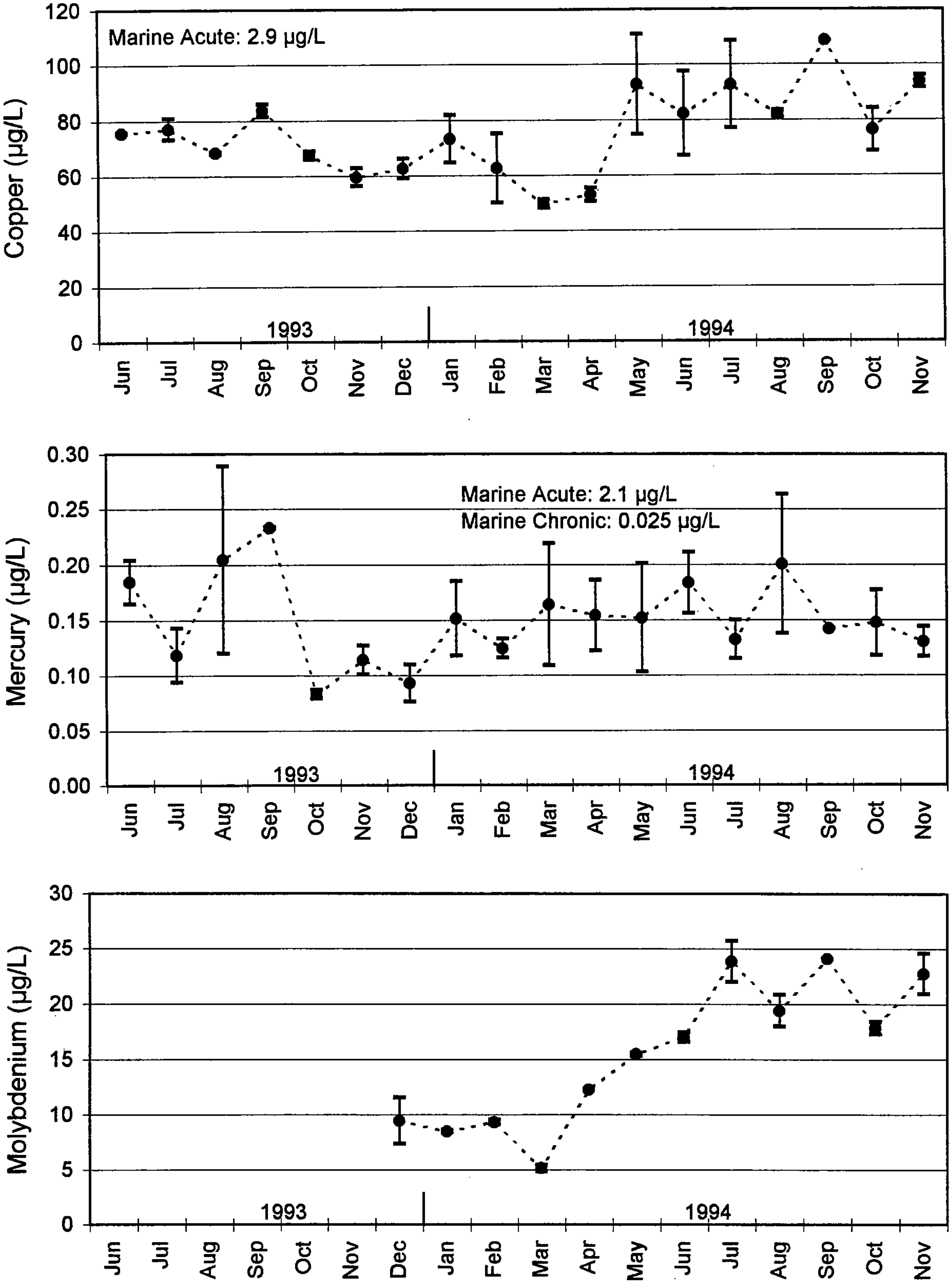


**Figure 11b.** Temporal response in metals concentrations (Cu, Hg, Mo) in Deer Island effluent from June 1993 to November 1994. Mean concentration (solid symbol) and the range of concentrations between the two sampling days for each month are shown.

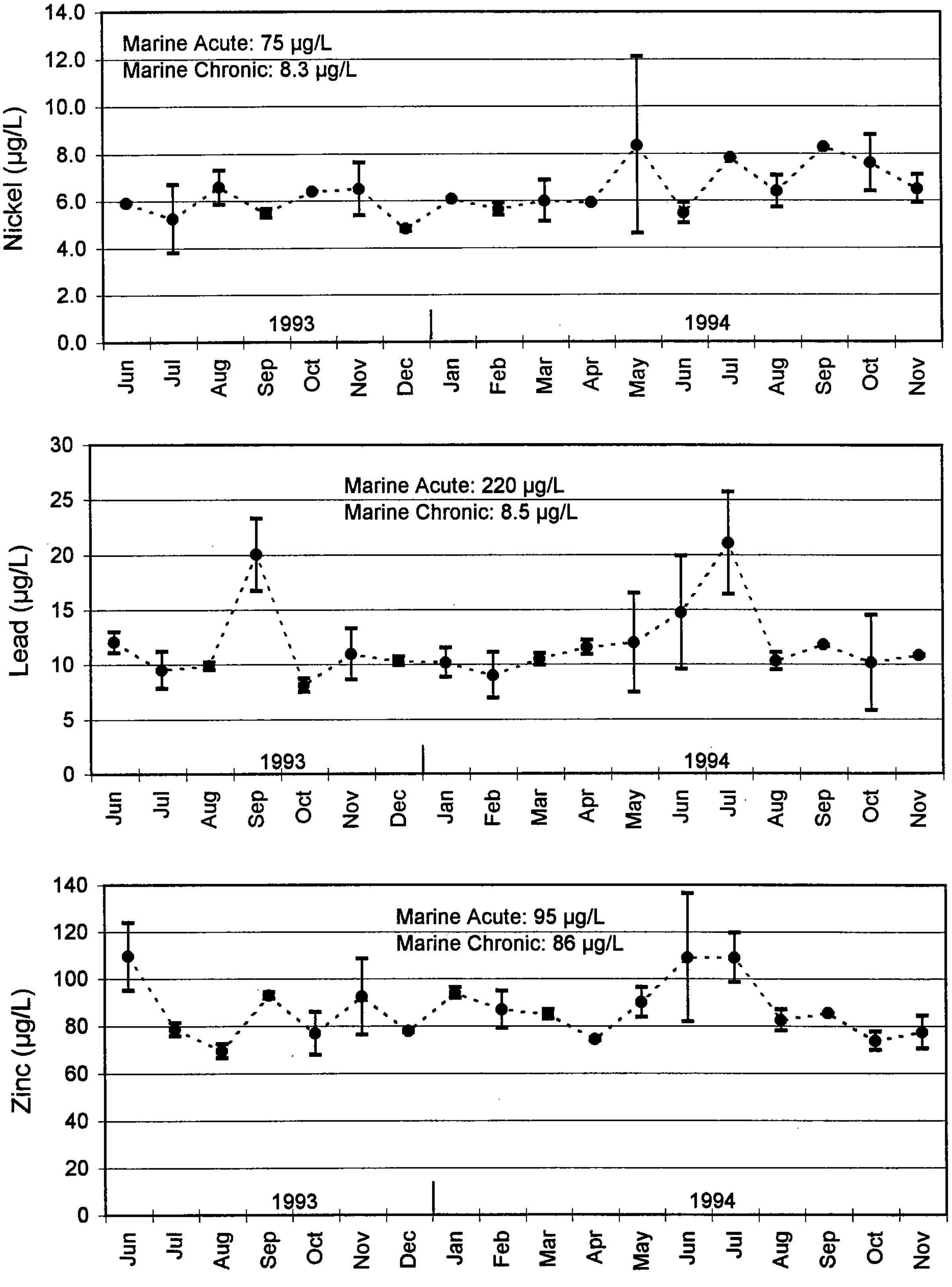


**Figure 11c.** Temporal response in metals concentrations (Ni, Pb, Zn) in Deer Island effluent from June 1993 to November 1994. Mean concentration (solid symbol) and the range of concentrations between the two sampling days for each month are shown.

No dramatic temporal trends were noted for any of the metals. However, concentrations of Cr and Cu appear to be slightly lower in the late fall and winter than in the summer. Between April and July 1994, Pb concentrations consistently increased; this trend was not evident in 1993. Concentrations of Mo in the effluent also increased consistently during 1994. Whether this represents a temporal trend or is part of a seasonal cycle can not be determined until more data are available. The observed concentrations may also be due to changes in the treatment plant operations or changes in discharge to the MWRA wastewater. Note that the summer/fall increase in Pb and Mo concentrations coincides with the lower flow rates during this period. Concentrations of Ni are fairly consistent during the sampling period but slightly higher concentrations were evident in 1994 relative to 1993.

As reported in Uhler *et al.* ( 1994), the concentrations of metals in the effluent are similar to concentrations measured in 23 effluents from the greater New York City area in 1992 (EPA, 1991) using comparable sampling methods, and "clean" processing and analysis procedures. Measured total recoverable values in the New York area in early 1991 ranged as follows across a variety of sewage treatment levels: 0.2–16 μg/L for Ag; 0.1–2.6 μg/L for Cd; 10–100 μg/L for Cu; <0.004-0.15 μg/L for Hg; 1–14 μg/L for Pb; 2–70 μg/L for Ni; and 15–175 μg/L for Zn.

### 3.1.4 Nutrients

The temporal trends for the various nutrient forms in the Deer Island primary effluent samples collected between December 1993 and November 1994 are considered in this section. Each major nutrient (nitrogen, phosphorus, silicate) plus organic carbon is discussed separately. The data represent the concentrations in the primary effluent prior to MWRA's conversion to the new Deer Island primary treatment plant in January 1995.

***Nitrogen*** — Total nitrogen (the sum of the particulate and total dissolved nitrogen) in the Deer Island primary effluent ranged between 740 and 1740 μM in the 24-hour composite samples (Figure 12). Differences in the total nitrogen concentration in the daily 24-hour composites samples collected three days apart generally varied from 25 μM to 350 μM. Such variability can be expected given the variability in the daily flows and nuances in the treatment process. Note that for three sample

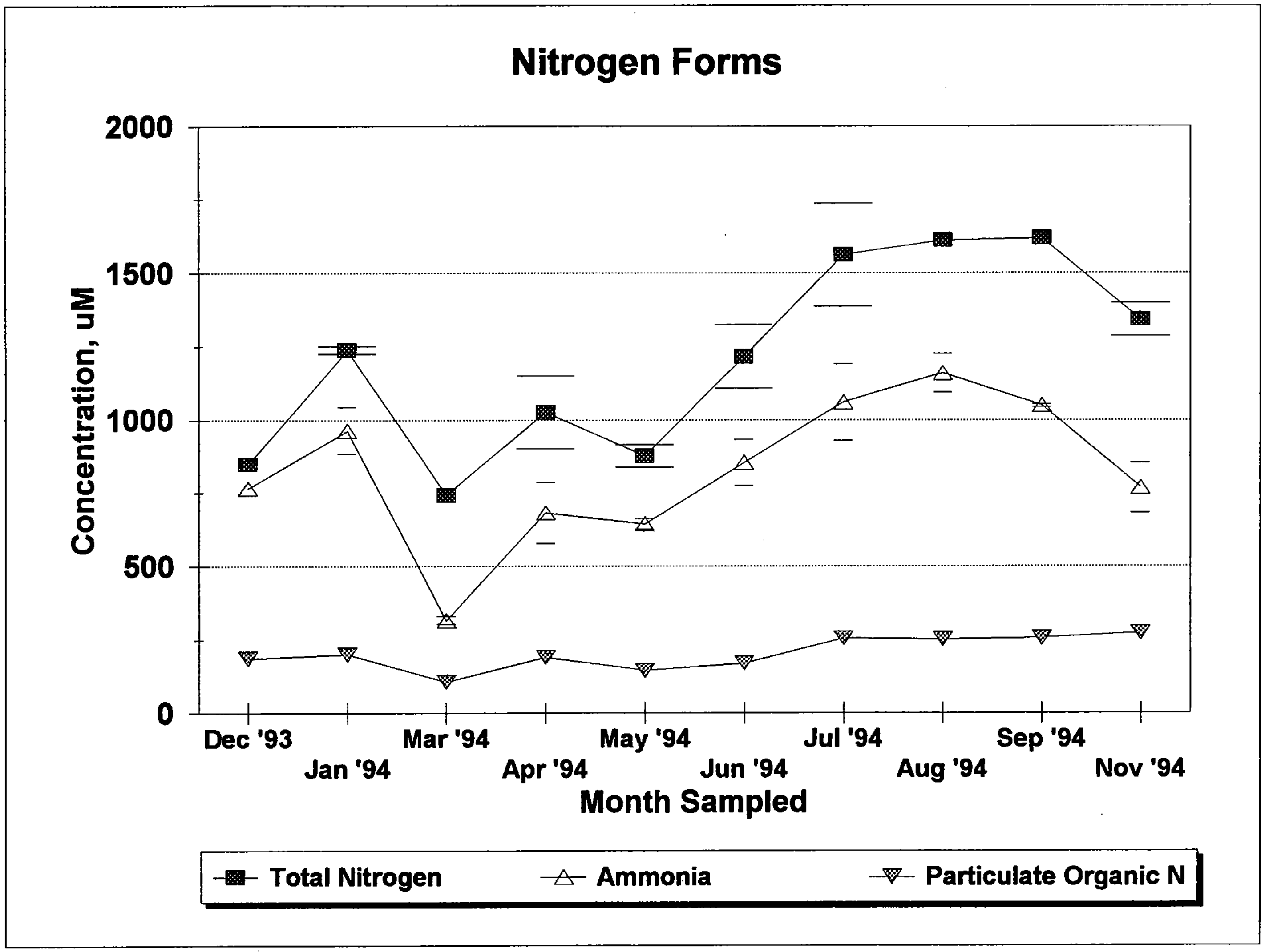


Figure 12. Temporal response in total nitrogen, ammonia, and particulate organic nitrogen concentrations in Deer Island effluent from December 1993 to November 1994. Mean concentration (symbol) and the range of concentrations between the two sampling days for each month are shown.

collection periods, data for a single sample are included in the data set because of failed collection, loss of samples during analysis, or suspected total dissolved nitrogen values.

Concentrations of total nitrogen in the effluent show a clear seasonal response. The winter/spring (December–May) concentrations, averaging 983 ± 182 μM, were lower than the summer/fall (June–November) concentrations which averaged 1433 ± 194 μM. This tend corresponds inversely with the flows measured in the winter and summer periods (see above).

Examination of the nitrogen forms comprising the total nitrogen concentration reveals that 50–70% of the nitrogen discharged in 1994 was in the form of ammonia (Figure 12). Concentrations of ammonia in the effluent ranged between ~300 and 1200 μM. The day-to-day and seasonal variability of ammonia was similar to the range for total nitrogen. Because of the large proportion (70–90%) of ammonia in the total dissolved nitrogen, the temporal variability of ammonia is similar to that for total dissolved nitrogen (Figure 13). Clear seasonal differences can also be noted in the ammonia data; the average summer concentrations (970± 174 μM) were higher than the average winter concentrations (664 ± 228 μM).

Concentrations of particulate organic nitrogen in the Deer Island effluent ranged between 180 and 300 μM (Figure 12). Concentrations of particulate nitrogen increased over the year (~100 to ~250 μM) and averaged 200 ± 55 μM. Concentrations measured during the winter/spring period averaged 162 ± 228 μM compared to 239 ± 41 μM during the summer. Particulate organic nitrogen contributed 14-21% of the total nitrogen in the effluent.

The concentration of nitrate + nitrite (Figure 13) in the effluent was low (<25 μM), except in March when these nitrogen forms contributed ~125 μM to the nitrogen in the effluent. This high concentration of nitrate + nitrate was associated with a distinctly low concentration of ammonia relative to the other sampling months. The summer/fall nitrate + nitrite concentrations, consistently ranging between 3 and 9 μM, were lower than concentrations measured during the winter. The winter/spring concentrations averaged 40 ± 45 μM and the summer/fall concentrations averaged 5.9 ± 1.7 μM. The high winter/spring nitrate + nitrite concentrations are primarily due to the March peak, although the other samples measured during this period are clearly higher than during the latter part of the year.

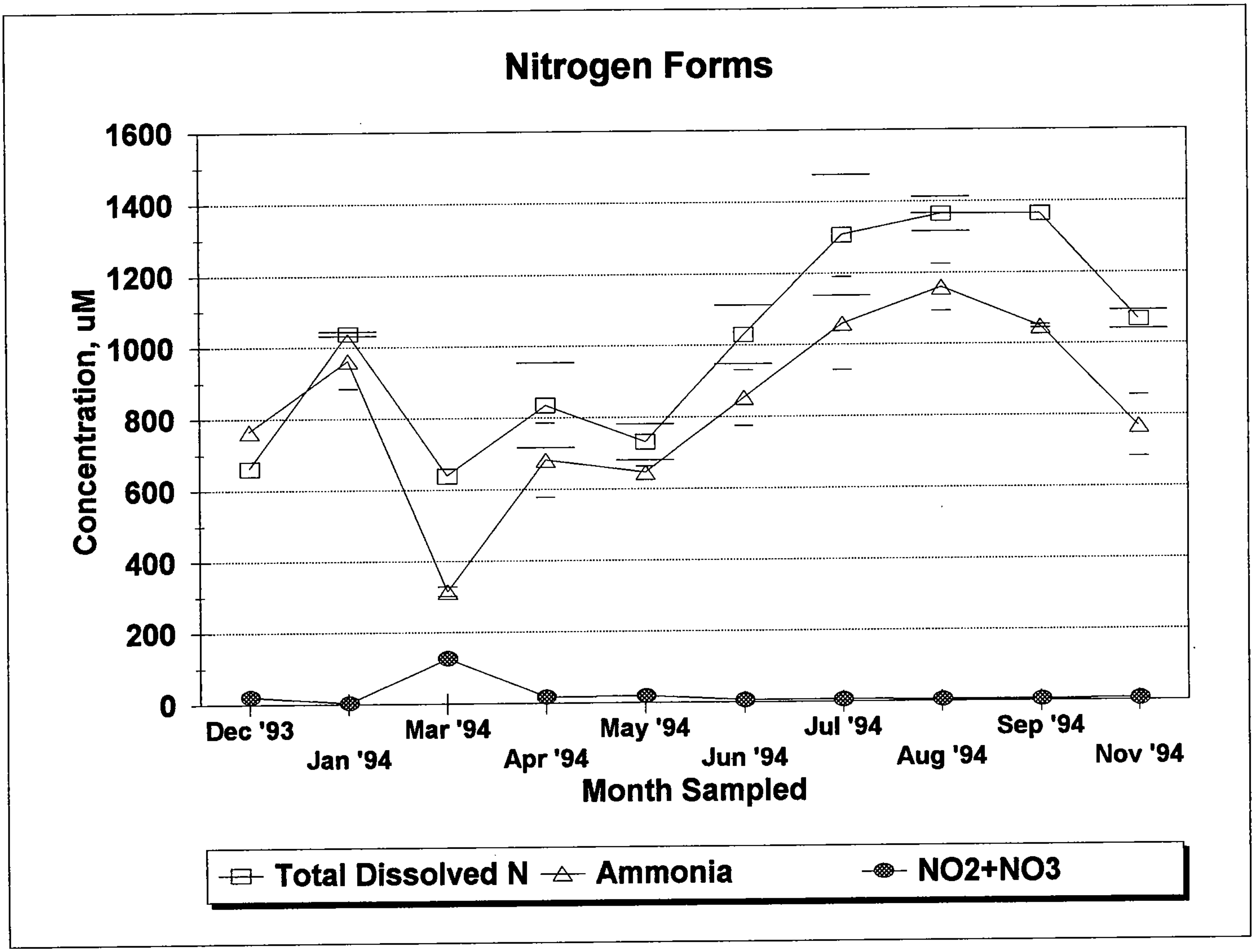


Figure 13. Temporal response in total dissolved nitrogen, ammonia, and nitrate plus nitrite concentrations in Deer Island effluent from December 1993 to November 1994. Mean concentration (symbol) and the range of concentrations between the two sampling days for each month are shown.

Alber and Chan (1994) summarized recent data on total Kjeldahl nitrogen (TKN) in the effluents from the Deer Island and Nut Island sewage treatment facilities. TKN measures organic nitrogen plus ammonia. Alber and Chan reported that the average 1993 TKN and ammonia concentrations in the Deer Island effluent were 1593 ± 278 and 682 ± 176 $\mu$M, respectively. The sum of the nitrate + nitrite was 53 ± 40 $\mu$M (conversion from mg/L to $\mu$M assumes that the results are reported as nitrogen). This average encompasses the range of concentrations measured in 1994, although the 1994 results appear to be low relative to the 1993 data. Statistical comparisons of these data sets were not conducted due to the limited number ($n$=6) of samples reported by Alber and Chan, because of differences in analytical methods used to estimate total nitrogen concentrations, and due to the seasonal nature of the 1994 concentrations. Alber and Chan's data suggest that ammonia constitutes approximately 43% of the total nitrogen discharged, while the 1994 data suggest that ammonia contributes a slightly higher fraction (50–70%) of the total nitrogen discharged from Deer Island. This difference may again be related to the analytical methods or to operational nuances at the treatment facility.

***Phosphorus*** — Total phosphorus concentrations in the Deer Island effluent (Figure 14) display a seasonal pattern similar to that discussed above for nitrogen (*i.e.*, higher in the summer/fall than in the winter/spring). Note that there is a steady increase in the total and dissolved phosphorus concentrations that characterize the second half of 1994. There is no indication in the data that the concentrations will return to those measured in late 1993 and early 1994. The reasons are not clear but, as in the case of nitrogen, the differences are probably related to different flows rates and possibly to the amount of runoff entering the collection system.

Because particulate phosphorus concentrations do not vary with season, they are consistent throughout the year. The summer/fall increase in total phosphorus is entirely due to dissolved forms of this nutrient. Inorganic phosphate comprises ~50% of the total dissolved phosphorus, a finding that is particularly evident during the summer and fall. Dissolved phosphorus in the effluent during the winter/spring period was ~60–75% of the total phosphorus concentration and was dominated by inorganic phosphate. A clear decrease in the contribution of inorganic phosphate to the dissolved phosphorus concentrations is evident in the summer/fall period - organic forms increase. This decrease can be attributed to an increase in the dissolved organic phosphorus concentrations as determined from the difference between total dissolved phosphorus and phosphate.

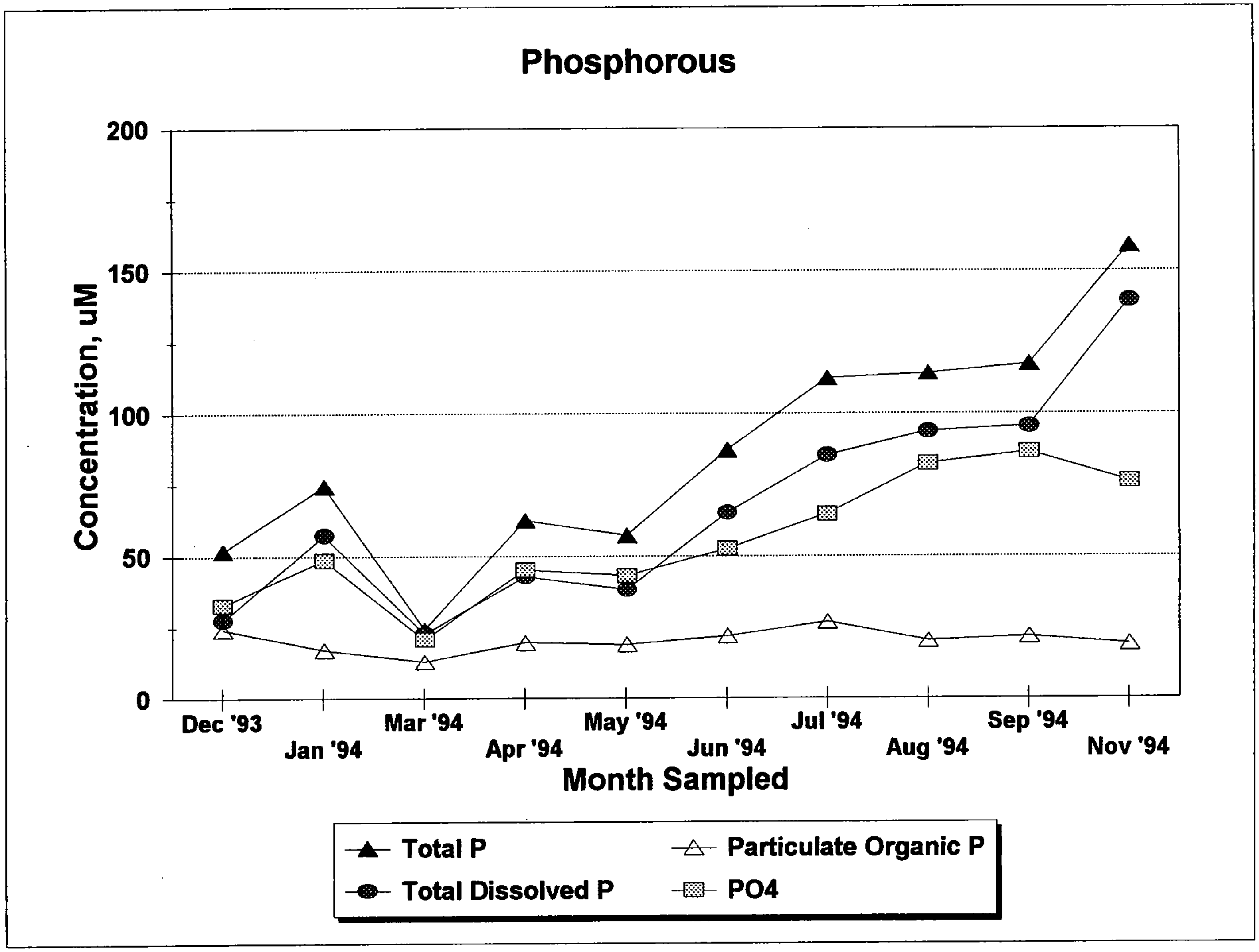


Figure 14. Temporal response in total phosphorous, total dissolved phosphorous, phosphate, and particulate phosphorous concentrations in Deer Island effluent from December 1993 to November 1994. Mean concentration (symbol) and the range of concentrations between the two sampling days for each month are shown.

Total phosphorus concentrations in the effluent ranged from 14 to 227 μM. The average total phosphorus concentration (86 ± 45 μM ) in 1994 was slightly less than the 1993 average concentration (116 ± 36 μM) reported by Alber and Chan (1994). The average total phosphorus concentrations were 54 ± 19 and 118 ± 41 μM for the winter/spring and summer/fall periods, respectively. In March, the total phosphorus concentration was significantly lower and corresponds to the lower ammonia and higher nitrate + nitrite concentrations that were also observed. The reasons for this are not clear but could relate to excess runoff. Flow rates were high in the days immediately preceding the sampling (Figure 2) and could be associated with storms or spring melt of the record snowfall experienced in New England during the winter of 1993/1994.

In 1994, phosphate concentrations in the Deer Island effluent ranged between 220and 88 μM (average = 55 ± 20 μM) and compared favorably with the 1993 average concentrations (67 ± 25 μM) reported by Alber and Chan (1994). The average phosphate concentration reported by Alber and Chan is similar to the 1994 summer/fall concentrations (71 ± 12 μM) which were about 50% of the average winter/spring concentration (39 ± 11μM).

***Silicate*** — In the effluent, the biologically available forms of silica, which include dissolved silica and biogenic particulate silica, were dominated by dissolved Si (92–96% of the total biologically available silicate). The concentration differences over the close spaced sampling periods differed by only a few μM. Concentrations of dissolved Si (Figure 15) in the effluent were relatively constant (110–175 μM) over the course of the year which is consistent with the concept that Si is more closely associated with the source water than with the sewage component of the effluent. The average dissolved Si concentration was 151 ± 21 μM. In contrast to nitrogen and phosphorus nutrients, dissolved silica concentrations decreased in the summer/fall period (143 ± 17 μM) relative to the winter/spring period 158 ± 8 μM, respectively). Biogenic silica ranged between 4 and 21 μM, with an annual average of 7.1 ± 3.8 μM. Little seasonal difference was noted (6.6 ± 1.8 μM in the summer/fall versus 7.6 ± 4.9 μM in the winter/spring) although the variability in the winter/spring period was greater.

***Organic Carbon*** — The seasonal variability of the dissolved, particulate, and total (sum of dissolved and particulate) organic carbon concentrations (Figure 16) was similar to that of nitrogen (*i.e.*, lower in the winter/spring relative to the summer/fall). Variability within the closely spaced sample

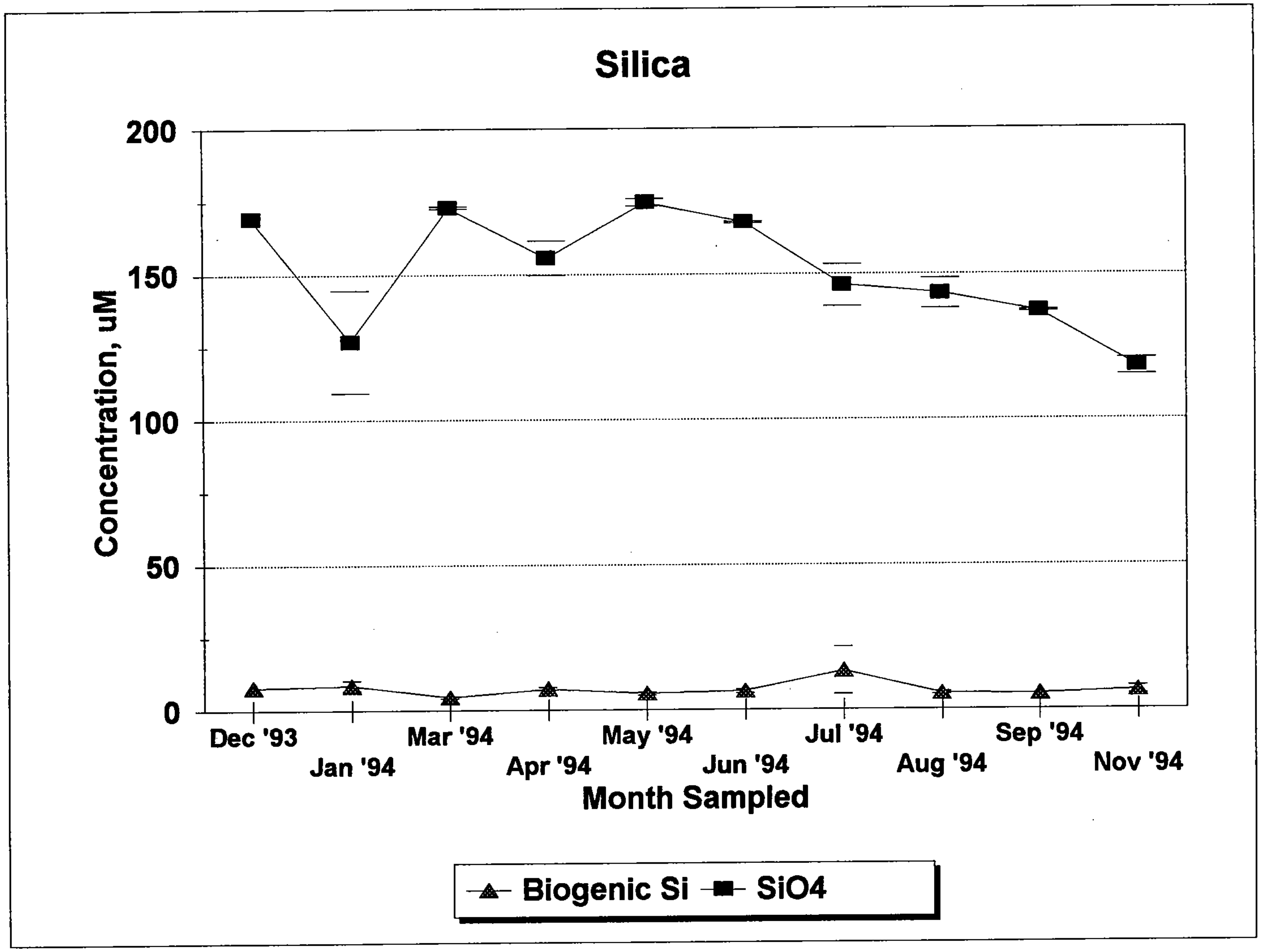


Figure 15. Temporal response in dissolved and biogenic silica in Deer Island effluent from December 1993 to November 1994. Mean concentration (symbol) and the range of concentrations between the two sampling days for each month are shown.

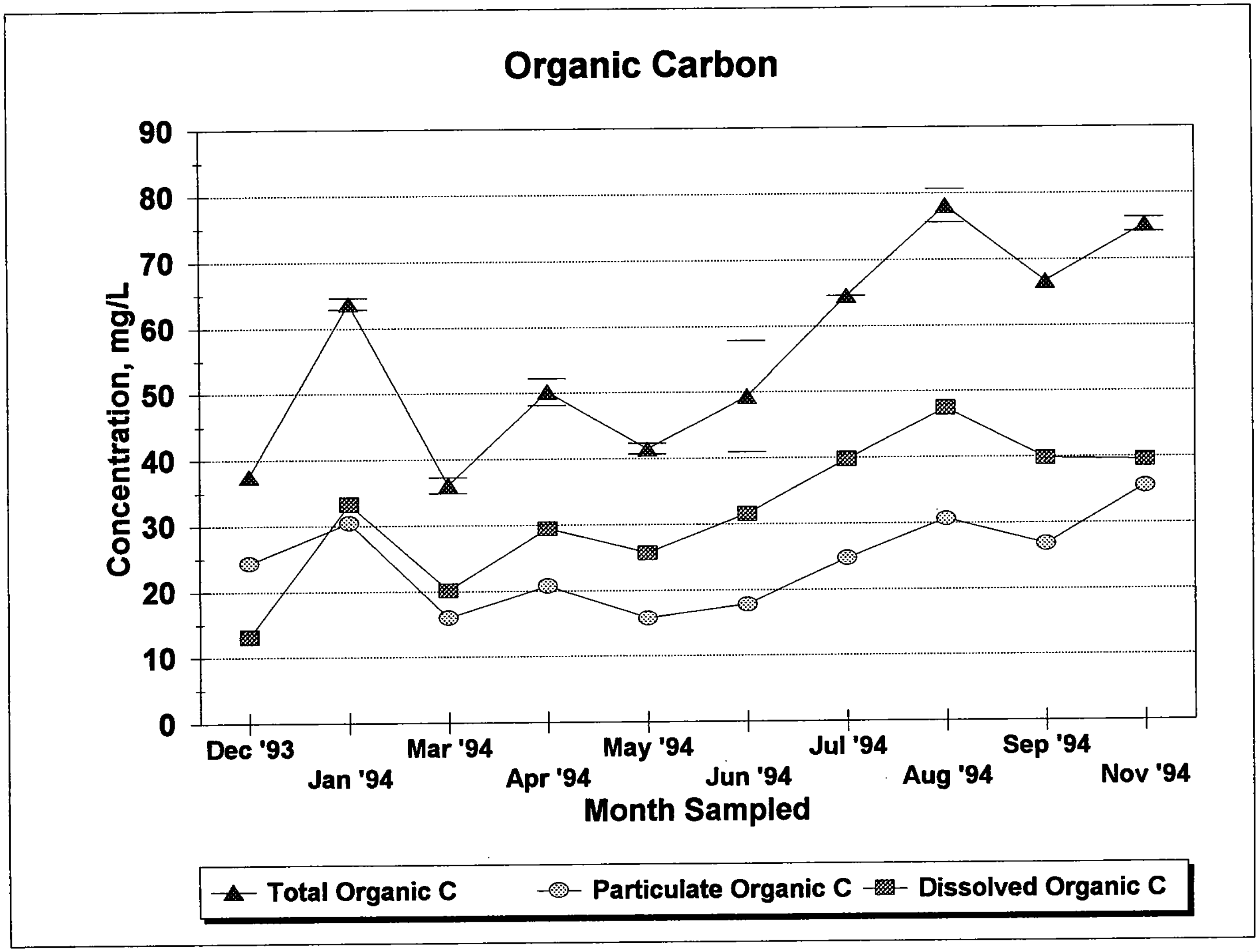


Figure 16. Temporal response in dissolved and particulate organic carbon concentrations in Deer Island effluent from December 1993 to November 1994. Mean concentration (symbol) and the range of concentrations between the two sampling days for each month are shown.

collections was generally <15 μM. Concentrations of total organic carbon in the effluent ranged between 35 and 80 mg/L throughout the year. In 1994, concentrations of dissolved and particulate organic carbon averaged 57 ± 15 and 24 ± 7 mg/L, respectively. Seasonally, the particulate organic carbon respectively averaged 21.1 ± 5.8 and 27.2 ± 6.4 mg/L in the winter/spring and summer/fall periods, while the dissolved organic carbon averaged 25.6 ± 6.4 and 39.6 ± 6.2 mg/L, respectively, in the winter/spring and summer/fall. As the indicated by these average concentrations, the dissolved component of the total organic carbon concentrations was generally higher than the particulate fraction. During the summer/fall period, the contribution of dissolved organic carbon increased relative to the total concentration.

*Nutrient Ratios* — The molar ratio of total nitrogen to total phosphorous (TN/TP) and dissolved inorganic nitrogen (DIN)/$PO_4$ during the year (Table 5) was close to the expected Redfield ratio (16). A high total nutrient ratio (TN/TP) was obtained for the March samples and high dissolved phase ratio (DIN/$PO_4$) was calculated for the December 1993 through March 1994 samples. Lower values were obtained for the summer/fall period and the lowest ratios were for the November 1994 samples. The deviations from the Redfield ratio may be due to typical seasonal responses or related to changing flow rates and runoff.

*Seasonal Changes in Sources to the MWRA Water Collection System* — If it is assumed that the concentrations of nutrients and contaminants in the major sewage sources are relatively constant throughout the year and that the treatment plant operates with the same efficiency year-round, the lower winter/spring concentrations of nitrogen, phosphorus, and organic carbon suggest that the sewage load entering the system in the winter is diluted with water that contains low concentrations of these nutrients. Conversely, the higher concentrations in the summer/fall suggest that the amount of low-nutrient water entering the system decreases. This supposition is supported by the lower effluent flow rates in the summer. The response of Si is the inverse of the other nutrients (*i.e.*, high in winter and low in summer), suggesting that this nutrient is not linked to the sewage input but rather to sources of water that contain higher silicate concentrations in the winter than in the summer. This response is consistent with the influx of stormwater runoff and melting snow (the winter of 1994 was characterized by record snow fall). Thus, silicate in the system may be more influenced by sources other than sewage.

**Table 5. Molar ratio of total nitrogen (TN) to total phosphorous (TP) and dissolved inorganic nitrogen (DIN) to phosphate ($PO_4$) in the Deer Island primary effluent in 1994.**

| Month | TN/TP | DIN/$PO_4$ |
|---|---|---|
| December 1993 | 16.3 | 24 |
| January 1994 | 16.6 | 19.8 |
| March 1994 | 30.5 | 21.2 |
| April 1994 | 16.4 | 15.5 |
| May 1994 | 15.3 | 15.4 |
| June 1994 | 13.9 | 16.4 |
| July 1994 | 13.9 | 16.5 |
| August 1994 | 14.1 | 14.1 |
| September 1994 | 13.8 | 12.2 |
| Novemebr 1994 | 8.4 | 10.2 |

The supposition that the seasonal concentrations in the effluent can be explained by differences in flow rate can be further evaluated using the ratio of the average winter/spring (W/S) concentrations to the average summer/fall (S/F) concentrations in the effluent. The expectation from this calculation is that contaminants that respond strictly to seasonal changes in the flow would have ratios that are similar to the ratio of average seasonal flows. Thus, by comparing these ratios with the ratio of effluent flow for the same periods, information on the relative correspondence between the seasonal flow and measured concentrations can be realize. The assumption is that, if the contaminants are entering the system in association with the major flows, the ratios would be similar to the flow ratio as long as no other process or source was operating to add or remove contaminants disproportionately to the flow. If the ratios are different, then factors other than flow affect the concentrations including changing source types or strengths. Further, if concentrations are inversely related to flow (*i.e.*, higher concentrations with lower flows) and in the same proportion as the flow, the inference would be that the contaminant is not associated with the source responsible for decreased flows in the system. That is, a decrease in the water entering the system would reduce the dilution in the system and increase contaminant concentrations. Conversely, if flows decrease and concentrations also decrease, the contaminant is likely associated with the water source causing the lower flow.

Table 6 shows the ratio of the W/S and S/F periods for the major contaminants in the effluent. The flow ratios were about 1.5 for the 1994 sampling dates and 1.32 based on the daily flows from Deer Island. Comparing the contaminant rates to these flow ratios suggests that the seasonal differences in total nitrogen, total dissolved nitrogen, ammonia, particulate nitrogen, total organic carbon, particulate organic carbon, Cu, and Cr are inversely proportional to the flow differences. Thus, the seasonal variability in the concentrations of these parameters is strongly related to reductions in inflow of water that does not contain substantial concentrations of these contaminants (*i.e.*, water that dilutes the major sources of sewage is not present in the S/F period). For total PAHs, LABs, and lindane, the seasonal concentrations appear to be directly proportional to the flow changes. Thus, these compounds are probably associated with water that dilutes the other sewage-related contaminants rather than being more associated with the sewage sources. Furthermore, the fact that the PAH distributions are clearly petrogenic in nature suggests that street runoff is the likely source of these contaminants; this is consistent with the snow and rainfall patterns that characterized 1994.

**Table 6. Comparison of ratio of the average winter/spring (December to May) and summer/fall (June to November) contaminant concentrations in the Deer Island effluents between December 1993 and November 1994 to the ratio of effluent flow. Analytes that respond proportionately to the flows are highlighted.**

| Compound | WS/SF | SF/WS |
|---|---|---|
| Flow (Daily data) | 1.32 | 0.76 |
| Flow (Sample collections) | 1.42 | 0.7 |
| PAH | 1.39 | 0.73 |
| PCB | 0.27 | 3.74 |
| LAB | 1.45 | 0.69 |
| Chlordanes | 1.16 | 0.85 |
| Lindane | 1.33 | 0.75 |
| DDTs | 0.41 | 2.43 |
| Ag | 0.83 | 1.2 |
| Cd | 1.06 | 0.95 |
| Cu | 0.74 | 1.36 |
| Cr | 0.71 | 1.4 |
| Hg | 0.9 | 1.12 |
| Mo | 0.48 | 2.08 |
| Ni | 0.87 | 1.14 |
| Pb | 0.81 | 1.24 |
| Zn | 0.95 | 1.06 |
| Total N | 0.69 | 1.46 |
| Total dissolved N | 0.68 | 1.46 |
| $NH_4$ | 0.68 | 1.47 |
| $NO_2 + NO_3$ | 6.8 | 0.15 |
| Particulate organic N | 0.68 | 1.47 |
| Total P | 0.46 | 2.17 |
| Particulate P | 0.82 | 1.22 |
| Phosphate | 0.55 | 1.83 |
| Dissolved Si | 1.11 | 0.9 |
| DOC | 0.65 | 1.54 |
| POC | 0.77 | 1.3 |
| TOC | 0.7 | 1.43 |

The ratios for total phosphorus, DDT, chlordanes and PCBs indicate that the concentrations of these contaminants are higher in the summer relative to the effluent flow. These contaminants may be associated with fertilizer applications or pest control, or activities that are generally more common in the spring and summer months. Mo is another element that clearly has a higher ratio than the flow rates and, therefore, suggests sources other than sewage. Other analytes that do not respond in proportion to the flows are dissolved and biogenic Si, nitrate and nitrite, the metals Ag, Cd, Hg, Pb, and Zn.

Although not definitive, the analysis described above has the potential to determine whether contaminants in the effluent are associated with the major sewage inputs or are responding to other sources such as street runoff or other more concentrated seasonal sources such as pest control or lawn fertilization. The collection of high quality, low-detection-limit data will continue to provide the ability to identify significant effects of the flow rate on concentrations of contaminants, thus providing an additional diagnostic tool for identifying potential sources of contaminants and also for understanding the temporal response of the primary treated effluent discharged from Deer Island.

### 3.1.5 *Clostridium perfringens*

*Clostridium perfringens* is an obligate-anaerobic bacterium that naturally inhabits the intestines of man and other mammals, and is commonly associated with sewage wastes. Concentrations of *Clostridium perfringens* spores were measured in 19 Deer Island effluent samples collected between December 1993 and November 1994. This organism is useful as a sewage tracer because each cell produces a metabolically inactive endospore which can survive in a dormant state outside the intestine when conditions preclude bacterial growth. The spores are resistant to most wastewater chlorination procedures and can survive in aquatic environments for long periods of time (Bisson and Cabelli, 1979; Davis and Olivieri, 1984; Hirata *et al.*, 1991).

Concentrations of *C. perfringens* spores in the Deer Island effluent decreased from $\sim 4.0 \times 10^4$ per 100 mL in December 1993 to $\sim 1.0 \times 10^4$ per 100 mL in May 1994. Concentrations remained near the lower end of the range for the remainder of the study (Figure 17). The reason for the decrease is not clear because lower flow rates with an equal input of the spores would result in higher

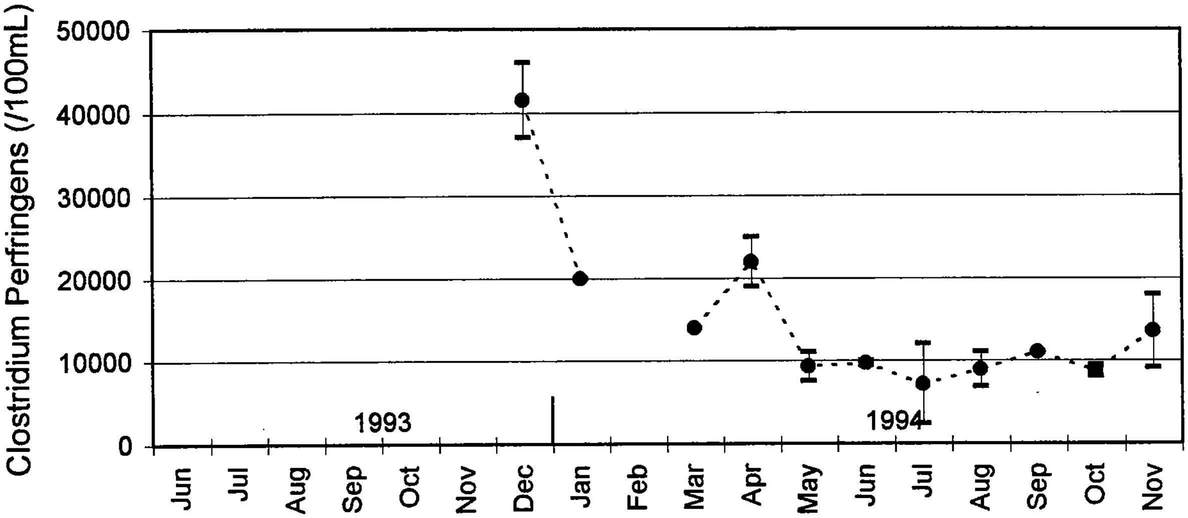


**Figure 17.** **Temporal response in *Clostridium perfringens* concentrations in Deer Island effluent from December 1993 to November 1994.**

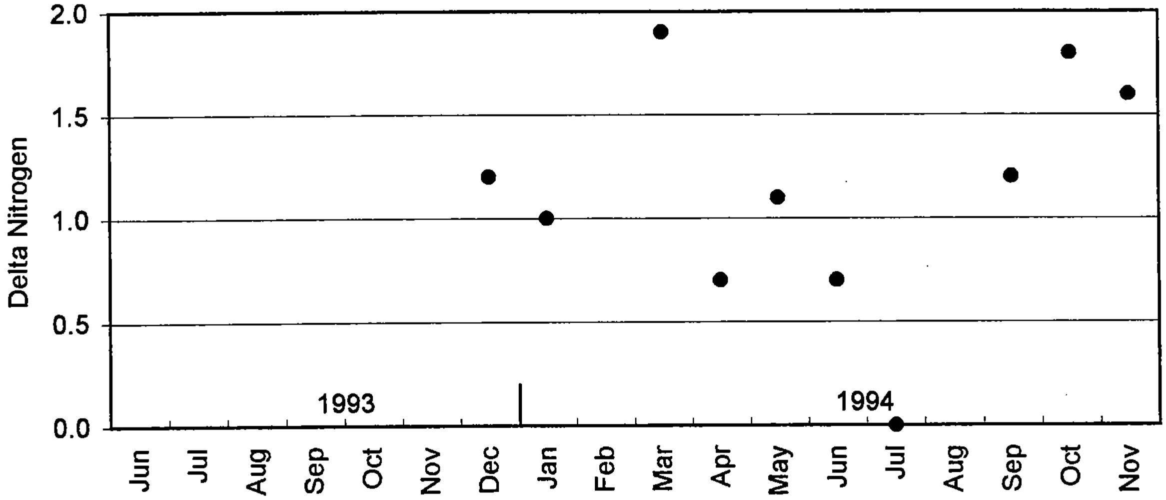
concentrations; no treatment plant improvements were completed and operational procedures remained essentially the same throughout the study period.

### 3.1.6 Stable Isotopes

*Nitrogen* — The stable nitrogen isotope ratio in the 10 samples of Deer Island effluent collected between December 1993 and November 1994 ranged between 0 and 1.9‰. Clear seasonal trends were not evident in the data. The average ratio — 1.12 ± 0.6‰ (Figure 18) — is only slightly higher than the $\delta^{15}N$ ratio for terrestrial materials, which is generally near 0‰, the ratio for atmospheric nitrogen (Peterson and Fry, 1987) and slightly lower than for marine organic matter (3.7 to 6.5‰) that sinks out of the euphotic zone (Altabet, 1988).

The nitrogen isotope ratios for 1994 Deer Island primary effluent samples are slightly less than those reported for particles in primary treated effluent discharged off the coast of southern California (Sweeney *et al.*, 1980); these ratios ranged from 2.0 to 3.0‰ and averaged 2.5‰. The ratio for the effluent is about three times lower than the nitrogen isotope ratio (3.3‰) reported for a single sludge sample collected from the Deer Island facility (Giblin *et al.*, 1992). The stable nitrogen isotope ratios for New York/New Jersey sludges sampled in 1991 ranged from 0.6 to 5.8‰ and averaged 3.4 ± 1.8‰ (Hunt *et al.*, 1993). Although most of the stable nitrogen isotope data available for comparison are from sludge materials, it is expected that the ratios for primary treated sludge would be similar to the ratio for the particulates remaining in the primary effluent because biological processes that can alter the ratios are not involved in the primary treatment. The fact that the 1994 ratios from the Deer Island plant are slightly lower than those from sludges may be indicative of differences in treatment or regional signatures in the source material of the sewage.

*Sulfur* — Three (March, June, and November) of the ten stable isotope samples collected from the Deer Island primary effluent in 1994 were too small to provide useful data. Sulfur stable isotope ratios ranged from 4.5 to 8.4‰ and averaged 5.8 ± 1.3‰ in 1994 (Figure 18). These values are consistent with the sulfur isotopes ratios for terrestrial vegetation; these ratios average between +2 and +6‰, and are distinct from ratios for marine plankton and algae which range between +17 and +21‰ (Peterson and Fry, 1987). The Deer Island primary effluent particles are slightly more



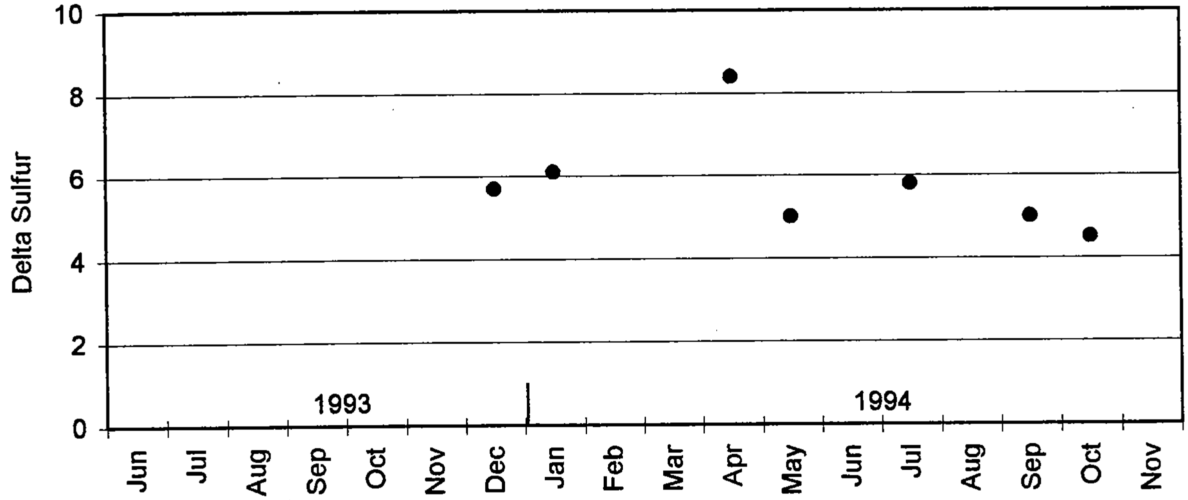


**Figure 18.** Temporal response in stable nitrogen (upper) and sulfur (lower) isotope ratios in Deer Island effluent particles from December 1993 to November 1994.

enriched in $\delta^{34}S$ than southern California sludge particles measured in the early 1980s (four samples of primary treated sludge ranged between -0.2 and +0.1 [Sweeney and Kaplan, 1980]) and also 1991 New York/New Jersey sludge samples in which sulfur stable isotope ratios ranged from 1.9 to 5.5‰, and averaged 3.2 ± 1.1‰ (Hunt *et al.*, 1993).

The clear separation of the sulfur isotope ratios for the effluent particles from the marine ratios make this isotope ratio a strong candidate for tracing the effluent discharge in Massachusetts Bay. The isotope ratio of nitrogen is less attractive as a tracer of the effluent particles because it is subject to significant modification by primary productivity (Altabet, 1988) and, more importantly, to bacterial degradation processes (Saino and Hattori, 1980; 1985). Use of both nitrogen and sulfur isotope ratios in the 106-Mile Site monitoring program demonstrated that the characteristic signatures of these elements, when used together, provided the ability to trace the particle transport in this deepwater environment (Hunt *et al.*, in press) and also into organisms (Van Dover *et al.*, 1992). It is recommended that both parameters be considered as potential tracers of the particulate matter from the MWRA effluent in Massachusetts Bay, particularly in the sediments near the outfall and possibly in the organisms collected routinely near the outfall. Such information would be useful, should the need arise, to determine if any responses in the sediments or organisms are due to the MWRA discharge.

### 3.1.7 Contaminant Loading

The estimates of contaminant and nutrient inputs to Massachusetts Bay presented in this section are based only on the 1994 Deer Island effluent data. Loading estimates for contaminants and nutrients that are available from Alber and Chan (1994), Uhler *et al.*, (1994), and Shea (1993a) are for the *combined Deer and Nut Island effluent*. The annual loading for selected organic contaminants from Deer Island and the combined discharge are presented in Table 7. These analytes (or analyte groups) were chosen based on their level of detection in the effluents.

***PAHs*** — The annual loading of total PAHs from Deer Island was calculated as 7270 Kg/year. About 56% of this loading was due to naphthalene and its alkyl homologues. Loading rates into Massachusetts Bay ranged from 270 Kg/month in November 1994 to a high of 1091 Kg/month in

**Table 7. Comparison of 1994 organic contaminant loading (Kg/yr) from Deer Island to previous studies.**

| Organic Contaminant | Deer Island | | | Deer Island Plus Nut Island[1] | | |
|---|---|---|---|---|---|---|
| | 1994 This Study | 1993 Uhler *et al.* (1994) | 1993 Alber and Chan (1993) | 1994 This Study | 1993 Alber and Chan (1993) | 1993 Shea (1993a) |
| ΣPAH | 7,338 | 5,414 | NA | 11,000 | NA | 4,700 |
| ΣNaphthalenes | 4,080 | 3,692 | NA[2] | 6,100 | NA | NA |
| Pyrene | 78 | | 49 | 117 | 59 | NA |
| Benzo[a]pyrene | 15 | 8 | 4 | 23 | 6.3 | NA |
| ΣLAB | 5,324 | NA | NA | 7,990 | NA | NA |
| ΣDDT | 21.6 | NA | NA | 32 | NA | NA |
| 4',4'-DDT | 4.0 | 2.0 | NA | 6 | NA | NA |
| ΣChlordane | 4.6 | NA | NA | 7 | NA | NA |
| Lindane | 4.9 | 4 | NA | 7 | NA | NA |
| Dieldrin | 0.77 | NA | NA | 1.2 | NA | NA |
| ΣPCB | 17 | 18 | NA | 26 | NA | 36 |

[1] Estimated by assuming the contaminant concentrations in the Nut Island effluent are the same as the Deer Island effluent and flow proportioning the loading based on the December 1993 to November 1994 flows (Deer Island 255; Nut Island 128 MGD), Deer Island loading estimate was multiplied by 1.5 to get the loading from both treatment plants.

[2] 2-methylnaphthalene estimated at 1,473 Kg/yr

March 1994. In February, petrogenic naphthalenes comprised 61% of the total PAHs; in January the contribution from petrogenic naphthalenes was 59%. Pyrene, a dominant pyrogenic PAH, contributed approximately 78 Kg/year; the highest loading rates occurred during March and April 1994. Benzo[a]pyrene is an analyte of interest because it is potentially carcinogenic; loading was calculated at 15 Kg/year. The combined loading estimate for the Deer Island and Nut Island facilities (Table 7) suggests that PAH loading was higher in 1994 than previously estimated. Pyrene and benzo[a]pyrene loading estimates were 2–3 times higher than estimates by Alber and Chan (1994).

***Pesticides and PCBs*** — The total annual DDT loading from Deer Island in 1994 was 22 Kg/year. The parent compound, 4,4'-DDT, contributed 18% of the total loading. Total chlordane and lindane loadings were 4.6 and 4.9 Kg/year, respectively. The heaviest loadings, however, were at different times of the year; chlordane loading was highest in May and June, while lindane contributions were greatest in September. Input of dieldrin is estimated at 0.77 Kg/year. This value takes into account adjustments made on dieldrin concentrations in individual samples based on extract re-analysis. The loading for PCBs was 17 Kg/year. The estimated PCB loading from both treatment plants was slightly less in 1994 compared to 1993. Because of error propagation and variability in day-to-day operations and flow rates, these differences are probably insignificant.

***Trace Metals*** — The annual input of metals associated with the Deer Island effluent in 1994 is summarized in Table 8. Because the concentrations of all nine metals were measured quantitatively in each sample and were found to be well above the method detection limits, the loading estimates are not biased by nondetectable results and are considered fully representative of the metals loading.

In 1994, the input of metals from Deer Island to Massachusetts Bay ranged from 29,610 Kg/year for Zn to 51 Kg/year for Hg. Estimated 1994 inputs of Cu, Pb, and Zn from Deer Island are in reasonable agreement with those developed by Alber and Chan (1994), the most recent compilation of loading estimates to the system. However, the Hg loading data reported by Alber and Chan (1994) appears to be at least four times higher than estimated using the 1994 Hg data. Poor quality control and very high method detection limits, both of which have recently been identified for many dischargers (EPA, 1993), contribute to overestimates of Hg in the effluent and are probably the reason for the discrepancy.

Table 8. **Comparison of 1994 metals contamiant loading (Kg/yr) from Deer Island to previous studies.**

| Organic Contaminant | Deer Island | | | Deer Island Plus Nut Island[1] | | |
|---|---|---|---|---|---|---|
| | 1994 This Study | 1993 Uhler *et al.* (1994) | 1993 Alber and Chan (1993) | 1994 This Study | 1993 Alber and Chan (1993) | 1993 Shea (1993a) |
| Ag | 1.730 | 1,129 | NA | 2,600 | NA | 2,030 |
| Cd | 250 | 150 | NA | 370 | NA | 430 |
| Cr | 1,420 | 931 | NA | 2,100 | NA | 2.450 |
| Cu | 25,456 | 19,626 | 21,500 | 38,200 | 31,400 | 30,780 |
| Hg | 51 | 42 | 164 | 75 | 215 | 140 |
| Mo | 4,875 | 1,642 | NA | 7,300 | NA | NA |
| Ni | 2,220 | 1,642 | NA | 3,300 | NA | 4,800 |
| Pb | 3,900 | 3,198 | 4,320 | 6,000 | 6,100 | 5,670 |
| Zn | 29,610 | 23,645 | 31,460 | 44,400 | 43,800 | 37,630 |

[1] Estimated by assuming the contaminant concentrations in the Nut Island effluent are the same as the Deer Island effluent and flow proportioning the loading based on the December 1993 to November 1994 flows (Deer Island 255; Nut Island 128 MGD), Deer Island loading estimate was multiplied by 1.5 to get the loading from both treatment plants.

Examination of monthly loading rates (see the appendix for graphic representations) suggests that there is a seasonal input signal that is primarily driven by changes in flow rates. For example, monthly Zn loading over the sampling period parallels the effluent flow rate; the highest loading occurs in the winter/spring. Most of the other metals (Ag, Cd, Cr, Hg, Ni, Pb) behave similarly, although monthly variability can be large and can mask the seasonal response.

In contrast to the loading of these metals, Mo loading rates are lower in the spring when flows are highest (~250 Kg/month in December through April and ~500 Kg/month through November). Because the Mo concentrations were lowest in March, which also had the highest flow rates, the data suggest that the high flows, associated with the melting of record snow fall and spring runoff, diluted the concentrations of Mo in the effluent; this implies that Mo enters the system through sources that are independent of the major water sources (*i.e.*, the MWRA source waters and associated sewage discharges).

Little seasonal influence on the loading of Cu was observed. Over the 18-month study period, Cu loading increased consistently from ~1600 Kg/month in June 1993 to ~2000 Kg/month in November 1994.

1994 estimates of the total input of Cd, Cr, and Pb from the Deer Island and Nut Island treatment facilities are similar to those reported by Shea (1993a). However, Ag and Cu loadings are generally higher while Hg, Ni, and Zn are lower. Shea's 1993 estimates did not have the benefit of a full tear of trace metals clean measurements in contrast to the seasonal cycle that was available for the 1994 estimates. Because of the seasonal trends and the continuous increase in Cu loading described above, Shea's estimates were probably skewed. The lower Hg loading in 1994 is due to improvements in the analytical data over the course of the study. Reasonably good agreement was found for two (Pb and Zn) of the four metals that were common to Alber and Chan's study. As observed for Shea's 1993 estimates, the Cu loadings were higher in 1994 while Hg loading was about three times lower than the Alber and Chan (1994) data.

*Nutrients* — On a mass basis, nutrients constitute the largest contribution of contaminants from the sewage treatment plants to Massachusetts Bay. Rather than toxic contaminant loadings on the order of Kg/year, nutrients are loaded to the system in hundreds to thousands of metric tons (mtons)/year (Table 9). In 1994, the largest loading of eutrophication-related nutrients from the Deer Island

Table 9. Comparison of 1994 nutrient loading (metric tons/yr) from Deer Island to previous studies.

| Nutrient Form | Deer Island | | Deer Island Plus Nut Island[1] | |
|---|---|---|---|---|
| | 1994 This Study | 1993 Alber and Chan (1993) | 1994 This Study | 1993 Alber and Chan (1993) |
| Ammonia | 3,710 | 4,430 | 5,570 | 6,240 |
| Nitrite | 21.3 | 53 | 32 | 95 |
| Nitrate | 125 | 274 | 190 | 425 |
| Particulate Nitrogen | 920 | NA | 1380 | NA |
| Total Dissolved Nitrogen | 4,560 | NA | 6,840 | NA |
| Total Nitrogen | 5,480 | 8,760[2] | 8,220 | 11,470 |
| Phosphate | 539 | 806 | 810 | 953 |
| Particulate Phosphorous | 195 | NA | 290 | NA |
| Total Dissolved Phosphorous | 632 | NA | 950 | NA |
| Total Phosphorous | 823 | 1,405 | 1,230 | 1,870 |
| Dissolved Silicate | 1,500 | NA | 2,250 | NA |
| Biogenic Silicate | 66 | NA | 100 | NA |
| Particulate Organic Carbon | 7,910 | NA | 11,900 | NA |
| Dissolved Organic Carbon | 10,300 | NA | 15,500 | NA |
| Total Organic Carbon | 18,300 | NA | 27,500 | NA |

[1] Estimated by assuming the nutrient concentrations in the Nut Island effluent is the same in the Deer Island effluent and flow proportioning the loading based on the December 1993 to November 1994 flows (Deer Island 255; Nut Island 128 MGD), Deer Island loading estimate was multiplied by 1.5 to get the loading from both treatment plants.

[2] As total Keldjhal nitrogen

treatment plant was total organic carbon (18,300 mtons/year), of which 56% was contributed as dissolved organic carbon. The loading of other nutrient forms from Deer Island ranged between ~20 mtons/year for particulate phosphorus to 5480 mtons of total nitrogen/year. Ammonia contributed the largest fraction (68%) of the total nitrogen discharged from this treatment plant. Total phosphorus (65% as particulate) was added at 820 mtons/year and about 1600 mtons/year of silica (96% dissolved) was discharged from Deer Island.

The loading estimates for Deer Island in 1994 were generally lower than the values estimated by Alber and Chan (1994) (Table 9). The 1994 ammonia loading was ~85% and nitrite was ~40% of the 1993 estimates. Total phosphorus and phosphate loadings were about 58% and 67% of the 1993 rate, respectively. The total loading estimated for both the Deer Island and Nut Island treatment facilities was also less than the value reported by Alber and Chan (1994); this was expected given the method of estimating the combined 1994 input. However, the differences appear to be smaller than seen in the Deer Island effluent alone which may reflect poor assumption regarding the similarity of the nutrient concentrations in the two effluents. In fact, Alber and Chan's data support lower nutrient concentrations in the 1993 Nut Island effluent relative to Deer Island. In addition, if the standard deviation of the loading input reported by Alber and Chan are considered, then the 1994 estimates fall within the 1993 loading range. These results emphasize the inherent variability in loading estimates and suggest that the 1994 nutrient loading was probably similar to previous years.

Seasonal loading trends were not clearly evident for dissolved organic carbon, total dissolved nitrogen, ammonia, or total nitrogen. In contrast, dissolved Si decreased from 147 mtons/month in March to 70–90 mtons/month in the summer and fall months. Biogenic Si loading was variable, although summer concentrations were less than early in the year. Total dissolved nitrogen, nitrate, and nitrite were highly variable, as reflected previously in the concentration data. Total dissolved phosphorus and phosphate loading generally increased in the summer relative to early in the year.

***Loading Summary*** — Generally, the loading estimates for 1994 are consistent with estimates for 1993, although the Hg input was decidedly lower and the PAH input was higher in 1994. Similarly, nutrient loading appears to be lower in 1994, but variability in the estimates precludes drawing specific conclusions. Seasonal loading of many organic and metal contaminants is apparent; the winter/spring high flow periods carry more contaminants than reduced flows in the summer and fall.

The exceptions to this are certain pesticides (*e.g.*, high chlordane loading in the early summer; high lindane loading in the late summer) and Mo which is generally higher in the low summer flow. Nutrient loading appears to be relatively constant, although Si loading decreases in the summer while phosphorus inputs increase relative to the high flow period.

### 3.1.8 Comparison to Water Quality Criteria

One question that is regularly posed regarding the presence of anthropogenic chemical contaminants in the effluent is "What are the potential environmental implications of these contaminants to the receiving environment?" The answer to this question is extremely complex and beyond the scope of this report. However, as a first-level evaluation, comparison of the effluent data to existing EPA aquatic life criteria can help address this question. The marine acute and chronic aquatic life criteria, the mean Deer Island effluent concentration over the 1993-1994 sampling period, and number of times effluent concentrations were higher than either water quality criteria (assuming zero dilution) are shown in Tables 10 (organics) and 11 (metals). The temporal relationships to effluent contaminant concentrations and aquatic life criteria can be seen in Figures 4, 8, 9, and 11.

***Trace Organics Compounds*** — None of the organic compounds in the 35 effluent samples analyzed between June 1993 and November 1994 exceeded acute aquatic life water quality criteria (Table 10). However, contaminant concentrations in the undiluted effluent were higher than the chronic aquatic life criteria for p,p' DDT, dieldrin, endrin, and heptachlor epoxide on one or more occasions. The p,p' DDT chronic criterion was exceeded most often (34 of 35 samples) and the average concentration in the effluent was about nine times the chronic criterion. Dieldrin and endrin occasionally exceeded the criteria. The average dieldrin concentration in the 12 samples with detectable concentrations was 2.4 ng/L, which is 40% above the chronic criterion.

***Trace Metals*** — Hg and Pb concentrations in undiluted effluent generally were higher than the marine chronic water quality criteria for most or all of the samples collected between June 1993 and November 1994 (Table 11). The mean Hg concentration in the effluent was approximately six times higher than the chronic aquatic life criterion. Pb concentrations were 40% higher than the chronic

**Table 10. Organic contaminant EPA aquatic life criteria (ng/L) and number of occurrences where samples exceeded criteria in undiluted effluent.**

| Parameter | Marine Acute Criteria | Marine Chronic Criteria | Mean Effluent Concentration | Number[1] of Exceedances of Marine Acute | Number[1] of Exceedances of Marine Chronic |
|---|---|---|---|---|---|
| **Pesticides** | | | | | |
| Aldrin | 1,300 | NC | 0.7 | 0 | NC |
| p,p'-DDT | 130 | 1 | 9.9 | 0 | 32 |
| Dieldrin | 710 | 1.9 | 2.4 [2] | 0 | 8 [3] |
| Endrin | 37 | 2.3 | 2.6 | 1 | 5 |
| Heptachlor | 53 | 3.6 | 0.7 | 0 | 1 |
| Heptachlor Epoxide | 53 | 3.6 | 1.3 | 0 | 3 |
| Lindane | 160 | NC | 14 | 0 | NC |
| **PAH** | | | | | |
| Acenaphthene | 970,000 | 710,000 | 163 | 0 | 0 |
| Fluoranthene | 40,000 | 16,000 | 194 | 0 | 0 |
| Naphthalene | 2,350,000 | NC | 1350 | 0 | NC |
| ΣPAH | 300,000 | NC | 20,761 | 0 | NC |

[1] Number of exceedances out of 35 samples

[2] Average concentrations in the 12 samples in which dieldrin was detected.

[3] Exceedances based on 18 samples.

**Table 11. Metals EPA aquatic life criteria (μg/L) and number of occurrences where samples exceeded criteria in undiluted effluent.**

| Parameter | Marine Acute Criteria | Marine Chronic Criteria | Mean Effluent Concentration | Number[1] of Exceedances of Marine Acute | Number[1] of Exceedances of Marine Chronic |
|---|---|---|---|---|---|
| Silver | 2.3 | NC[2] | 4.86 | 34 | NC |
| Cadmium | 43 | 9.3 | 0.67[3] | 0 | 0 |
| Chromium | 1100 | 50 | 3.99 | 0 | 0 |
| Copper | 2.9 | NC | 74.7 | 35 | NC |
| Mercury | 2.1 | 0.025 | 0.151 | 0 | 35 |
| Nickel | 75 | 8.3 | 6.30[4] | 0 | 2[4] |
| Lead | 220 | 8.5 | 11.8 | 0 | 30 |
| Zinc | 95 | 86 | 87.0 | 7 | 14 |

[1] Number of exceedances out of 35 measurements over a 18-month period.

[2] No established criterion.

[3] The suspected cadmium value was not included in the mean.

[4] The two suspected nickel values were not included in the mean or WQC exceedances.

aquatic life criterion. Zn concentrations were higher than the chronic aquatic life criterion in 14 of 35 samples, although the mean effluent Zn concentration was only 1% higher than the criterion.

Cu concentrations exceeded the marine acute aquatic life criteria in all 35 samples collected; the mean effluent concentration of Cu (74.7 $\mu$g/L) was 25 times higher than the criterion. Ag concentrations in the effluent exceeded the acute aquatic life criterion 34 of 35 times, although the mean effluent concentrations were only a factor of two higher than the criterion. Finally, Zn concentrations were higher than the acute criterion in 7 of the 35 sampling events. All other metals were below the acute criterion in the effluents.

***Summary Remarks on the Aquatic Life Criteria —*** Selected metal and organic contaminants in undiluted Deer Island effluent were found at concentrations that occasionally were higher than established acute and/or chronic aquatic life criteria. Among the metals, Cu concentrations show the greatest difference (a factor of about 25 higher) between the effluent concentration and the aquatic life criterion. For the organic compounds, the concentrations of dieldrin in March, June, and August samples exceeded the chronic aquatic life criteria by a factor of about 2—3. The p,p' DDT exceeded the chronic aquatic life criterion by a factor of 5—10, with one June sample exceeding the criterion by a factor of ~60. The remaining metals and organic contaminants exceeded the established criteria by more modest factors, generally less than a factor of five and then only occasionally.

In terms of environmental impact, concentrations of the contaminants in the undiluted effluent are not paramount; rather, it is the concentration of the contaminants in the receiving environment, after dilution with receiving water, against which the aquatic life criteria should be judged. Assuming that the concentrations of metals and organic contaminants in the effluent are relatively invariant, the expected 50- to 100-fold dilution of the effluent within a few tens to hundreds of meters of the diffuser (Shea, 1993a) will ensure that all metals and organic contaminants will be diluted to concentrations below established acute or chronic aquatic life criteria, and thus, in terms of the aquatic life criteria, will pose little threat to organisms in the receiving waters. Furthermore, as described in Uhler *et al.* (1994), nonconservative behavior of many of the contaminants may be expected as the effluent mixes with seawater, additionally reducing the concentrations in the receiving waters. Thus, planned dilution and chemical-physical transformation of biologically available forms of metals will further decrease the expected metals concentrations and organic chemicals well below any applicable aquatic life criteria.

Lastly, the estimates comparing effluent concentrations to marine aquatic life criteria are based on the present level of primary treatment and current concentrations of contaminants in the discharge. As source-point reduction continues and as improvements to the primary treatment plant become operational, and certainly when secondary treatment is phased in, further reductions the concentrations of toxic compounds in the effluent can be expected, with concomitant decreases in loadings to the system and reduced potential for exceeding applicable aquatic life criteria. The potential for secondary treatment to reduce the present inputs of metals, organic contaminants, and nutrients is considered in the next section.

## 3.2 Pilot Treatment Plant

### 3.2.1 Organic Contaminants

The concentrations of organic contaminants in the influent and effluents of the five pilot treatment plant tests were generally similar (Table 12 ). Compounds were variably removed by the treatment processes. In several cases, effluent concentrations were higher than the influent concentrations. Analytical variability associated with the laboratory measurements is likely the reason for this because the concentrations in the samples were usually very low and measurement variability can be high for low-level organic contaminant analysis. Increases in concentrations of contaminants during the treatment process should not occur because there are no additions of these contaminants during the standard secondary treatment process. The CEPT process does include addition of ferric chloride certified for drinking water. Organic contaminants are unlikely to be associated with this compound. Data from the CEPT test suggest that the addition of ferric chloride can effectively reduce the concentrations of organic contaminants, although the removal efficiency appears to depend on the compound class. For example, lindane appears to be slightly removed (20%) by this treatment whereas the removal efficiency of DDT and chlordane is higher (50-60%). Removal efficiencies for total PCBs, total PAHs, and total LABs were about 70% for this test.

**Table 12. Removal efficiency of organic contaminants during the pilot treatment plant studies. Concentration units are in ng/L except for PAH and Lab which are in μg/L; efficiencies are in percent. Suspect data and associated removal efficiencies are shown in italics.**

| Event Date | Data type | Analytical results and removal efficiencies | | | | | |
|---|---|---|---|---|---|---|---|
| | | PAH | PCB | Chlordanes | DDTs | Lindane | LAB |
| 12-7-93 | Influent | 21.3 | 29.1 | 9.3 | 49.6 | 12 | 20.7 |
| | 1° Effluent | 14.5 | 21.4 | 9.9 | 31.5 | 9.9 | 16.9 |
| | CEPT | 6.2 | 8.41 | 4.4 | 18.2 | 9.6 | 5.1 |
| | 1° efficiency (%) | 32 | 26 | *-7* | 37 | 18 | 18 |
| | CEPT (%) | 71 | 71 | 53 | 63 | 20 | *75* |
| | 1° versus CEPT | 57 | 61 | 56 | 42 | 3 | 70 |
| 6-1-94 | Influent | 16.6 | 42.9 | 10.3 | 57.3 | 10.8 | 11.3 |
| | 1° Effluent | 11.3 | 30.4 | 8.9 | 92.6 | 8.5 | 9.02 |
| | 2° Effluent | 2.03 | 10.4 | *18.6* | 34.6 | 6.6 | 5.25 |
| | 1° efficiency (%) | 32 | 29 | 14 | *-61* | 21 | 20 |
| | 2° efficiency (%) | 88 | 76 | *-61* | 41 | 39 | 53 |
| | 1° versus 2° | 82 | 66 | *-87* | 64 | 22 | 42 |
| 6-3-94 | Influent | 24.8 | 40.9 | 8.7 | 356 | 8.5 | 11.4 |
| | 1° Effluent | 6.99 | 21.5 | 8.6 | 157 | 10.2 | *19.8* |
| | 2° Effluent | 1.15 | 6 | 3.5 | 92.9 | 5.3 | 6.71 |
| | 1° efficiency (%) | 72 | 47 | 1 | 56 | *-20* | *-75* |
| | 2° efficiency (%) | 95 | 85 | 60 | 74 | 38 | 41 |
| | 1° versus 2° | 84 | 72 | 59 | 41 | 48 | 66 |
| 7-15-94 | Influent | 30 | 62 | 1.2 | 73.7 | 8.8 | 8.21 |
| | 1° Effluent | 18.3 | 66 | 1.2 | 56.3 | 8.7 | 7.26 |
| | 2° Effluent | 0.439 | 0 | *3.4* | 4.4 | *15.6* | 1.51 |
| | 1° efficiency (%) | 39 | *-7* | 0 | 24 | 1 | 12 |
| | 2° efficiency (%) | 99 | 100 | *-163* | 94 | *-77* | 82 |
| | 1° versus 2° | 98 | 100 | *-183* | 92 | *-79* | 79 |
| 7-29-94 | Influent | 93.8 | 77 | 6.9 | 117 | 11.1 | 11.7 |
| | 1° Effluent | 20.2 | 47 | *0* | 98 | 10.4 | 6.89 |
| | 2° Effluent | 0.826 | 0 | 3.1 | 17 | 11.8 | 1.46 |
| | 1° efficiency (%) | 79 | 39 | *100* | 17 | 6 | 41 |
| | 2° efficiency (%) | 99 | 100 | 55 | 85 | -6 | 68 |
| | 1° versus 2° | 96 | 100 | NA | 82 | -14 | 79 |

[1] $CL_4$(52) was not included in the total concentration due to an analytical interference

As suggested above and discussed in detail below, the removal efficiencies for organic contaminants with the biological secondary treatment varies with the organic compound class. For the pesticides, only DDT, chlordane, and lindane were detected in the influent and effluent samples. Of the pesticides that could be detected and quantified, the removal efficiencies during primary treatment varied from low (lindane and chlordane) to intermediate (DDTs). PCB removal was high in two of primary treatment tests, while LAB removal was low. Removal of PAHs varied from 32% (intermediate) to 79% (high).

For the secondary treatment process, removal efficiency of lindane was again low, while PCB, DDT, and PAH removal efficiencies were high, especially if the July tests are considered most representative of the expected secondary treatment plant operations. The secondary treatment data for chlordane suggest that the removal efficiency is intermediate. However, the data set is too noisy to develop more specific conclusions. LAB removal by secondary treatment was variable (41–82%) but, in the July tests, was >68%.

compounds were removed with particularly high efficiency (>99%) in the July tests. Should this be the typical operating efficiency, the secondary treatment will be very effective in reducing the input of these organic contaminants from the MWRA discharge to Massachusetts Bay and, relative to the present primary treated sewage, a substantial decrease in loading of contaminants from the MWRA discharge will be realized.

Total DDT concentrations varied widely in the influent (50–360 ng/L). In spite of this, the secondary removal efficiency was high, with three of the four tests producing secondary removal efficiencies of 75% of more. The primary removal efficiency ranged from 17 to 56%; thus secondary treatment effectively doubled the amount removed during primary treatment.

Chlordane concentrations in the influent were less variable than the DDT concentrations; influent concentrations were 7–10 ng/L in four of the five tests. The primary treatment process was relatively inefficient in removing these compounds (7–29%). The effectiveness of the secondary treatment is difficult to evaluate because the secondary effluent concentrations in two of the four tests were higher than the influent concentrations. The two tests with the expected lower concentrations in the secondary effluent suggested that this process could remove ~50% of the chlordane entering the treatment process. Further testing must be conducted to define the efficiency of the treatment in removing these compounds. Such testing should include more field and laboratory replicates to control the variability associated with the analysis.

Lindane removal was very low in both the primary and secondary treatment processes. The low influent concentrations (8.5–12 ng/L) and the analytical variability resulted in higher concentrations of lindane in the effluent than in the influent in two of the five tests. Concentrations in the primary effluent were relatively constant, ranging from 8.5 to 10.4 ng/L. Given the apparent low removal efficiencies for lindane, these concentrations may be reasonably representative of the Deer Island effluent after both primary and secondary treatment.

PAH concentrations in the influent ranged between 16 and 94 μg/L. The high variability is expected given the potential for urban runoff to enter the MWRA collection system. Secondary treatment was very effective in removing PAHs; 80–98% of the PAHs in the primary effluent were removed by the secondary process. Based on results of the limited testing, it is expected that secondary treatment will significantly decrease PAH loading to Massachusetts Bay.

In contrast to PAHs, LAB concentrations in the influent to the pilot treatment plant were relatively constant (8–21 μg/L). In four of the five influent samples, concentrations were in the 8–12 μg/L range. LAB removal by secondary treatment was moderately effective; compared to the removal efficiency of primary treatment, significantly greater removal was achieved by secondary treatment. As suggested for PAHs, data from this limited set of tests suggest that secondary treatment will substantially decrease the LAB loading to Massachusetts Bay.

***PAH and LAB Cluster and Principal Component Analysis*** — Samples from the pilot treatment plant (influent, primary and secondary effluent) were subjected to principal components analysis (PCA) to determine if the level of sewage treatment affected the PAH and LAB analyte distributions, and to determine if a different source signal may be expected when the secondary treatment plant becomes operational. Included in this comparison were the results from the Deer Island primary treated effluents sampled between June 1993 and November 1994. The combination of the two data sets allowed comparison of the discharges during this period with discharges that can be expected from the upgraded primary plant in 1995 and 1996 and the secondary treatment.

Comparison of the two treatment plants clearly demonstrates that the normalized PAH distributions in the pilot treatment plant influent and primary effluent are similar to the PAH distributions observed in the 1993 and 1994 Deer Island effluents (Figure 19). The results suggest that primary treatment does not substantially alter the signature of the source (influent) PAHs because a distinct separation between the PAH distributions in the influent and primary effluent samples was not evident. The influent and effluent of the primary plant clustered together on the basis of similar distributions of low-molecular-weight PAHs, and relatively high concentrations of the alkyl homologues of naphthalene, fluorene, phenanthrene, dibenzothiophene, and chrysene.

In contrast, the secondary effluent from the pilot treatment plant showed a clustering that is clearly separate from both the parent influent and the primary effluent. In addition, the June and July pilot treatment plant samples were widely separated from each other. June samples contained almost no low-molecular-weight PAHs and analyte concentrations increased with increasing molecular weight. The concentrations of most contaminants in the July samples were much lower than concentrations measured in June.

PCA analysis of the LAB data generally did not identify a distinct separation of the pilot treatment plant influent and primary effluent from that observed in the Deer Island effluent; the main reason for this lack of separation is that the LAB PCA analysis showed a range in the distributions as previously discussed. The pilot plant influent samples also generally fell within the grouping observed for the Deer Island primary effluent. Only the July 29 influent sample separated from the main group of samples and the primary sample, while falling within the general sample grouping, is clearly different from the source sample. Thus, there is some suggestion that primary treatment may alter the source signature for LABs. However, consideration of all the data that are available from these initial tests does not generally support clear separation of the LAB signature from the parent source during primary treatment.

Of the four secondary treatment samples that were analyzed for LAB, only the July samples separated clearly from the main sample grouping (Figure 20). Although the separation of secondary treated samples from the primary samples is not as clear as observed for the PAH data, the results are sufficient to suggest that secondary treatment may change the LAB signature relative to the presently discharged primary effluents.

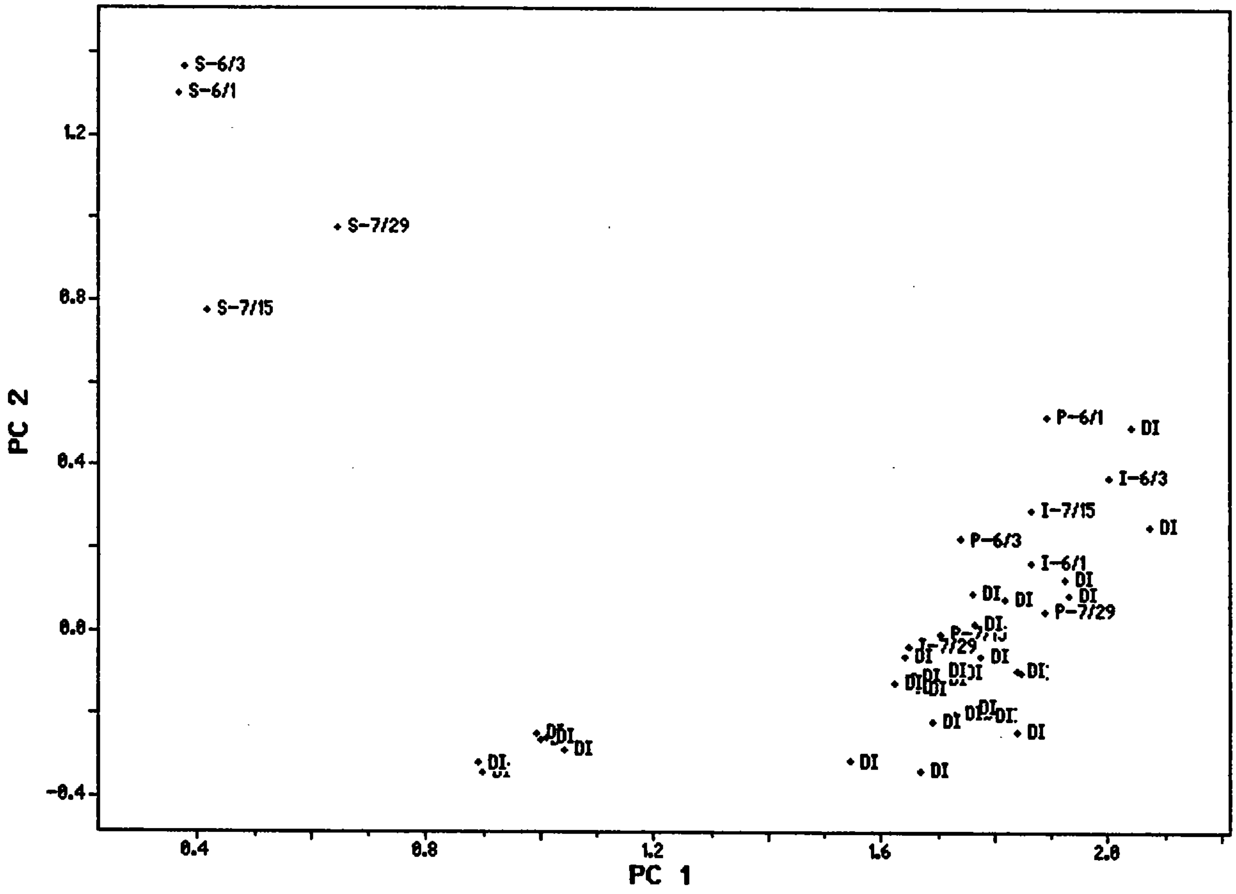


Figure 19. Principal components analysis comparing the PAH distributions in the pilot treatment plant influent, primary and secondary effluents, and the 1993 and 1994 Deer Island effluents. Samples with the prefix s are secondary samples; those with p are primary samples; I indicates the raw sewage input to the pilot plant; DI designates the Deer Island samples.

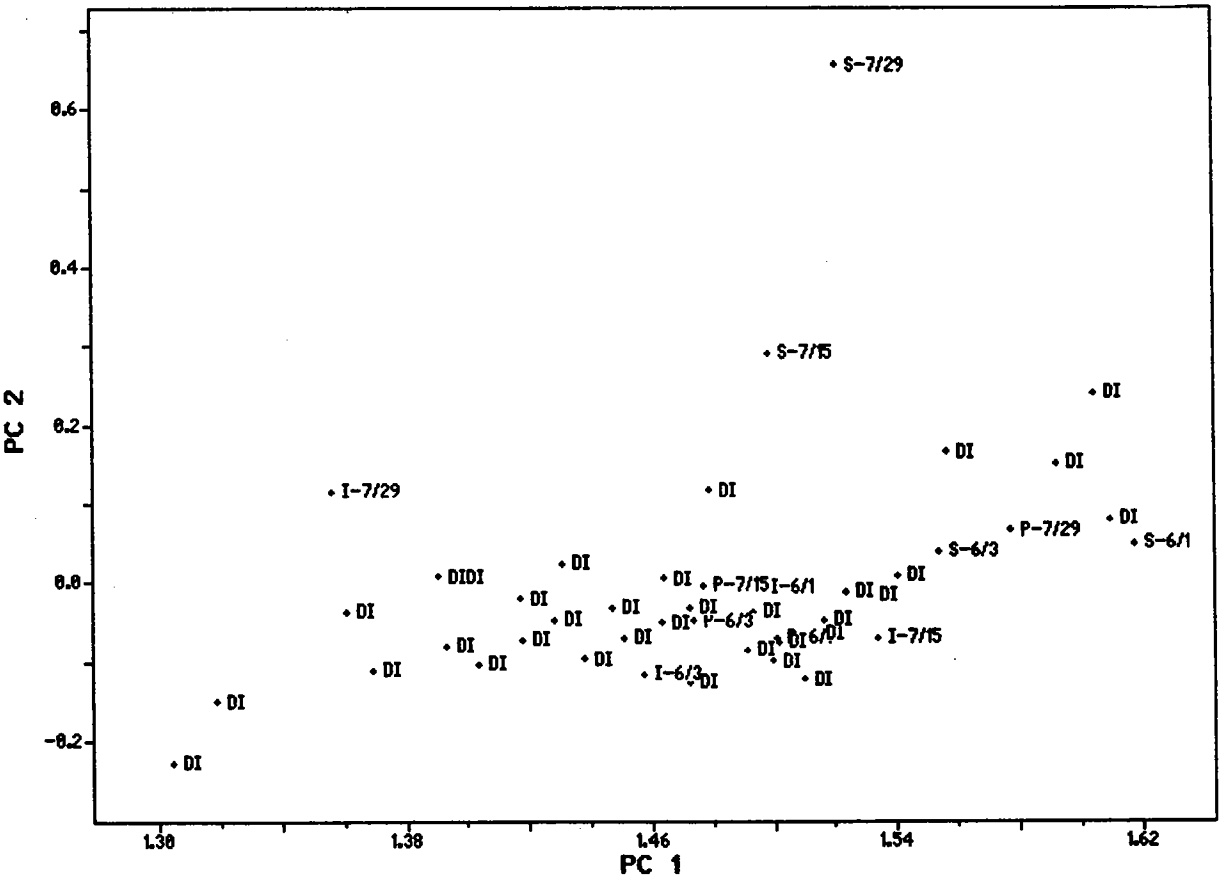


Figure 20. Principal components analysis comparing LAB distributions in the pilot treatment plant influent, primary and secondary effluents, and the 1993 and 1994 Deer Island effluents. Samples with the prefix s are secondary samples; those withp are primary samples; I indicates the raw sewage input to the pilot plant; DI designates the Deer Island samples.

The results of these initial pilot plant tests convincingly suggest that the secondary treatment process, scheduled for operation at the MWRA Deer Island sewage treatment facility in 1996, will likely result in alteration of the LAB and PAH source characteristics relative to present primary discharges and by extension the past sludge discharges. If validated in future tests, these altered source characteristics, if sufficiently consistent and statistically defined, could be used to trace the MWRA post-secondary treatment inputs to Massachusetts Bay. Such changes, if not properly characterized, could also confound future data interpretation of chemical input to the sediments and the historical signatures recorded by the sediments. Thus, testing of the changes in source characteristics resulting from secondary treatment should be continued once pilot plant design changes are completed. The evaluations should be continued until an adequate database to describe variability across seasons and operational conditions is developed.

***Comparison to Water Quality Criteria and Receiving Water Concentrations*** — Table 13 compares the organic contaminant concentrations measured in the pilot treatment plant primary effluent are compared to the 1994 Deer Island effluent results, the ambient water column concentrations in Massachusetts Bay, and the EPA water quality criteria. The concentrations in the pilot plant primary effluent are generally within the range of values measured in 1994 in the Deer Island primary effluent. The data set is too limited to determine if the new primary process will result in significantly lower organic contaminant discharges to Massachusetts Bay. Continued evaluations of the new treatment plant in 1994 will provide the best evidence for improvements in primary effluent quality.

Concentrations of chlordane in the pilot treatment plant primary effluent in July 1994 were generally less than reported ambient water column concentrations in Massachusetts Bay (Table 3-4). Concentrations of PCBs and lindane were about five times higher than those in Massachusetts Bay, while total DDT was 30–50 times higher than in Massachusetts Bay. Total PAH concentrations in the primary effluent were about 200 times higher than in the receiving waters.

In contrast to the primary effluent, the July concentrations of organic compounds in the secondary effluent from the pilot plant treatment (Table 13) were equal to or less than those in the receiving water, except for total DDT, lindane, and total PAHs, which were only 5–10 times higher in the

Table 13. Comparison of organic compound concentrations in the Pilot Treatment Plant effluent with concentrations measured in the Deer Island effluent in 1994, ambient concentrations in Massachusetts Bay, and EPA chronic water quality criteria. Pilot plant results are the concentration range measured in the tests conducted in July 1994.

| Element | 1994 Deer Island Concentration Range (ng/L) | Pilot Plant Effluent Concentration (ng/L) | | Ambient water concentrations in Massachusetts Bay (ng/L) | EPA Chronic Water Quality Criteria |
|---|---|---|---|---|---|
| | | 1° | 2° | | |
| PAH | 12,900 - 32,000 | 18,300 & 20,200 | 440 & 830 | 41 to 97[1]<br>~140[2] | a |
| PCB | 17 - 110 | 47 & 66 | 0 & 0 | < 10[1] | b |
| Chlordanes | 0 - 75 | 0 & 1.2 | 3.1 & 3.4 | ~ 4[1, 3] | c |
| DDTs | 5 - 180 | 56 & 98 | 4.4 & 17 | < 1.7[1] | d |
| Lindane | 2 - 16 | 8.7 & 10.4 | 11.8 & 15.6 | 1.6 to 2.7[1] | b |
| LAB | 7,470 - 22,370 | 7,300 & 6,900 | 1,500 & 1,500 | NA | b |
| Endrin | ND | ND | ND | < 0.4[1] | 2.3 |

[1] Battelle (1992), 15 samples from Massachusetts Bay area

[2] Wade *et al.*, (1987), one station sampled at two depths near the outfall site

[3] cis-Chlordane was the only compound detected at > 0.4 ng/L; value represents the concentration of this compound

[a] No established chronic criteria for $\sum$PAH, Acute = 300,000 ng/L; chronic criteria for acenaphthene = 710,000 ng/L, fluoranthene = 16,000 ng/L

[b] No established criteria

[c] Heptachlor = 3.6 ng/L; Heptachlor Epoxide = 3.6 ng/L

[d] p,p'-DDT 1 ng/L

effluent than in the receiving waters. LAB concentrations are not available for the waters of Massachusetts Bay.

Given the rapid dilution that is expected from the diffuser system, the secondary treatment data suggest that effluent concentrations will be diluted to ambient levels near the outfall. Comparison of the effluent concentrations to available marine aquatic life water quality criteria indicates that exceedances should not be expected. Because the contaminant concentrations in the receiving waters will be low or, more likely, diluted into the present background concentrations, it is not recommended that these compounds be included in the intensive monitoring of the receiving water. Rather, the effluent monitoring program should be the major focus of the contaminant monitoring effort; the fish, shellfish, and sediment monitoring components of program should detect significant or unacceptable inputs to the system.

### 3.2.2 Trace Metals

Trace metal concentrations measured in the pilot treatment plant tests were relatively consistent for the five tests conducted (Table 14). For most tests, lower concentrations were clearly evident in the treated wastes relative to the influent concentrations. Unfortunately, several data points are suspect (*e.g.*, higher concentrations in the effluent than in the influent), which limits the ability to examine all metals across all tests. Theoretically, increases in metal concentrations should not occur because the system is essentially closed (no additions during treatment) and the method for total recoverable metals should measure all metal forms. Examination of the analytical quality control data suggests that several of the apparent discrepancies could be due to analytical variability. For example, the effluent Hg concentrations were approximately twice the influent concentration for two (June 1 and June 3, 1994) of the four tests. The analytical variability associated with the Hg analysis was relatively high which could explain some of differences noted. Likewise, higher Mo in the secondary effluent from the July 15, 1994 test, and Cr and Ni in the CEPT effluent from the December 1993 test could be an artifact of analytical variability. Other results are not easily explained by analytical variability and are more likely the result of extraneous contamination during sample collection or processing. The erratic nature of these high values suggests that random contamination of the samples may have occurred. It is especially difficult to estimate Cd removal because high values

**Table 14. Removal efficiency of metals during the pilot treatment plant studies. Concentration units are in μg/L; removal efficiencies are in percent. Suspect data and associated removal efficiencies are shown in italics.**

| Event Date | Data type | Analytical results and removal efficiencies | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|
| | | Ag | Cd | Cu | Cr | Hg | Mo | Ni | Pb | Zn |
| 12-7-93 | Influent | 5.82 | 0.63 | 58.8 | 2.98 | 0.14 | 13.1 | 4.7 | 14.2 | 81 |
| | 1° Effluent | 4.36 | 0.5 | 38.6 | 1.71 | 0.084 | 11.9 | 3.7 | 7.6 | 70 |
| | CEPT | 1.64 | 0.34 | 29.2 | 2.39 | 0.02 | 11.5 | 5.7 | 2.8 | 51 |
| | 1° efficiency (%) | 25 | 21 | 34 | 43 | 40 | 9 | 21 | 47 | 14 |
| | CEPT (%) | 72 | 46 | 50 | 20 | 86 | 12 | *-23* | 80 | 37 |
| | 1° versus CEPT | 62 | 32 | 24 | -40 | 77 | 3.4 | *-55* | 63 | 27 |
| 6-1-94 | Influent | 5.9 | 0.99 | 66 | 3.1 | 0.061 | 17.5 | 4.7 | 10 | 122 |
| | 1° Effluent | 4.3 | 0.51 | 51 | 3.1 | *0.11* | 15.7 | 4.8 | 7.6 | 112 |
| | 2° Effluent | 1.3 | 0.45 | 23.5 | 1.2 | 0.03 | 13.6 | 3.8 | 3.1 | 43 |
| | 1° efficiency (%) | 26 | 49 | 23 | 0 | *-77* | 10 | -1 | 24 | 8 |
| | 2° efficiency (%) | 77 | 55 | 65 | 60 | 51 | 22 | 20 | 69 | 64 |
| | 1° versus 2° | 70 | 12 | 54 | 60 | 72 | 13 | 21 | 59 | 61 |
| 6-3-94 | Influent | 5.7 | 3.9 | 69 | 3.1 | 0.11 | 18 | 6.6 | 8.5 | 85 |
| | 1° Effluent | 2.6 | 4.1 | 36 | 2.1 | 0.075 | 13.7 | 5.1 | 6.3 | 63 |
| | 2° Effluent | 1.6 | *19* | 37 | 1.9 | *0.24* | 11.3 | 3.8 | 3.8 | 59 |
| | 1° efficiency (%) | 55 | -5.6 | 48 | 31 | 31 | 24 | 24 | 26 | 27 |
| | 2° efficiency (%) | 72 | *-389* | 46 | 38 | *-122* | 37 | 44 | 55 | 30 |
| | 1° versus 2° | 39 | *-362* | -3 | 9.9 | -219 | 18 | 26 | 40 | 5 |
| 7-15-94 | Influent | 7.1 | 0.53 | 76 | 6.1 | 0.55 | 29.9 | 81 | 22.7 | 101 |
| | 1° Effluent | 2.9 | 0.48 | 57 | 5.8 | 0.1 | 23.6 | 80 | 20.2 | *297* |
| | 2° Effluent | 0.45 | 1.39 | 6.8 | 2.7 | 0.017 | *28.6* | 5.3 | 1.1 | 25 |
| | 1° efficiency (%) | 60 | 9 | 25 | 4.6 | 81 | 21 | 3 | 11 | *-195* |
| | 2° efficiency (%) | 94 | *-162* | 91 | 56 | 97 | 4 | 94 | 95 | 75 |
| | 1° versus 2° | 84 | *-190* | 88 | 54 | 83 | *-21* | 93 | 95 | *92* |
| 7-29-94 | Influent | 3 | 0.93 | 77 | 7.7 | 0.81 | 24 | 5.9 | 74 | 175 |
| | 1° Effluent | 2.5 | 0.24 | 31 | 7 | 0.059 | 22.5 | *9.2* | 7.4 | 88 |
| | 2° Effluent | 0.64 | 0.031 | 8.1 | 1.9 | 0.023 | 24.5 | 5.5 | 1.4 | 33 |
| | 1° efficiency (%) | 17 | 74 | 59 | 8 | 93 | 6 | *-58* | 91 | 50 |
| | 2° efficiency (%) | 79 | 97 | 89 | 76 | 97 | -2 | 7 | 98 | 81 |
| | 1° versus 2° | 75 | 87 | 74 | 73 | 61 | -9 | 41 | 78 | 62 |

were detected in two of the five tests. Because unexplained high concentrations were found once each for Ni, Pb, and Zn, interpretation of the results is difficult.

Examination of the test results that are not compromised by unexplained high concentrations suggests that the secondary treatment process achieves high removal efficiencies (>75% from the influent) for Ag, Cu, Hg, and Pb. Intermediate removal efficiencies were noted for Cr, Ni, and Zn, while low removal efficiency was suggested for Mo. Due to variability in the analytical data, characterization of Cd removal is problematic.

The CEPT test conducted in December 1993 suggests that metal removal efficiencies grouped similarly to the other treatment tests (primary treatment followed by biological secondary treatment). High removal efficiencies were suggested for Ag, Hg, and Pb; intermediate removal efficiencies were noted for Cd, Cu, and Zn; and low removal efficiency was found for Mo. Cr and Ni removal in the CEPT process was difficult to characterize due to higher concentrations in the CEPT effluent relative to the primary treatment. Reasons for the increase in Cr and Ni in the CEPT effluent are not clear from this experiment, but could be related to analytical uncertainty or be related to the ferric chloride used in the CEPT test. The ferric chloride used in this test was an industrial waste byproduct of titanium dioxide production and can also contain significant concentrations of other metals, particularly Cr (Brown *et al.*, 1983). Experimental studies of the transport behavior of this waste, following addition to seawater (Fox *et al.*, 1986), suggest that Cu and Cd are not effectively scavenged by the Fe floc that forms when the ferric chloride is added to the seawater. If similar effects occur when the ferric chloride is added to the sewage effluent, some metals may not be readily removed by the flocculation process, and result in increased concentrations in the CEPT-treated effluent. Additional tests and evaluations are needed to determine if this effect is real and, if so, whether the chemical addition is contributing concentrations of Cr, Ni, or other metals to the effluent.

Furthermore, this single CEPT treatment test does not allow one to draw conclusions concerning the effectiveness of this process relative to the planned biological secondary treatment process. The data from this one test do, however, suggest that the CEPT process could be effective in reducing metal concentrations in the sewage effluent.

Comparison of the removal efficiency of the primary treatment process to the pilot treatment plant results shows high variability among the metals and also among the five tests conducted. Variability is to be expected in these test results due to daily nuances in the operational characteristics of the plant, and also because the system was undergoing operational testing and shakedown and was not necessarily operating consistently or at maximum efficiency. Thus, the specific removal efficiencies estimated from these early tests must be considered preliminary. These initial tests do, however, suggest that the new primary treatment process will be effective in removing a substantial fraction of the metals entering the treatment plant. Although there is substantial variability in the removal efficiencies, the tests generally indicate that primary treatment alone will remove a substantial amount (~20 to ~90%) of the Ag, Cr, Cu, Hg, and Pb — metals that are considered to be particle reactive. The primary treatment process appears to be relatively inefficient for removal of Cd, Mo, Ni, and Zn. Comparison of the concentrations of metals in the pilot plant primary effluent with Deer Island primary treatment plant effluent shows that the pilot plant concentrations are generally within the range measured in 1993 and 1994 (Table 15). Insufficient data are available to suggest whether or not the upgraded Deer Island primary treatment plant that came on line in January 1995 will result in lower metals loading to the Boston Harbor/Massachusetts Bay system.

Comparison of the metals removal efficiencies for the full treatment process (through secondary) is subject to similar caveats expressed above. However, there are several observations that can be made relative to expected improvements in metals loading to Massachusetts Bay when the secondary treatment process becomes operational. The data from the tests conducted in 1994 show that secondary treatment was consistently effective in the removal of Ag. Between 72 and 84% of the Ag in the influent was removed, regardless of the test or operational status of the facility. In contrast, secondary treatment removed variable amounts of Cu (46-89%) in the four tests that were conducted. Note that removal efficiencies were ~88% in the two July tests, when many of the operational aspects of the facility had been optimized. Similar patterns were noted in the removal efficiency for Hg, Pb, and Zn.

Variable removal efficiencies were observed for Cr, Mo, and Ni. Note that Pb removal was apparently more effective when the influent concentrations were elevated. As shown in Table 14, the secondary treatment can be expected to substantially lower the concentrations of most metals in the

**Table 15. Comparison of metal concentrations in the Pilot Treatment Plant effluent with concentrations measured in the Deer Island effluent in 1994, ambient concentrations in Massachusetts Bay, and EPA chronic water quality criteria. Pilot plant results are the highest concentrations measured in the tests conducted in July 1994. Results preceded with the ~ indicate the concentrations in the two tests were similar.**

| Element | 1994 Deer Island Concentration Range (µg/L) | Pilot Plant Effluent Concentration (µg/L) | | Ambient water concentrations in Massachusetts Bay | EPA Chronic Water Quality Criteria |
|---|---|---|---|---|---|
| | | 1° | 2° | | |
| Ag | 3.1 - 7.5 | ~3 | ~0.6 | NA | 2.3[1] |
| Cd | 0.39 - 1.4 | ~0.5 | ~0.03 | 0.02 - 0.03[2]<br>0.02 - 0.3[3] | 9.3 |
| Cr | 2.7 - 11 | 7 | ~2.7 | 0.10 - 0.18[2] | 50 |
| Cu | 48 - 111 | 57 | ~8 | 0.1 - 0.3[2]<br>~0.3[3] | 2.9[1] |
| Hg | 0.10 - 0.26 | 0.1 | ~0.02 | 0.0005 - 0.0014[2]<br>~0.003[3] | 0.025 |
| Mo | 5 - 25 | ~22 | ~28 | NA | NA |
| Ni | 4.6 - 30[4] | 9[5] | ~5 | 0.26 - 1.6[2]<br>~1.5[3] | 8.3 |
| Pb | 5.8 - 26 | ~20 | ~1.4 | 0.03 - 0.19[2]<br>~0.2[3] | 8.5 |
| Zn | 70 - 136 | ~88 | ~30 | 0.08 - 0.57[2]<br>~0.6[3] | 86 |

[1] Chronic criteria are not available; value is the acute water quality criteria

[2] Battelle , 1992; Date from 15 samples

[3] Wade *et al.*, 1987; Two sample depths from the outfall area analyzed in replicate

[4] 21 of 23 samples are less than 9 µg/L

[5] One very high result (80 µg/L) was measured in one test

Deer Island effluent and, thus, reduce loading to the system. The most notable decreases will be in the Cu and Hg concentrations.

Speculatively, if the July test results are considered representative of the effluent quality that can be expected from secondary treatment at the Deer Island treatment plant, then metal concentrations in the effluent will be well below any applicable marine water quality criteria (Table 15). On the basis of the two July tests, only Cu would be higher in the effluent than allowed by the EPA water quality criterion and then only by a factor of 2–3. The only other metals that approach the chronic marine water quality values are Hg and Ni which were respectively within ~70–95% and ~60% of the published water quality criteria. Considering the predicted effluent dilutions of ~100:1 within several meters of the outfall diffuser and 500:1 over the nearfield areas (Shea, 1993b), it is doubtful that any exceedance of water quality criteria will occur. In fact, if the effluent concentrations measured in the pilot plant secondary effluent are achieved, increases in the ambient concentrations of several metals will be difficult to detect except possibly in the plume immediately adjacent to the outfall. The metals that are most likely to be detected above ambient concentrations are Zn, Ni, and Cu. Thus, measuring metals in the receiving waters is not recommended for the long-term outfall monitoring strategy. Rather, monitoring should focus on validating the initial dilutions and plume behavior. Once validated, direct monitoring of the effluent concentrations and flow rates will be the most cost-effective means of evaluating potential impact of metals. This, coupled with the planned fish, shellfish, and sediment contaminant monitoring programs, should be more than sufficient to detect adverse impact and assign cause.

### 3.2.3 Nutrients

Samples for nutrient analysis were collected during two test runs in June and two runs in July 1994. The analytical results from these tests are reported in Tables 16 and 17. The average nutrient concentrations for the two analytical replicates are shown for all parameters except the dissolved inorganic nutrients, for which results represent a single analysis. For each of the elements (nitrogen, phosphorus, silica, and organic carbon), dissolved forms, that cannot be measure directly, were estimated as the difference between the total dissolved concentration and measures of the dissolved inorganic species (*i.e.*, dissolved organic nitrogen was calculated as the difference between the total

**Table 16. Estimated removal efficiency for nitrogen forms during the 1994 pilot treatment plant studies. Concentration units are in μM; removal efficiencies are in percent. For nitrogen phases that have been calculated using measured values, negative results indicate the data were within the analytical error of the methods. Removal efficiencies for these phases are thus suspect and are shown in italics. Note that positive efficiencies indicate removal by the treatment process; negative values indicate increases within the treatment.**

| Event Date | Data type | Analytical results and removal efficiencies | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|
| | | $NH_3$ | $NO_2$ | $NO_3$ calculated | $NO_2$ + $NO_3$ | DON calculated | TDN | PON | TN calculated |
| 6-1-94 | Influent | NR | NR | NR | NR | NR | NR | NR | NR |
| | 1° Effluent | 965 | 0.32 | 0.39 | 0.71 | -50 | 916 | 281 | 1197 |
| | 2° Effluent | 958 | 0.41 | 1.12 | 1.53 | 53 | 1013 | 111 | 1124 |
| | 1° versus 2° (%) | 0.73 | -28 | -187 | -115 | *208* | -11 | 61 | 6 |
| 6-3-94 | Influent | NR | NR | NR | NR | NR | NR | NR | NR |
| | 1° Effluent | 1230 | 2.04 | 6.63 | 8.67 | -7.7 | 1231 | 302 | 1533 |
| | 2° Effluent | 1020 | 0.46 | 0.71 | 1.17 | 129 | 1150 | 181 | 1331 |
| | 1° versus 2° (%) | 17 | 77 | 89 | 87 | *1780* | 6.6 | 40 | 13 |
| 7-15-94 | Influent | 752 | 1.09 | -0.61 | 0.48 | 400 | 1152 | 291 | 1443 |
| | 1° Effluent | 627 | 1.07 | -0.71 | 0.36 | 407 | 1034 | 209 | 1243 |
| | 2° Effluent | 940 | 8.6 | 2.65 | 11.3 | 182 | 1133 | 36 | 1169 |
| | 1° efficiency (%) | 17 | 1.8 | *-16* | 25 | -1.8 | 10.2 | 28.2 | 13.9 |
| | 2° efficiency (%) | -25 | -689 | *534* | -2243 | 55 | 1.6 | 88 | 19 |
| | 1° versus 2° (%) | -50.1 | -704 | *473* | -3025 | 55 | -9.6 | 83 | 6 |
| 7-29-94 | Influent | 939 | 0.86 | -0.44 | 0.42 | 193 | 1132 | 401 | 1533 |
| | 1° Effluent | 946 | 1.11 | -0.6 | 0.51 | 170 | 1117 | 247 | 1364 |
| | 2° Effluent | 925 | 3.1 | 2.04 | 5.14 | 118 | 1048 | 33.8 | 1082 |
| | 1° efficiency (%) | -0.7 | -29 | *-36* | -21 | 11.5 | 1.3 | 38.4 | 11 |
| | 2° efficiency (%) | 1.5 | -261 | *564* | -1124 | 39 | 7.4 | 92 | 29 |
| | 1° versus 2° (%) | 2.2 | -179 | *440* | -908 | 31 | 6.2 | 86 | 21 |

**Table 17.** Removal efficiencies of phosphorous, silica, and organic carbon forms during the pilot treatment plant studies. Concentration units are in $\mu$M except for DOC and POC which are in mg/L; removal efficiencies are in percent. For the various forms that were calculated using the difference between measured values, negative results indicate that there was little contribution from the calculated form. Removal efficiencies for these phases are thus suspect and are shown in italics. Note that positive efficiencies indicate removal by the treatment process; negative values indicate increases within the treatment.

| Event Date | Data type | Analytical results and removal efficiencies | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | $PO_4$ | DOP Calculated | TDP | POP | TP Calculated | Si | Bio Si | T Si Calculated | DOC | POC | TC Calculated |
| 6-1-94 | Influent | NR | NR | NR | NR | NR | NR | NR | NR | NR | NR | NR |
| | 1° Effluent | 40.1 | *-3.2* | 36.9 | 20.6 | 57.5 | 179 | 7.8 | 187 | 22 | 27.5 | 49.5 |
| | 2° Effluent | 30.1 | 15.9 | 46 | 11.5 | 57.5 | 185 | 4.6 | 190 | 17.5 | 8.2 | 25.7 |
| | 1° versus 2° (%) | 25 | 597 | -25 | 44 | 0 | -3.4 | 41 | -1.5 | 20 | 70 | 48 |
| 6-3-94 | Influent | NR | NR | NR | NR | NR | NR | NR | NR | NR | NR | NR |
| | 1° Effluent | 49.3 | 10.6 | 59.9 | 30.6 | 90.5 | 182 | 5.8 | 188 | 34.4 | 28.9 | 63.3 |
| | 2° Effluent | 39.5 | 7.8 | 47.3 | 24.9 | 72.2 | 177 | 6.6 | 184 | 18 | 13.5 | 31.5 |
| | 1° versus 2° (%) | 20 | 26 | 21 | 19 | 20 | 2.8 | -13 | 2.3 | 48 | 53 | 50 |
| 7-15-94 | Influent | 38.5 | 36.8 | 75.3 | 20.8 | 96.1 | 127 | 12.1 | 139 | 42.8 | 30.8 | 73.6 |
| | 1° Effluent | 37.2 | 35.2 | 72.4 | 20.5 | 92.9 | 118 | 7.2 | 125 | 40.2 | 17.5 | 57.7 |
| | 2° Effluent | 0.49 | 2.2 | 2.7 | 5 | 7.6 | 118 | 1.8 | 120 | 9.6 | 2.1 | 11.7 |
| | 1° Efficiency (%) | 3.4 | 4.3 | 3.9 | 1.4 | 3.3 | 7.1 | 41 | 10 | 6.1 | 43 | 22 |
| | 2° Efficiency (%) | 99 | 94 | 96 | 76 | 92 | 7.1 | 85 | 14 | 78 | 93 | 84 |
| | 1° versus 2° (%) | 99 | 94 | 96 | 76 | 92 | 0 | 74 | 4.3 | 76 | 88 | 80 |
| 7-29-94 | Influent | 55.4 | 31.8 | 87.2 | 25.6 | 113 | 135 | 8.9 | 144 | 53.4 | 56.2 | 61.5 |
| | 1° Effluent | 59.2 | 15.8 | 75 | 24.3 | 99 | 136 | 7.8 | 144 | 44.7 | 11.6 | 56.3 |
| | 2° Effluent | 19.9 | 10.3 | 30.2 | 4.78 | 35 | 136 | 1.8 | 138 | 10 | 1.9 | 11.9 |
| | 1° Efficiency (%) | -6.9 | 50 | 14 | 5 | 12 | -0.7 | 12 | 0 | 16 | 79 | 8.5 |
| | 2° Efficiency (%) | 64 | 68 | 65 | 81 | 69 | -0.7 | 79 | 4.2 | 81 | 97 | 81 |
| | 1° versus 2° (%) | 66 | 35 | 60 | 80 | 65 | 0 | 76 | 4.1 | 78 | 94 | 79 |

dissolved nitrogen and the inorganic species). This calculation was made for each sample and the mean concentrations were then calculated. Measurement of the total concentrations were not included in the analytical protocols. Thus, the total concentration of these elements was calculated as the sum of the particulate forms and the total dissolved concentrations. The nutrient concentrations and removal efficiencies of the forms that were calculated from measured data are labeled as calculated in Table 16 and 17. Note that for several parameters the calculated concentrations are negative. This reflects low concentrations of the calculated form in the samples and also the analytical variability associated with the various measurements (variable and can range from 0 to 25 as the relative percent difference). Note also that this seriously affects the estimated recovery efficiencies; thus, the estimates based on these results can not be used.

Pilot treatment plant influent data were not collected for the June tests. Thus, the only removal efficiencies that could be estimated were between the primary and secondary trains. For consistency, this was also estimated for the other two tests.

Comparisons of the nutrient concentrations in the primary and secondary pilot treatment plant effluents and the 1994 Deer Island primary treated effluents are presented in Table 18. The results presented in this table suggest that, relative to concentrations in the primary effluent, the secondary treatment process reduces the concentrations of total nitrogen, particulate nitrogen, total phosphorus, dissolved phosphorus, phosphate, and both the dissolved and particulate forms of organic carbon. Nitrate + nitrite may increase and the ammonia and silicate will be relatively unchanged with secondary treatment.

The discussion that follows focuses more specifically on the removal efficiencies of each of the nutrient forms measured during the pilot treatment plant studies conducted in 1994. Each of the nutrient elements (nitrogen, phosphorus, silica, organic carbon) are discussed separately.

***Nitrogen*** — In the two tests where pilot treatment plant influent concentrations were available, 19 and 29 percent of the total nitrogen was removed by the secondary treatment train (Table 16). Careful examination of this table shows that most of the nitrogen removal resulted when the particulate phase was removed, although there was also a small decrease in the total dissolved nitrogen concentration. During the July 15 test, the net decrease in nitrogen during secondary treatment was about 274 $\mu$M.

**Table 18. Comparison of nutrient concentrations in the Pilot Treatment Plant effluents with concentrations measured in the Deer Island effluent in 1994 and the range of ambient concentrations in Massachusetts Bay.**

| Element | 1994 Deer Island Concentration Range (μM) | Pilot Plant Effluent Concentration (μM) | | Ambient water concentrations in Massachusetts Bay (μM) |
|---|---|---|---|---|
| | | 1° | 2° | |
| Total Nitrogen | 750 - 1750 | 1200 -1500 | 1100 - 1300 | 4 - 84 |
| Dissolved Nitrogen | 650 - 1500 | 900 - 1200 | 1000 - 1150 | 0.6 - 40 |
| Ammonia | 300 - 1300 | 625 - 1200 | 950 - 1000 | 0 - 15 |
| $NO_2 + NO_3$ | 2 - 120 | 0.5 - 9 | 1.5 - 11 | 0 - 14 |
| Particulate Nitrogen | 220 - 270 | 200 - 300 | 30 - 180 | 0.02 - 19 |
| | | | | |
| Total Phosphorus | 50 - 160 | 58 - 100 | 8 - 70 | NA |
| Dissolved Phosphorus | 25 - 140 | 35 - 90 | 3 - 50 | 0.06 - 5 |
| $PO_4$ | 20 - 85 | 40 - 60 | 1 - 40 | 0 - 3.4 |
| Particulate Phosphorus | 12 - 25 | 20 - 30 | 5 - 25 | NA |
| | | | | |
| Silicate | 109- 125 | 120 - 180 | 120 - 180 | 0 - 22 |
| Biogenic Silica | 7 - 20 | 6 - 8 | 2 - 7 | NA |
| | | | | |
| Dissolved Organic Carbon (mg/L) | 12 - 48 | 20 - 45 | 10 - 20 | 65 - 560 |
| Particulate Organic (mg/L) Carbon | 17 - 35 | 10 - 30 | 2 - 15 | 3 - 67 |

The treatment process decreased the particulate (255 μM) and dissolved organic nitrogen concentration (218 μM) by a combined total of about 473 μM. This internal loss in organic nitrogen forms was counterbalanced by an increase in the ammonia (188 μM) and nitrate + nitrate (10 μM) concentrations. The July 29 test resulted in a larger net removal of nitrogen relative to the July 15 test, primarily because the internal conversion of the organic to inorganic nitrogen forms was not large. If it is assumed that these two tests represent possible operating scenarios for the Deer Island secondary treatment plant, the July 29 operations could be construed as the more desirable because more nitrogen was removed by the treatment process and inorganic moieties, [particularly ammonia, the most form most available to phytoplankton and thus least desirable in the discharge], was not increased relative to the influent and also relative to the primary treatment train.

Primary treatment alone removed 11–14% of the total nitrogen in the influent. Examination of all tests for removal efficiency between the primary and secondary treatment shows a variable net removal of nitrogen ranging between 6 and 21%. Thus, secondary treatment removes a small fraction of the nitrogen that passes through the primary treatment. These preliminary data suggest that the primary treatment alone removes almost half the nitrogen that is removed by the full secondary treatment. The majority of this loss results from removal of particulate nitrogen forms.

The results from these pilot treatment plant test runs are encouraging because the treatment process reduces the nitrogen levels that will be discharged to Massachusetts Bay through the new MWRA outfall. Furthermore, the data suggest that the treatment process can be controlled such that forms of nitrogen that are more available to phytoplankton can be minimized during treatment. Unfortunately, the tests were conducted during shakedown of the plant. This, and the limited set of tests, only allow estimates of the impact that the secondary treatment plant will have on nitrogen loadings to the Harbor and Bay to be preliminary. Nevertheless, such extrapolations are explored later. However, clearly more information is required before definitive conclusions can be drawn.

***Phosphorus*** — In the two July tests, secondary treatment respectively removed 70 and 90% of the total phosphorus entering the pilot treatment plant (Table 17). About 80% of the phosphorus that was removed was from the dissolved phase and the remainder was from the particulate phase. Within the dissolved phosphorus phase, phosphate and dissolved organic phosphorus were equally removed. Removal efficiencies estimated for the primary treatment alone were low, with <10% removal.

Comparison of the primary and secondary removal across all four tests in the summer of 1994 shows a range of removal efficiencies (0–92%). The highest removals were obtained in July when plants were operating more closely to the design specifications. These data suggest than >65% of the phosphorus in the primary effluent will be removed by the secondary treatment. Thus, the majority of the phosphorus removal will occur during the secondary treatment. However, much more information is required before such conclusions can be definitive.

***Silicate*** — Limited removal of silicate phases was observed during the two July tests. The maximum removal was estimated at 14%. More than 94% of the biologically active Si was in the dissolved form in the influent. The results from the analytical replicates are variable which makes it difficult to determine if particulate or dissolved forms are more effectively removed by the treatment process. This limited data set suggests that ~75% of the particulate phase may be lost. Comparison of the secondary treatment to primary treatment showed that secondary treatment resulted in little relative improvement of Si removal. Thus, the secondary treatment will likely have little impact on the overall loading of Si to Massachusetts Bay.

***Organic Carbon*** — Concentrations of dissolved and particulate organic carbon are approximately equal in the influent. The July test results indicate that at least 80% of the total organic carbon (sum of dissolved and particulate) entering the pilot treatment plant will be removed by the secondary treatment process. The data suggest that >90% of the particulate organic carbon and ~80% of the dissolved organic carbon are removed during secondary treatment. Removal of organic carbon by secondary treatment suggests that the DOC pool decreases in the secondary effluent by >50% compared with the primary treatment alone. The July tests suggest that primary treatment removes ~75–80% of the organic carbon that passes the primary treatment process. The results of the two July tests also suggest that >90% of the particulate organic carbon will be removed by secondary treatment. These results, although preliminary, clearly suggest substantial removal of organic carbon phases, thus BOD by the secondary treatment. If the July data are considered representative of the expected MWRA secondary treatment plant operations, then most of the organic carbon removal will be through the secondary treatment process.

***Nutrient Ratios*** — The nitrogen/phosphorus ratios in the pilot treatment plant effluents are shown in Table 19. Except for the slightly elevated values in the two June tests, the nutrient ratios in the

**Table 19. Nutrient ratios in the pilot treatment plant primary and secondary effluents.**

| Effluent type Ratio | 6-1-94 | 6-3-94 | 7-15-94 | 7-29-94 |
|---|---|---|---|---|
| Primary TN/TP | 20.8 | 16.9 | 13.4 | 13.8 |
| Primary DIN/$PO_4$ | 24.0 | 25.1 | 16.9 | 16.0 |
| | | | | |
| Secondary TN/TP | 19.5 | 18.4 | 153[a] | 30.9 |
| Secondary DIN/$PO_4$ | 31.8 | 25.8 | 1,940[a] | 46.7 |

[a] Phosphate value is very low; ratios are suspect

primary effluent were as expected, based on the Redfield ratio. The July test values are essentially the same as reported for the 1994 Deer Island effluent, in which the dissolved inorganic ratio is slightly higher than the total nutrient ratio.

In contrast, the total nutrient ratios calculated for the secondary effluent are distinctly higher than for the primary effluent. In addition, the ratios for the dissolved nutrients in the secondary effluents are also higher than for the total nutrients for this level of treatment. One set of very high values in the July 15 secondary effluent was caused by inexplicably low phosphate concentrations in the effluent. Unfortunately, this confounds data interpretation and further emphasizes the need for additional measurements when the plant is fully operational. Regardless, the data clearly suggest altered nutrient ratios in the secondary effluent relative to the primary effluent that is now discharged from Deer Island. The higher ratio in the secondary treatment effluent indicates that secondary treatment is more efficient in removing phosphorus than in removing nitrogen.

Given the apparent changes in the N/P ratio that will occur during secondary treatment, it is legitimate to ask if the more efficient phosphorus removal and the higher nutrient ratios in the secondary treated effluent will have significant impact on the productivity in Massachusetts Bay. Typically, the DIN/P ratio in Massachusetts Bay is $<16$ and phosphate concentrations do not fall to zero. This indicates that there is always sufficient phosphate in the water column to support primary production, even as nitrogen is depleted. That facts that the N/P ratio in the secondary effluent is $>13$ and the evidence that the dissolved nutrient N/P ratio in the secondary effluent is likely to be $>25$, suggest that the altered N/P ratio will have little effect on the receiving waters. In other words, the secondary effluent that is less rich in phosphate is not likely to have more impact than primary effluent that is more enriched in phosphate.

In contrast, more efficient removal of phosphorus from the sewage and its transfer to the sludge generated by the secondary treatment may improve the quality of the sewage sludge that is generated. Particularly, the N/P ratio in the sludge is likely to decrease, providing a fertilizer that is enriched in phosphorus relative to the primary sludge. Counter to this argument of improved sludge quality, is the possible decrease in quality associated with the more effective transfer of contaminants to the sludge relative to the primary treatment process. However, major changes may not occur on a concentration basis because there will be a concomitant increase in solids removal and the production of additional solids by the treatment process. Thus, while improvements in the effluent are to be expected, it is important that sludge quality also be carefully evaluated when the secondary treatment is implemented.

### 3.2.4 Implications of the Pilot Treatment Plant Results

Given the operational difficulties encountered during startup of the pilot treatment plant and the limited set of data useful for estimating efficiencies, the results from these tests must be considered preliminary. Continued improvements to the system should refine these estimates. Nevertheless, improved effluent quality and distinct decreases in the loading of many contaminants to Massachusetts Bay can be expected. It is thus instructive to explore the decrease in loading from the Deer Island treatment facility that might occur should the full-scale treatment plant achieve the efficiencies measured in the July 1994 pilot plant tests. Estimates of loading, based on the 1994 effluent characterization monitoring, and removal efficiencies realized by the pilot secondary treatment plant in July 1994 were used to develop these loading estimates (Table 20). The results in Table 20 provide preliminary information on the expected loading. Substantial reductions in the loading of most toxic contaminants can be expected and particularly those that are of major concern in Massachusetts Bay (*e.g.*, Hg, Cu, PAHs, and PCBs). A substantial amount of organic carbon will also be removed, which will significantly reduce the BOD input to the system. In contrast, limited removal of nitrogen will likely occur, although the reduction will be more than that of Si, providing a medium that is slightly more favorable to diatom production than to the other phytoplankton species.

Comparison of the removals estimated from these pilot plant studies to expected removal used to develop the loading estimates in the Supplemental Environmental Impact Statement (EPA, 1988) shows reasonably good agreement. For example, the SEIS estimated that Hg and Cu removal would be 70 and 73%, relative to primary treatment. These estimates compare with 70 and 85% in this study. The parameters showing the greatest differences in removal efficiency estimates between 1988 and 1994 are Pb (20 versus 80%, in 1988 and 1994, respectively) and DDT (0 versus 85%). Also, the SEIS estimated no nitrogen removal by secondary treatment which, by design, was a conservative assumption. The pilot plant data suggest that ~15% of the nitrogen will be removed. Interestingly, the cBOD removal efficiency estimated in the SEIS was ~90%, which is the same as established for

Table 20. **Revised loading estimates to Massachusetts Bay from the combined Deer Island and Nut Island discharge using the secondary treatment plant efficiency relative to primary treated effluents and 1994 primary effluent loading data. SEIS loading estimates and removal efficiencies are included for comparison.**

| Compound | SEIS Loading estimates - primary effluent (EPA, 1988) (Kg/yr) | 1994 Loading estimate - primary effluent (kg/yr) | 1994 Estimated removal efficiency between 1° and 2° (%) | 1994 Loading estimate for full secondary treatment (Kg/yr) | SEIS Loading estimates - secondary treatment (EPA, 1988) (Kg/yr) | SEIS Removal efficiencies between 1° and 2° (%) |
|---|---|---|---|---|---|---|
| ΣPAH | NA | 11,000 | 95 | 550 | NA | NA |
| ΣPCB | 527 | 26 | 95 | 1 | 41 | 92 |
| ΣLAB | NA | 7,990 | 80 | 1,600 | NA | NA |
| ΣChlordane | NA | 7 | ~50 | ~4 | NA | NA |
| Lindane | NA | 7 | <25 | ~5 | NA | NA |
| ΣDDTs | 27 | 32 | 85 | 5 | 28 | 0 |
| Ag | 2,081 | 2,600 | 80 | 520 | 296 | 86 |
| Cd | 1,186 | 370 | ~50 | ~185 | 700 | 41 |
| Cu | 43,059 | 38,200 | 85 | 5,730 | 11,900 | 72 |
| Cr | 8,802 | 2,100 | 65 | 735 | 3,520 | 60 |
| Hg | 643 | 75 | 70 | 23 | 205 | 68 |
| Mo | NA | 7,300 | <10 | ~6,600 | NA | NA |
| Ni | 11,135 | 3,300 | ~50 | ~1,650 | 8,910 | 20 |
| Pb | 6,219 | 6,000 | 85 | 900 | 4,951 | 20 |
| Zn | 86,125 | 44,400 | 80 | 8,880 | 34,500 | 60 |
| Total N | 12,000,000 | 8,220,000 | 15 | 6,990,000 | 12,000,000 | 0 |
| Total P | NA | 1,230,000 | 80 | 246,000 | NA | NA |
| Silica | NA | 2,250,000 | 5 | 2,138,000 | Na | NA |
| DOC | NA | 15,500,000 | 75 | 3,875,000 | Na | NA |
| POC | NA | 11,900,000 | 90 | 1,190,000 | NA | NA |

the total organic carbon in these pilot plant studies. Thus, it appears that the removal assumptions used in the SEIS will likely be met or exceeded once the MWRA secondary plant is operational.

Table 20 also includes the annual loading estimates from the SEIS (EPA, 1988) for both primary and secondary treatment. Comparison of the 1994 and 1988 estimates show that both primary and secondary loading estimates in 1988 are much larger than the 1994 estimates. For the secondary treatment, the SEIS loading estimates were 5 to 40 times the 1994 estimates. The only parameter showing higher loading estimates for 1994 is Ag which is about twice the 1988 estimate. PCB loading estimates in 1988 show the highest difference from 1994 (40 times); mercury loading was estimated to be about 10 times greater in 1988 relative to the 1994 estimates. The differences in the estimates between 1988 and 1994 likely result from two factors. The first is better definition of data requirements for conducting loading estimates and application of methodologies with detection limits that are appropriate to estimating loading, as apposed to strictly compliance monitoring which generally carry much high detection limit requirements. The second is the very effective toxics reduction program that has been implemented by MWRA.

Note also that the contaminant loadings projected on the basis of the 1994 pilot treatment plant tests are consistent with, if not slightly less than (25-100%), the projections provided in Shea (1993a). The Pb projections made by Shea are much higher than estimated in this present report (*i.e.*, 4500 vs 900 Kg/year).

It is also interesting to evaluate the impact of secondary treatment and continued discharge at the present Deer Island Light location on the loading of nutrients and contaminants to Boston Harbor relative to the transfer of all discharges into Massachusetts Bay. Presently, monitoring and scientific data indicate that about ~80% of contaminants and nutrients in the present primary effluent discharged at the Deer Island location is exported into Massachusetts Bay. About 20% is retained in the Harbor if degradation process are not considered for organic contaminants (denitrification for nitrogen). Thus, for every 100 Kg of a contaminant that is discharged, less than 20 Kg is retained in the Harbor. For compounds that are efficiently removed by secondary treatment, the 100 Kg now discharged would be reduced to 10-30 Kg, assuming removal efficiencies of 70-90%. Because the hydrodynamics of the Harbor are unlikely to change, 20% of this load (or 2-6 Kg) would be retained in the Harbor if discharge continued at its present location. If degradation is factored into the assumptions even lower amounts would be retained in the Harbor. Thus, when full secondary treatment becomes available, relocation of the effluent conveyance system into Massachusetts Bay will, in effect, be used to transfer ~2-6% of the present contaminant load that is discharged to the Harbor. For contaminants that are less likely to be removed (*i.e.,* nitrogen), the effective transfer will much greater. Under this scenario, the relocation of the diffuser will transfer ~18% of the present load of poorly removed contaminants.

Based on the projected low loadings to Massachusetts Bay when secondary treatment is fully operational, one additional implication can be drawn. Specifically, the substantial reductions in loading will make it very difficult to measure changes in concentrations within the sediments and organisms, relative to present reservoirs especially in the locations that are removed from the diffuser (particularly the farfield). Detection of the input using effluent-specific tracers, as considered previously, will likely be the best method to develop transport and fate conclusions relative to the discharge. Furthermore, future assessments should compare the expected loadings in the nearfield and areas immediately adjacent to the outfall diffuser system to inventories in the upper few centimeters of the sediment to determine when detectable changes in the sediments might be expected to develop. Post-discharge monitoring can then be focused on time intervals that are likely to be important for detecting the contaminant buildup in the sediments, thus providing a more cost-effective monitoring strategy.

## 4.0 FINDINGS AND CONCLUSIONS

This section summarizes the findings from the effluent characterization and provides conclusions, implications, and recommendations for the continuing effluent characterization and the Harbor and Outfall Monitoring Project. The discussion is focused around the study objectives defined in the introduction to this report.

### 4.1 Deer Island Effluent Characteristics

***Evaluation of Persistent Anthropogenic Metal and Organic Contaminants in the Effluent.*** In 1994, concentrations of metals and organic contaminants in the Deer Island effluent were similar to those reported in 1993. Contaminant concentrations measured in the effluent between December 1993 and November 1994 ranged as follows: 13-32 $\mu$g/L for total PAHs; 17–110 ng/L for total PCBs; 0–74 ng/L for total chlordanes; 2–68 ng/L for lindane; and 7.5–22 $\mu$g/L for total LABs. Reanalysis of samples containing high dieldrin concentrations (>10 ng/L) demonstrated that the high concentrations observed in 1993 were due to an unknown interferant. Confirmed concentrations of dieldrin were generally <5 $\mu$g/L. Metal concentrations (in $\mu$g/L) ranged as follows: 3-8.6 for Ag; 0.4–1.4 for Cd; 1.7–11 for Cr; 48–111 for Cu; 0.1–0.26 for Hg; 5–25 for Mo; 4.6–9 for Ni; 6–26 for Pb; and 70–136 for Zn.

Relative to EPA aquatic life criteria, concentrations of organic compounds were less than the available acute criteria in the undiluted effluent. Values that were higher than the EPA chronic criteria were consistently found for p,p'-DDT, and occasionally for dieldrin, endrin, and heptachlor. Ag and Cu were consistently higher than the available marine aquatic life criteria in the undiluted effluent. Hg and Pb consistently exceeded the chronic marine criteria, while Zn was occasionally higher. Consideration of the effluent dilution that will occur at the diffuser demonstrates that all contaminants exceeding marine criteria in the effluent will be diluted well below applicable criteria within a few hundred meters of the diffuser. Thus, violations of aquatic life criteria are not expected when the discharge is relocated to Massachusetts Bay.

***Evaluation of Effluent Nutrient Concentrations and Other Parameters Related to Eutrophication Issues.*** Total nitrogen, ammonia, nitrate + nitrite, total phosphorus, and phosphate concentrations in the 1994 Deer Island effluents 1994 were similar to those reported previously. Concentrations (in $\mu$M) ranged as follows: 750–1750 for total nitrogen; 650–1500 for dissolved nitrogen; 300–1300 for ammonia; and 220–270 for particulate nitrogen. Ammonia contributed the largest fraction (50–70%) to the total nitrogen and contributed 70-90% of the total dissolved nitrogen. Phosphate concentrations (in $\mu$M) were also similar to those reported previously and ranged as follows: 50-160 for total phosphorus; 25–140 for total dissolved phosphorus; 20-85 for phosphate; and 12-25 for particulate phosphate. Concentrations of both total and dissolved phosphorus increased during the late half of 1994. Particulate phosphorus was relatively constant throughout the sampling period; the increases detected in late 1994 were due to dissolved forms, primarily increases in the dissolved organic phosphorus concentrations. Dissolved Si concentrations were relatively constant although decreases were evident in the summer months. Biogenic Si concentrations were low ($<21$ $\mu$M) and contributed $<10\%$ to the total biologically available Si concentrations in the effluents. The concentrations of dissolved and particulate organic carbon were about equal in the effluent; the dissolved form consistently contributed $\sim 60\%$ of the total organic carbon in the effluents.

***Determination of Long-Term (e.g., Monthly and Seasonal) Changes in the Concentrations of Effluent Contaminants and Nutrients.*** As reported previously by Uhler *et al.* (1994), daily and monthly variability could be detected in the treatment plant effluents. The daily and monthly variability was not sufficient to mask seasonal trends, particularly for the nutrients. Seasonal trends were evident for concentrations of PAHs, chlorinated pesticides (*e.g.*, DDTs and lindane), and PCBs. Concentrations of PAHs were highest in the winter/spring period, while concentrations of PCBs were low in the summer and early fall. The concentrations of chlorinated pesticides, when detected, were relatively constant, but showed occasional spikes that were 5–10 times higher than the typical concentrations measured in the effluent. Seasonal trends in the metals data were not evident, although Mo concentrations increased from 10 to 20 $\mu$g/L between March and July. Although not showing a distinct seasonal trend, Cu concentrations did consistently increase between June 1993 and November 1994. Nutrient concentrations were generally higher in the summer when the flow was reduced. Si concentrations generally decreased in the summer when effluent flows were reduced.

***Estimation of Monthly and Annual Contaminant-Specific Loading to Massachusetts Bay.*** The estimated input of contaminants and nutrients to the Boston Harbor/Massachusetts Bay system was consistent with estimates developed in 1993 by Alber and Chan (1994) and by Shea (1993a). Nutrients, by virtue of the relatively higher concentrations in the effluents, contributed the largest loading on a mass basis. Inputs ranged from 32 mtons/year for nitrite to 8220 mtons/year for total nitrogen. Estimated loadings were 1230 mtons of total phosphorus/year, 2250 mtons of dissolved silicate/year, and 27,500 mtons of total organic carbon/year. Nutrient loadings estimated for 1994 are at the lower end of the range provided in Alber and Chan (1994).

Inputs of organic contaminants ranged from < 10 Kg/year for total chlordanes and lindane to 10,900 Kg/year for PAHs. The latter is over twice the 1993 estimate made by Shea (1993a). Dieldrin loading was ~1 Kg/year, while PCBs were discharged at ~26 Kg/year.

Of the metals, Cu and Zn were discharged at the highest rates, 38 and 44 mtons/year, respectively. All other metals were discharged at <7500 Kg/year; Cd discharged at 370 Kg/year. Hg loading was estimated at 75 Kg/year, or about three times lower than previous estimates, and is directly related to the implementation of clean metals sampling protocols and methods with appropriately low method detection limits. The Cu loading is ~25% higher than estimated for 1993. Except for Hg and Cu, loading of the other metals was similar to the recent estimates.

***Identification of Unique Chemical "Fingerprints."*** Principal component analysis was used to determine that the PAHs in the effluent were primarily petrogenic in nature, as reported previously in Uhler *et al.* (1994). The principal component analysis indicated that these compounds grouped very tightly, except in the November/December time periods, and were dominated by low-molecular-weight compounds that were similar to refined petroleum products. The LABs were similar in composition throughout the 18-month sampling period, even though the concentrations systematically declined from 30 to 15 μg/L between mid 1993 and mid 1994. The N/P ratio in the effluents, typically 16, is consistent with the terrestrial source of the organic material. Similarly, the stable isotope nitrogen and sulfur isotope ratios of particulate matter filtered from the effluent are typical of terrestrial sources. The $\delta^{15}$N ranged between 0 and 2‰ (average=~~2.5~~ 1.1 ‰); the $\delta^{24}$S ranged between 4 and 8‰ (average=5.8‰). In terms of effluent tracers, the sulfur isotopes probably can be used more effectively than nitrogen because of the larger difference in the ratio relative to seawater, and the fact that the ratio appears to respond less to productivity and bacteria degradation. *Clostridium perfringens* spores in the effluent were also measured and ranged between 1 and 4 x $10^4$ spores/100 mL. A sharp decrease in the spore concentrations occurred in the early winter of 1994; the lower concentrations are thus more representative of the 1994 sampling period.

## 4.2 Pilot Treatment Plant

The findings and implications resulting from the pilot treatment plant studies are presented below. The information focuses on the efficiency of the secondary treatment, alterations in source characteristics during secondary treatment, changes in loading to Massachusetts Bay, and receiving water quality.

The first objective of the pilot plant study was to:

> *Evaluate the effectiveness of the pilot treatment plant primary and secondary treatment for removal of metals, organic contaminants, and nutrients.*

***Treatment Plant Effectiveness*** — The preliminary tests of the secondary biological treatment process conducted in 1994 showed that the removal efficiency of the primary and secondary treatment process was variable and depended on concentrations of the various contaminants measured in the influent, on the operational status of the treatment plant system, and on specific contaminant or nutrient species. Even though there is significant variability among the tests, the results are encouraging in that the concentrations of several contaminants (*e.g.*, Hg, Cu, PCBs, and PAHs), that are of concern in the receiving waters of Massachusetts Bay, will be substantially reduced through secondary treatment. Other contaminants (*e.g.*, total nitrogen, Si, and Mo) will not be substantially reduced through secondary treatment. Because the operational aspects of the pilot treatment plant were still being optimized, evaluations to confirm the findings from 1994 should continue, with the objectives to optimize the treatment process and to quantify the variability in treatment efficiency and relationship to operation conditions.

Relative to the primary effluent, the biological secondary treatment in the pilot plant resulted in very high removal efficiency (>85%) for total PAHs, total PCBs, Cu, Pb, and particulate organic carbon. High removal efficiencies (70-85%) were evident for total LABs, total DDTs, Ag, Hg, Zn, total phosphorus, and dissolved organic carbon. Chlordane, Cd, Cr, and Ni were removed with 20 to 70% efficiency, while lindane, Mo, total nitrogen, dissolved Si, and biogenic Si were inefficiently (<20%) removed by secondary treatment. A single test of the CEPT process in December 1993 suggested that relatively high removal efficiencies for many of the chemical contaminants could be obtained using this process. Further tests are required to provide definitive conclusions regarding the efficiency of this treatment relative to the primary and full secondary treatment.

***Loading*** — The preliminary removal efficiencies identified from the pilot plant secondary treatment process suggest that contaminant loading to Massachusetts Bay will be substantially reduced. Compared to the 1994 estimates, loading reductions, that are similar to the removal efficiencies listed above, can be expected. Of special note is the very high removal efficiency of dissolved and particulate organic carbon (~90% relative to the present primary effluent). This large reduction is expected to have significant impacts on the cBOD in the effluent and, thus, on the oxygen demand in the receiving waters. The significant reductions in loading that are expected from full secondary treatment must also be considered relative to monitoring of sediments for contaminants. Because the loading rate will be much lower and because of the expected dilution of the effluent by the diffuser, it may take several years for contaminant concentrations in the sediments to be significantly altered. Thus, it is questionable whether extensive annual nearfield or Bay-wide sediment monitoring will detect significant changes over short time scales. For this reason, annual measurements of contaminants in the sediments should be considered a low priority. Sufficient information on inputs of contaminants could be realized through more focused sample collection at stations very near the diffuser. Soft-bottom stations near the diffuser could be occupied based on the 1994 ROV video reconnaissance survey results (Coats *et al.*, 1995).

The second objective of the pilot plant study was to

> *Estimate the effluent quality that will be achieved when full secondary treatment is implemented.*

***Effluent Quality*** — The pilot plant results strongly suggest that the quality of the effluent will be excellent, especially from the perspective of priority pollutants. Prior to discharge, only a few contaminants in the secondary effluent will exceed EPA marine water quality criteria. Those that do (*e.g.*, Cu, Hg) will be rapidly diluted to well below their applicable aquatic life water quality criteria within a few meters of the diffuser. Because the contaminant concentrations are expected to be low in the effluent and also because high dilution is expected, increases in the concentrations of contaminants in the water column will be very difficult to detect. Therefore, the monitoring program should focus on chemical measurements in the effluents, confirming the plume dynamics, and verifying the predicted dilutions. Furthermore, measurements in the sediments and biota in the vicinity of the diffuser will be the most cost-effective method for evaluating fate and potential for impact. The expected decrease in dissolved and particulate organic carbon will also significantly help to improve effluent quality and to reduce oxygen demand in the receiving waters.

*Secondary Effluent Characteristics* — In addition to lower concentrations in the effluent, secondary treatment will likely alter the source characteristics of several parameters relative to the present primary treatment. Specifically, the ratio of nitrogen to phosphorus (N/P) will likely increase from ~16 to possibly 30 as phosphorus removal becomes more efficient than nitrogen removal. As a result of this differential removal, the quality of the MWRA sewage sludge for fertilizer will likely increase as more phosphorus is transferred to sludge. The altered N/P ratio is expected to have little effect on the productivity of receiving waters because the system is clearly nitrogen limited.

In addition, the data from the secondary treatment process suggest that this treatment is likely to change the characteristic fingerprints of the LAB and PAH analytes relative to the present primary discharge. Principal component analyses demonstrates a clear separation of the secondary effluents from the pilot plant influent and primary effluents. Such changes in source characteristics may enable the signature of the secondary effluent to be traced more effectively within the receiving environment; thus characterizations must continue to ensure that the signature is adequately determined.

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# APPENDIX A

## Contaminant and nutrient data

MWRA Effluents:  PAH/LAB Analysis
Data in ng/L

| Sample_ID | | 39307241 | 39307242 | 39308543 | 39308544 | 39310239 | 39310242 | 39312031 | 39312032 | 39313118 | 39313117 | 39314666 |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Date_sampled | | 6/16/93 | 6/18/93 | 7/14/93 | 7/16/93 | 8/11/93 | 8/13/93 | 9/15/93 | 9/17/93 | 10/15/93 | 10/17/93 | 11/10/93 |
| Sample_size (L) | | 1.00 | 1.00 | 2.00 | 2.00 | 2.00 | 2.00 | 2.00 | 2.00 | 2.00 | 2.00 | 2.00 |
| naphthalene | N | 1407.78 | 1433.90 | 1015.22 | 1081.25 | 2453.10 | 1281.05 | 2236.04 | 1393.58 | 1347.56 | 926.95 | 953.72 |
| C1-naphthalenes | N1 | 1755.00 | 1760.98 | 1136.05 | 1167.34 | 1935.34 | 1737.23 | 3986.78 | 2331.17 | 2729.83 | 1520.35 | 1880.64 |
| C2-naphthalenes | N2 | 2575.43 | 2542.80 | 1488.48 | 1469.64 | 3100.37 | 3027.87 | 6376.54 | 3952.32 | 5039.65 | 2825.21 | 3545.95 |
| C3-naphthalenes | N3 | 2351.19 | 2345.02 | 1338.53 | 1281.96 | 3127.63 | 3240.74 | 5471.81 | 3941.00 | 10899.12 | 7080.41 | 9090.53 |
| C4-naphthalenes | N4 | 1073.19 | 1124.18 | 631.26 | 556.03 | 1921.07 | 1975.76 | 2896.94 | 2380.60 | 2764.16 | 1804.91 | 2177.30 |
| biphenyl | BI | 231.84 | 218.85 | 134.16 | 120.04 | 224.02 | 205.79 | 425.11 | 276.95 | 270.06 | 142.38 | 176.53 |
| acenaphthylene | AE | ND | ND | ND | ND | 12.88 | 12.35 | ND | 10.56 | 461.66 | 547.19 | 555.85 |
| acenaphthene | AC | 146.80 | 154.20 | 111.94 | 126.18 | 153.40 | 174.84 | 188.52 | 162.07 | 186.93 | 112.73 | 183.89 |
| dibenzofuran | DI | 92.32 | 90.80 | 79.66 | 67.58 | 100.89 | 121.14 | 12.04 | 111.69 | 110.65 | 65.68 | 90.27 |
| fluorene | F | 189.58 | 191.58 | 137.23 | 123.90 | 205.12 | 236.98 | 274.64 | 231.12 | 156.21 | 95.63 | 214.02 |
| C1-fluorenes | F1 | 732.61 | 457.05 | 280.59 | 358.04 | 416.71 | 516.81 | 601.86 | 419.42 | 566.95 | 312.26 | 487.08 |
| C2-fluorenes | F2 | 398.25 | 416.70 | 241.41 | 225.67 | 582.13 | 616.58 | 753.53 | 660.26 | 583.69 | 391.64 | 535.36 |
| C3-fluorenes | F3 | 413.46 | 462.83 | 240.66 | 231.64 | 651.83 | 675.08 | 807.05 | ND | 1014.74 | 822.54 | 1058.80 |
| phenanthrene | P | 404.80 | 432.27 | 329.20 | 305.76 | 406.33 | 494.65 | 496.53 | 471.80 | 461.18 | 138.85 | 475.91 |
| anthracene | A | 47.89 | 50.22 | 20.57 | 32.44 | 46.59 | 58.91 | 57.25 | 51.16 | 74.37 | 41.56 | 69.87 |
| C1-phenanthrenes/anthracene | P1 | 474.65 | 517.24 | 306.27 | 287.37 | 527.12 | 564.92 | 656.79 | 587.60 | 677.43 | 435.18 | 674.13 |
| C2-phenanthrenes/anthracene | P2 | 546.54 | 588.57 | 317.28 | 304.35 | 590.44 | 580.08 | 737.34 | 642.91 | 827.74 | 586.21 | 796.93 |
| C3-phenanthrenes/anthracene | P3 | 325.32 | 341.92 | 154.40 | 159.38 | 360.51 | 373.19 | 417.51 | 361.88 | ND | ND | ND |
| C4-phenanthrenes/anthracene | P4 | 163.63 | 199.91 | 106.54 | 106.56 | 213.73 | 205.98 | 209.26 | 210.02 | 345.75 | 258.23 | 336.11 |
| dibenzothiophene | D | 70.11 | 72.64 | 44.62 | 45.46 | 74.13 | 81.84 | 88.65 | 98.28 | 81.60 | 48.24 | 69.73 |
| C1-dibenzothiophenes | D1 | 213.74 | 182.25 | 117.88 | 114.55 | 211.09 | 209.13 | 271.04 | 227.16 | 254.04 | 182.39 | 232.55 |
| C2-dibenzothiophenes | D2 | 303.44 | 300.62 | 165.58 | 155.58 | 317.42 | 338.67 | 394.75 | 352.17 | 322.28 | 204.67 | 291.54 |
| C3-dibenzothiophenes | D3 | 291.61 | 256.13 | 157.90 | 141.96 | 288.92 | 271.71 | 354.17 | 315.78 | 318.17 | 249.92 | 325.71 |
| fluoranthene | FL | 176.44 | 205.64 | 167.18 | 146.25 | 160.21 | 189.04 | 181.15 | 167.94 | 271.49 | 123.21 | 237.44 |
| pyrene | PY | 174.18 | 199.79 | 144.41 | 136.29 | 146.47 | 172.49 | 172.75 | 155.79 | 238.68 | 113.26 | 222.53 |
| C1-fluoranthenes/pyrenes | FP1 | 126.17 | 135.89 | 94.75 | 87.18 | 123.93 | 123.01 | 130.11 | 117.70 | 198.61 | 122.65 | 252.56 |
| benz[a]anthracene | B | 60.91 | 75.51 | 65.78 | 54.07 | 46.22 | 45.32 | 53.77 | 41.03 | 82.09 | 32.99 | 78.53 |
| chrysene | C | 74.78 | 74.68 | 65.07 | 50.24 | 51.09 | 57.61 | 57.79 | 48.00 | 96.64 | 39.74 | 90.89 |
| C1-chrysene | C1 | 66.08 | 70.77 | 45.58 | 50.58 | 57.35 | 53.20 | 60.99 | 41.59 | 48.34 | 24.44 | 58.15 |
| C2-chrysene | C2 | 45.74 | ND | 32.71 | 32.80 | 40.94 | 50.99 | 56.32 | 51.43 | 70.90 | 40.91 | 86.81 |
| C3-chrysene | C3 | ND | ND | ND | ND | 30.56 | 27.10 | 30.79 | 23.02 | ND | ND | ND |
| C4-chrysene | C4 | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND |
| benzo[b]fluoranthene | BB | 61.69 | 84.75 | 72.14 | 55.28 | 49.60 | 50.32 | 56.64 | 41.66 | 108.61 | 34.85 | 86.99 |
| benzo[k]fluoranthene | BK | 22.76 | 27.41 | 20.65 | 20.51 | 18.08 | 19.99 | 22.69 | 17.02 | 33.69 | 11.38 | 28.08 |
| benzo[e]pyrene | BE | 34.72 | 39.39 | 34.36 | 30.37 | 28.00 | 28.08 | 28.37 | 18.22 | 50.31 | 17.77 | 45.18 |
| benzo[a]pyrene | BA | 33.49 | 39.49 | 20.88 | 25.16 | 23.46 | ND | 30.12 | 20.08 | 57.71 | 16.36 | 50.59 |
| perylene | PER | 12.04 | 12.26 | 8.14 | 8.42 | 6.26 | ND | 10.05 | 5.29 | 16.85 | 5.87 | 15.13 |
| indeno[1,2,3-c,d]pyrene | IP | 75.08 | 74.91 | 58.06 | 62.19 | 127.05 | 128.04 | 144.95 | 80.88 | 94.55 | 38.87 | 83.97 |
| dibenz[a,h]anthracene | DA | ND | ND | ND | ND | 6.79 | 5.74 | 6.62 | 5.02 | 11.97 | 5.86 | 9.63 |
| benzo[g,h,i]perylene | BP | 34.86 | 52.12 | 43.19 | 32.72 | 26.65 | 23.62 | 26.65 | 17.01 | 49.50 | 15.60 | 37.87 |
| Total PAH | | 15208.12 | 15233.27 | 9428.33 | 9254.74 | 18863.43 | 17975.85 | 28783.91 | 20041.18 | 30923.62 | 19436.79 | 25606.69 |
| 1-phenyl decanes | C10 | 3350.62 | 2203.09 | 2819.29 | 2701.28 | 2144.18 | 2152.93 | 2115.10 | 1736.63 | 2622.81 | 2183.84 | 2993.53 |
| 1-phenyl undecanes | C11 | 8771.92 | 11330.34 | 8175.77 | 7136.09 | 7663.58 | 9054.96 | 7338.11 | 6607.22 | 9955.89 | 8321.57 | 13607.26 |
| 1-phenyl dodecanes | C12 | 9680.18 | 11233.72 | 8557.49 | 8237.87 | 8545.65 | 9532.64 | 7807.71 | 7096.92 | 11180.33 | 10070.88 | 13791.58 |
| 1-phenyl tridecanes | C13 | 5740.79 | 5327.51 | 4222.67 | 4153.33 | 4747.88 | 5248.57 | 4493.51 | 4168.29 | 8979.18 | 8244.70 | 9923.38 |
| 1-phenyl tetradecanes | C14 | 2890.38 | 2932.65 | 1758.64 | 1656.91 | 2019.98 | 2109.59 | 1872.47 | 1608.43 | 3337.09 | 2998.41 | 3695.92 |
| Total LAB | | 30433.89 | 33027.31 | 25533.86 | 23885.48 | 25121.27 | 28098.69 | 23626.90 | 21217.49 | 36075.30 | 31819.39 | 44011.66 |

ND = Not Detected

MWRA Effluents: PAH/LAB Analysis
Data in ng/L

| Sample_ID | 39314667 | 39315830 | 39315831 | 39400237 | 39400238 | 39401154 | 39401155 | 39402880 | 39402881 | 39404054 | 39404211 |
|---|---|---|---|---|---|---|---|---|---|---|---|
| Date_sampled | 11/17/93 | 12/8/93 | 12/10/93 | 1/12/94 | 1/14/94 | 2/2/94 | 2/4/94 | 3/16/94 | 3/18/94 | 4/13/94 | 4/15/94 |
| Sample_size (L) | 2.00 | 2.00 | 2.00 | 2.00 | 2.00 | 2.00 | 2.00 | 2.00 | 2.00 | 2.01 | 2.01 |
| naphthalene | 1064.36 | 1675.74 | 1093.91 | 1789.37 | 1703.44 | 1615.47 | 1447.68 | 1584.27 | 1342.69 | 1515.89 | 1832.47 |
| C1-naphthalenes | 2139.04 | 2791.69 | 1668.86 | 3532.76 | 3105.48 | 3326.05 | 2835.32 | 2755.85 | 2452.13 | 2583.22 | 3503.54 |
| C2-naphthalenes | 3927.03 | 4572.72 | 3107.41 | 6414.53 | 5330.81 | 5775.55 | 4750.72 | 3984.73 | 3857.73 | 3760.99 | 5512.08 |
| C3-naphthalenes | 9715.38 | 3834.48 | 2952.59 | 5892.98 | 4743.16 | 5278.33 | 4295.68 | 3449.48 | 3348.05 | 3361.69 | 4846.71 |
| C4-naphthalenes | 2488.89 | 2279.07 | 1883.12 | 2959.38 | 2404.54 | 2694.82 | 2166.22 | 1503.86 | 1615.03 | 1468.41 | 2336.61 |
| biphenyl | 191.74 | 336.40 | 182.63 | 474.37 | 448.07 | 354.50 | 299.85 | 319.31 | 317.43 | 350.62 | 480.06 |
| acenaphthylene | 549.41 | 13.26 | 14.21 | 25.84 | 13.58 | ND | 11.96 | 20.84 | 18.68 | 19.28 | 19.43 |
| acenaphthene | 162.55 | 172.54 | 170.08 | 228.27 | 204.82 | 218.96 | 202.18 | 190.09 | 169.75 | 190.63 | 250.95 |
| dibenzofuran | 92.16 | 111.85 | 104.10 | 155.22 | 141.37 | 140.53 | 123.02 | 119.48 | 107.36 | 112.56 | 157.16 |
| fluorene | 199.80 | 263.07 | 229.10 | 413.79 | 352.50 | 357.02 | 317.68 | 298.26 | 243.78 | 265.88 | 411.78 |
| C1-fluorenes | 520.66 | 559.98 | 877.26 | 972.49 | 725.43 | 693.56 | 620.06 | 861.96 | 632.68 | 681.55 | 1075.95 |
| C2-fluorenes | 640.35 | 921.47 | 813.68 | 1365.57 | 1198.91 | 1252.77 | 1029.14 | 1000.61 | 956.05 | 1003.11 | 1418.48 |
| C3-fluorenes | 1001.38 | 936.80 | 787.17 | 1499.97 | 1279.49 | 1365.65 | 1086.47 | 767.21 | 685.91 | 813.81 | 1158.80 |
| phenanthrene | 447.99 | 444.62 | 460.38 | 751.02 | 639.07 | 690.36 | 635.27 | 739.22 | 616.50 | 653.94 | 962.73 |
| anthracene | 59.92 | 49.50 | 57.15 | 70.24 | 52.48 | 60.18 | 45.68 | 44.36 | 34.37 | 45.01 | 71.02 |
| C1-phenanthrenes/anthracene | 754.68 | 827.66 | 794.51 | 1469.75 | 1230.71 | 1405.31 | 1117.82 | 1042.29 | 990.60 | 1026.08 | 1636.70 |
| C2-phenanthrenes/anthracene | 949.33 | 1026.29 | 944.16 | 1754.58 | 1429.14 | 1533.48 | 1270.56 | 1059.12 | 1018.11 | 1091.71 | 1675.91 |
| C3-phenanthrenes/anthracene | ND | 654.71 | 607.62 | 1158.58 | 916.90 | 920.04 | 698.74 | 536.18 | 524.14 | 616.82 | 906.33 |
| C4-phenanthrenes/anthracene | 397.23 | 304.90 | 311.53 | 453.22 | 415.53 | 406.06 | 376.72 | 302.80 | 254.65 | 274.19 | 379.02 |
| dibenzothiophene | 69.50 | 93.43 | 87.75 | 131.69 | 108.59 | 117.00 | 97.50 | 114.69 | 100.31 | 116.78 | 171.73 |
| C1-dibenzothiophenes | 250.89 | 238.70 | 276.78 | 362.49 | 284.43 | 324.72 | 259.67 | 357.03 | 322.35 | 369.21 | 564.71 |
| C2-dibenzothiophenes | 340.05 | 470.03 | 429.09 | 748.22 | 595.95 | 593.80 | 481.00 | 446.10 | 412.63 | 461.96 | 708.73 |
| C3-dibenzothiophenes | 376.92 | 403.86 | 368.68 | 634.92 | 531.56 | 494.77 | 402.06 | 333.20 | 330.15 | 343.47 | 535.99 |
| fluoranthene | 170.80 | 146.01 | 179.78 | 196.15 | 194.40 | 150.30 | 151.51 | 432.08 | 252.50 | 241.68 | 261.01 |
| pyrene | 167.12 | 172.44 | 199.95 | 267.02 | 230.83 | 201.62 | 185.90 | 396.53 | 261.57 | 284.38 | 336.68 |
| C1-fluoranthenes/pyrenes | 200.53 | 183.66 | 229.69 | 302.19 | 260.19 | 253.11 | 214.16 | 263.21 | 199.31 | 256.26 | 330.71 |
| benz[a]anthracene | 52.34 | 45.94 | 68.53 | 62.39 | 54.52 | 49.15 | 44.58 | 123.06 | 65.82 | 64.09 | 76.83 |
| chrysene | 58.02 | 61.94 | 91.42 | 89.06 | 84.81 | 74.83 | 65.21 | 193.58 | 112.35 | 102.21 | 109.45 |
| C1-chrysene | 50.64 | 68.77 | 122.70 | 85.51 | 73.11 | 94.73 | 70.29 | 103.81 | 67.82 | 82.31 | 98.39 |
| C2-chrysene | 79.21 | 84.68 | ND | 124.44 | 86.03 | 113.21 | 95.88 | 84.81 | 67.89 | 74.01 | 102.07 |
| C3-chrysene | ND | ND | ND | 64.45 | 62.91 | 54.46 | 63.32 | 66.75 | 39.18 | 51.85 | 62.10 |
| C4-chrysene | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND |
| benzo[b]fluoranthene | 53.08 | 45.93 | 70.51 | 72.00 | 75.22 | 55.14 | 48.07 | 241.93 | 126.77 | 105.82 | 108.92 |
| benzo[k]fluoranthene | 16.53 | 19.33 | 38.62 | 26.09 | 22.38 | 15.87 | 14.83 | 72.53 | 41.96 | 32.42 | 35.44 |
| benzo[e]pyrene | 30.06 | 23.84 | 46.67 | 44.90 | 43.39 | 30.86 | 28.25 | 121.03 | 65.79 | 55.07 | 60.49 |
| benzo[a]pyrene | 28.35 | 29.80 | 49.51 | 42.06 | 40.42 | 28.09 | 22.73 | 100.71 | 50.03 | 45.63 | 54.46 |
| perylene | 8.13 | 16.35 | 11.09 | 10.62 | 10.41 | 8.84 | 6.35 | 23.39 | 11.67 | 11.44 | 13.14 |
| indeno[1,2,3-c,d]pyrene | 50.29 | 26.57 | ND | 30.99 | 30.52 | 23.33 | 20.89 | 117.54 | 62.02 | 48.30 | 51.30 |
| dibenz[a,h]anthracene | 5.76 | ND | ND | 8.84 | 10.07 | 7.64 | 6.47 | 14.64 | 14.01 | 7.08 | 7.19 |
| benzo[g,h,i]perylene | 24.17 | 21.86 | 31.17 | 36.99 | 36.62 | 29.27 | 23.33 | 109.35 | 58.87 | 47.97 | 51.08 |
| Total PAH | 27334.21 | 23929.89 | 19361.41 | 34722.95 | 29171.79 | 30809.38 | 25632.77 | 24295.88 | 21848.64 | 22637.32 | 32376.15 |
| 1-phenyl decanes | 2974.38 | 1844.68 | 1536.89 | 2116.83 | 1721.34 | 1637.55 | 1889.79 | 1360.46 | 1273.20 | 1673.72 | 1756.10 |
| 1-phenyl undecanes | 9007.11 | 6376.81 | 6383.37 | 6950.04 | 6092.31 | 4992.67 | 7046.88 | 3410.26 | 4081.66 | 5303.31 | 4086.81 |
| 1-phenyl dodecanes | 10754.79 | 7291.56 | 7972.74 | 8110.42 | 7541.72 | 6172.77 | 8562.08 | 4429.35 | 4855.79 | 7349.27 | 5737.65 |
| 1-phenyl tridecanes | 9622.30 | 3365.34 | 4023.40 | 4526.88 | 4096.09 | 3440.12 | 4368.59 | 2408.97 | 2858.27 | 3944.91 | 3320.26 |
| 1-phenyl tetradecanes | 3278.55 | 1226.44 | 1270.00 | 1927.20 | 1662.13 | 1585.91 | 1577.22 | 886.95 | 819.90 | 967.39 | 1173.63 |
| Total LAB | 35637.12 | 20104.83 | 21186.40 | 23631.37 | 21113.59 | 17829.02 | 23444.56 | 12495.99 | 13888.80 | 19238.60 | 16074.45 |

ND = Not Detected

MWRA Effluents:  PAH/LAB Analysis
Data in ng/L

| Sample_ID | 39405371 | 39405747 | 39405748 | 39407459 | 39407462 | 39408814 | 39408815 | 39409914 | 39410840 | 39410841 | 39412306 | 39412307 |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Date_sampled | 5/13/94 | 6/1/94 | 6/3/94 | 7/13/94 | 7/15/94 | 8/10/94 | 8/12/94 | 9/14/94 | 10/12/94 | 10/14/94 | 11/15/94 | 11/17/94 |
| Sample_size (L) | 2.00 | 2.01 | 2.01 | 2.01 | 2.02 | 2.10 | 0.51 | 2.15 | 2.01 | 1.98 | 2.28 | 1.98 |
| naphthalene | 1402.39 | 1334.59 | 1105.64 | 1348.52 | 1157.80 | 1357.12 | 667.24 | 1264.73 | 1620.33 | 1045.85 | 922.51 | 843.17 |
| C1-naphthalenes | 1809.22 | 1856.85 | 1208.45 | 2209.30 | 1746.26 | 2364.76 | 920.54 | 1759.63 | 2376.20 | 945.58 | 937.04 | 898.13 |
| C2-naphthalenes | 2563.20 | 2903.39 | 1943.39 | 4829.72 | 2888.10 | 4316.09 | 1529.93 | 2503.82 | 3005.63 | 1429.49 | 1865.42 | 1790.82 |
| C3-naphthalenes | 2455.79 | 2638.91 | 1940.64 | 5178.30 | 2831.53 | 3909.88 | 1582.13 | 1975.95 | 2058.51 | 1360.72 | 5243.88 | 5317.10 |
| C4-naphthalenes | 1181.38 | 1291.10 | 910.77 | 2355.34 | 1662.47 | 1950.86 | 983.58 | 981.82 | 901.50 | 792.41 | 774.93 | 633.54 |
| biphenyl | 251.06 | 264.83 | 201.77 | 378.40 | 258.75 | 325.76 | 139.32 | 288.08 | 356.92 | 131.53 | 124.85 | 118.23 |
| acenaphthylene | ND | 21.48 | ND | 27.24 | 11.79 | 18.07 | 20.33 | ND | ND | ND | 648.40 | 1199.87 |
| acenaphthene | 181.02 | 130.04 | 73.18 | 216.55 | 168.96 | 254.71 | 71.26 | 138.08 | 126.84 | 62.95 | 157.18 | 101.56 |
| dibenzofuran | 95.13 | 66.15 | 80.87 | 100.30 | 133.04 | 147.83 | 57.37 | 130.57 | 136.88 | 52.01 | 245.49 | 222.06 |
| fluorene | 234.47 | 234.13 | 179.97 | 296.47 | 287.20 | 325.25 | 126.64 | 291.96 | 276.31 | 80.89 | 160.55 | 114.38 |
| C1-fluorenes | 534.70 | 557.05 | 413.43 | 921.63 | 797.51 | 954.25 | 314.84 | 503.91 | 612.10 | 497.51 | 272.09 | 216.72 |
| C2-fluorenes | 600.94 | 727.35 | 597.21 | 1191.86 | 965.29 | 1087.22 | 634.73 | 966.31 | 729.16 | 642.03 | ND | 224.44 |
| C3-fluorenes | 658.70 | 1037.66 | 887.34 | 1479.89 | 1057.89 | 1396.86 | 681.89 | 727.92 | 684.06 | 640.23 | ND | ND |
| phenanthrene | 462.59 | 446.82 | 328.17 | 520.43 | 483.61 | 770.05 | 329.79 | 497.88 | 435.63 | 271.28 | 371.58 | 249.19 |
| anthracene | 26.59 | 31.72 | 34.76 | 64.54 | 65.69 | 78.65 | 22.57 | 24.98 | 35.10 | 24.30 | 47.05 | 24.92 |
| C1-phenanthrenes/anthracene | 718.27 | 995.88 | 725.61 | 1289.43 | 1080.13 | 1482.00 | 705.17 | 769.37 | 565.35 | 580.42 | ND | 488.04 |
| C2-phenanthrenes/anthracene | 780.21 | 1156.88 | 779.24 | 1576.21 | 1341.73 | 1755.12 | 1031.86 | 877.87 | 671.01 | 801.53 | ND | ND |
| C3-phenanthrenes/anthracene | 455.50 | 737.99 | 451.09 | 904.73 | 894.86 | 1130.93 | 789.12 | 491.85 | 380.97 | 475.30 | ND | ND |
| C4-phenanthrenes/anthracene | 161.48 | 331.53 | 223.41 | 434.91 | 353.28 | 616.69 | 513.17 | 255.46 | 206.68 | 218.85 | ND | ND |
| dibenzothiophene | 75.09 | 56.44 | 49.97 | 100.50 | 116.48 | 133.86 | 37.18 | 121.57 | 29.79 | 33.30 | 71.22 | 43.69 |
| C1-dibenzothiophenes | 216.98 | 235.08 | 184.30 | 415.40 | 427.75 | 483.34 | 193.01 | 237.44 | 190.59 | 159.25 | ND | 156.96 |
| C2-dibenzothiophenes | 327.90 | 369.62 | 300.06 | 542.33 | 541.04 | 532.51 | 243.20 | 393.09 | 310.84 | 275.97 | ND | ND |
| C3-dibenzothiophenes | 269.16 | 316.48 | 271.76 | 404.06 | 386.08 | 377.77 | 228.29 | 273.03 | 280.48 | 273.48 | ND | ND |
| fluoranthene | 156.29 | 114.40 | 143.22 | 276.44 | 229.11 | 354.76 | 143.88 | 150.91 | 219.93 | 121.20 | 169.14 | 130.62 |
| pyrene | 163.67 | 147.20 | 152.39 | 314.87 | 263.60 | 393.09 | 166.82 | 181.26 | 187.24 | 132.65 | 196.27 | 154.67 |
| C1-fluoranthenes/pyrenes | 159.63 | 246.06 | 174.58 | 364.78 | 309.94 | 477.57 | 293.05 | 205.14 | 151.25 | 195.43 | ND | ND |
| benz[a]anthracene | 59.90 | 62.55 | 58.02 | 79.87 | 38.82 | 82.37 | 79.23 | 40.36 | 32.37 | 26.65 | 4.66 | 54.36 |
| chrysene | 101.23 | 88.01 | 82.77 | 109.00 | 55.99 | 121.18 | 111.29 | 59.53 | 40.43 | 38.67 | 4.77 | 68.66 |
| C1-chrysene | 102.04 | 204.82 | 117.37 | 147.54 | 67.99 | 189.94 | 248.85 | 64.07 | 32.44 | 62.82 | ND | 88.73 |
| C2-chrysene | 115.79 | 302.32 | 131.50 | 167.82 | 87.04 | 265.77 | 327.91 | 83.47 | ND | 106.72 | ND | ND |
| C3-chrysene | ND | 128.40 | ND | ND | 34.67 | 140.20 | 240.76 | ND | ND | ND | ND | ND |
| C4-chrysene | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND |
| benzo[b]fluoranthene | 93.43 | 58.24 | 69.54 | 63.23 | 43.21 | 91.02 | 80.28 | 45.50 | 32.17 | 23.06 | 72.49 | 53.91 |
| benzo[k]fluoranthene | 30.62 | 17.68 | 24.66 | 33.83 | 13.19 | 28.15 | 23.23 | 15.37 | 9.82 | 8.01 | 20.83 | 19.77 |
| benzo[e]pyrene | 49.10 | 36.58 | 40.64 | 46.38 | 30.54 | 54.69 | 53.49 | 26.54 | 18.44 | 16.07 | 39.24 | 44.15 |
| benzo[a]pyrene | 43.19 | 38.30 | 43.43 | 55.39 | 26.69 | 51.31 | 39.54 | 27.13 | 16.12 | 15.28 | 42.61 | 39.40 |
| perylene | 13.58 | 14.07 | 11.93 | 7.62 | 11.47 | 89.91 | 14.53 | 7.37 | 5.27 | 5.71 | ND | 20.47 |
| indeno[1,2,3-c,d]pyrene | 60.13 | 103.74 | 42.41 | 41.86 | 20.68 | 43.71 | 38.61 | 72.16 | 77.27 | 57.79 | 26.30 | 25.83 |
| dibenz[a,h]anthracene | 10.05 | 12.15 | 8.24 | 14.28 | ND | 7.27 | 6.15 | ND | ND | ND | 5.90 | ND |
| benzo[g,h,i]perylene | 19.39 | 25.09 | 15.97 | 61.98 | 39.18 | 54.05 | 64.07 | 26.87 | 21.44 | 15.77 | 19.39 | 56.46 |
| Total PAH | 16639.80 | 19341.57 | 14007.69 | 28570.96 | 20929.33 | 28214.58 | 13754.84 | 16480.99 | 16835.08 | 11620.70 | 12443.79 | 13399.80 |
| 1-phenyl decanes | 1075.00 | 807.27 | 1486.02 | 898.31 | 519.77 | 941.88 | 2014.05 | 763.88 | 1373.97 | 1841.00 | 1116.19 | 1483.41 |
| 1-phenyl undecanes | 4699.89 | 3014.39 | 5506.76 | 2906.37 | 2002.02 | 3127.53 | 7485.08 | 2510.79 | 4594.34 | 6499.89 | 4299.99 | 5071.93 |
| 1-phenyl dodecanes | 4956.94 | 3339.68 | 6416.31 | 2434.64 | 2216.81 | 2634.56 | 5958.37 | 3162.30 | 5170.56 | 6648.66 | 5209.75 | 6785.39 |
| 1-phenyl tridecanes | 2496.08 | 1774.34 | 3321.53 | 1476.36 | 1132.95 | 1953.79 | 3588.03 | 1402.56 | 2375.60 | 2785.77 | 1508.43 | 2715.42 |
| 1-phenyl tetradecanes | 961.81 | 1138.33 | 1480.30 | 497.51 | 853.53 | 548.69 | 1530.10 | 392.40 | 685.80 | 655.95 | ND | 784.40 |
| Total LAB | 14189.73 | 10074.00 | 18210.92 | 8213.18 | 6725.09 | 9206.45 | 20575.62 | 8231.93 | 14200.26 | 18431.27 | 12134.36 | 16840.54 |

ND = Not Detected

MWRA Effluents: PCB/Pesticide Analysis
Data in ng/L

| Sample_ID | 39307241 | 39307242 | 39308543 | 39308544 | 39310239 | 39310242 | 39312031 | 39312032 | 39313118 | 39313117 | 39314666 | 39314667 |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Date_sampled | 6/16/93 | 6/18/93 | 7/14/93 | 7/16/93 | 8/11/93 | 8/13/93 | 9/15/93 | 9/17/93 | 10/15/93 | 10/17/93 | 11/10/93 | 11/17/93 |
| Sample_size (L) | 1.00 | 1.00 | 2.00 | 2.00 | 2.00 | 2.00 | 2.00 | 2.00 | 2.00 | 2.00 | 2.00 | 2.00 |
| ALDRIN | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND |
| CIS-CHLORDANE | 3.61 | 6.15 | 8.13 | 4.30 | 1.70 | 0.82 | 1.12 | 0.83 | 2.31 | 2.55 | 2.00 | 4.82 |
| 2,4-DDD | ND | ND | 2.42 | 1.22 | ND | ND | ND | ND | 1.03 | 1.63 | 1.22 | 1.00 |
| 2,4-DDE | 17.26 | 15.76 | 20.60 | 9.98 | 3.81 | 28.22 | 5.08 | 4.80 | ND | ND | ND | ND |
| 2,4-DDT | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND |
| 4,4-DDD | 23.90 | 25.79 | 17.74 | 16.79 | ND | ND | ND | ND | ND | ND | ND | ND |
| 4,4-DDE | 3.98 | 3.99 | 3.47 | 2.80 | 3.36 | 3.36 | 13.17 | 12.67 | 2.43 | 2.43 | 2.84 | 2.33 |
| 4,4-DDT | 6.31 | 9.38 | 9.81 | 6.73 | 4.59 | 0.80 | 11.97 | 4.36 | 5.46 | 8.91 | 6.85 | 6.83 |
| DIELDRIN | MI | MI | MI | MI | 1.84 | 2.20 | 2.03 | 1.15 | ND | ND | ND | ND |
| ENDRIN | ND | ND | ND | ND | 7.38 | 57.85 | 3.26 | 2.37 | ND | ND | ND | 4.07 |
| HEPTACHLOR | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND |
| HEPTACHLOR EPOXIDE | ND | ND | ND | ND | 0.96 | 0.95 | 1.16 | 1.33 | ND | ND | ND | ND |
| HEXACHLOROBENZENE | 101.45 | 93.80 | 165.14 | 106.53 | ND | 5.62 | ND | ND | 48.17 | 69.69 | 39.12 | 52.37 |
| LINDANE | 14.03 | 15.80 | 15.02 | 12.83 | 16.04 | 16.29 | 16.87 | 11.91 | 13.25 | 20.19 | 12.97 | 12.44 |
| MIREX | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | 2.50 | 11.73 |
| TRANS-NONACHLOR | 3.82 | 7.11 | 4.48 | 5.11 | 10.12 | 16.90 | 1.90 | 0.76 | 1.63 | 1.57 | 1.41 | 0.88 |
| CL2(08) | ND | ND | 8.64 | ND | ND | ND | ND | ND | ND | ND | ND | ND |
| CL3(18) | 7.94 | 7.61 | 13.80 | 8.44 | 1.97 | ND | ND | ND | 1.43 | 0.88 | 1.04 | 0.55 |
| CL3(28) | 25.46 | 28.29 | 20.37 | 21.48 | 3.69 | 3.90 | 3.89 | ND | 3.16 | 4.99 | 2.50 | 3.16 |
| CL4(44) | ND | 5.77 | 5.25 | 3.43 | 1.99 | 8.26 | 3.77 | ND | 1.69 | 3.58 | 1.68 | 2.65 |
| CL4(52) | 13.40 | 13.03 | 13.58 | 4.54 | 2.57 | 1.74 | 3.65 | 2.05 | 2.69 | 8.03 | 3.94 | 5.28 |
| CL4(66) | 1.24 | 1.52 | 1.21 | 1.30 | ND | ND | ND | ND | 0.53 | 0.94 | 0.63 | 0.33 |
| CL4(77) | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND |
| CL5(101) | 2.31 | 2.03 | 2.78 | 2.60 | ND | ND | 2.76 | 1.30 | 1.99 | 2.50 | 1.96 | 1.13 |
| CL5(105) | 1.88 | 2.53 | ND | ND | ND | ND | ND | ND | 1.79 | 1.59 | 1.73 | 1.68 |
| CL5(118) | ND | ND | 4.64 | 2.23 | ND | ND | 2.97 | 2.14 | 2.77 | 2.94 | 2.81 | 2.15 |
| CL5(126) | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND |
| CL6(128) | ND | ND | ND | ND | ND | ND | ND | 2.14 | 0.53 | 0.79 | 0.53 | 0.30 |
| CL6(138) | 2.88 | 3.51 | 3.52 | 3.23 | 36.27 | 14.90 | 55.72 | 39.93 | 11.57 | 11.75 | 13.99 | 43.34 |
| CL6(153) | 6.89 | 10.10 | 4.45 | 8.59 | ND | ND | 1.96 | 2.17 | 3.67 | 4.61 | 4.78 | 3.14 |
| CL7(170) | 1.83 | 2.61 | 5.27 | 3.85 | MI | MI | MI | MI | 1.54 | 1.54 | 2.53 | ND |
| CL7(180) | 35.74 | 34.52 | ND | ND | 32.62 | 34.12 | 36.36 | 24.15 | 32.40 | 29.60 | 28.85 | 54.81 |
| CL7(187) | ND | 1.75 | 1.45 | 1.72 | 2.67 | 2.93 | 2.64 | 1.89 | 1.27 | 1.24 | 1.42 | ND |
| CL8(195) | ND | ND | ND | ND | ND | ND | 11.41 | 7.97 | 0.77 | 0.62 | 0.78 | ND |
| CL9(206) | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND |
| CL10(209) | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND |
| Total PCB | 99.57 | 113.27 | 84.96 | 61.41 | 81.78 | 65.85 | 125.13 | 83.74 | 67.80 | 75.60 | 69.17 | 118.52 |
| Total DDT | 51.45 | 54.92 | 54.04 | 37.52 | 11.76 | 32.38 | 30.22 | 21.83 | 8.92 | 12.97 | 10.91 | 10.16 |
| Total Chlordane | 7.43 | 13.26 | 12.61 | 9.41 | 12.78 | 18.67 | 4.18 | 2.92 | 3.94 | 4.12 | 3.41 | 5.70 |

ND = Not Detected
MI = Matrix Interference

MWRA Effluents: PCB/Pesticide Analysis
Data in ng/L

| Sample_ID | 39315830 | 39315831 | 39400237 | 39400238 | 39401154 | 39401155 | 39402880 | 39402881 | 39404054 | 39404211 | 39405310 | 39405371 |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Date_sampled | 12/8/93 | 12/10/93 | 1/12/94 | 1/14/94 | 2/2/94 | 2/4/94 | 3/16/94 | 3/18/94 | 4/13/94 | 4/15/94 | 5/11/94 | 5/13/94 |
| Sample_size (L) | 2.12 | 2.00 | 2.00 | 2.00 | 2.00 | 2.00 | 2.00 | 2.00 | 2.01 | 2.01 | 2.00 | 2.00 |
| ALDRIN | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND |
| CIS-CHLORDANE | 8.93 | 5.05 | 1.44 | 1.95 | 2.97 | 2.10 | 5.01 | 0.24 | 2.49 | 3.04 | 32.34 | 58.50 |
| 2,4-DDD | 1.96 | 3.37 | 1.55 | 2.30 | 2.72 | 2.51 | ND | ND | ND | ND | ND | ND |
| 2,4-DDE | 0.57 | 1.33 | ND | 0.73 | ND | ND | ND | ND | ND | ND | 5.18 | 11.77 |
| 2,4-DDT | 6.50 | 8.01 | 4.90 | 5.72 | 5.89 | 6.14 | ND | ND | ND | ND | ND | ND |
| 4,4-DDD | 38.21 | 38.89 | 29.07 | 31.51 | 23.89 | 30.11 | ND | ND | ND | ND | 37.57 | 37.73 |
| 4,4-DDE | 3.18 | 3.57 | 3.03 | 3.48 | 3.23 | 2.49 | 0.56 | 0.53 | 1.00 | 0.94 | 7.71 | 9.81 |
| 4,4-DDT | 6.33 | 6.31 | 5.10 | 5.88 | 7.42 | 4.47 | 4.28 | 4.21 | 4.80 | 7.79 | 4.58 | 5.60 |
| DIELDRIN | ND | ND | MI | 2.50 | 2.10 | MI | 5.04 | 4.25 | ND | 5.17 | 2.20 | MI |
| ENDRIN | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND |
| HEPTACHLOR | ND | ND | ND | ND | ND | ND | ND | 1.27 | ND | ND | ND | ND |
| HEPTACHLOR EPOXIDE | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | 6.44 | 12.71 |
| HEXACHLOROBENZENE | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND |
| LINDANE | 12.77 | 10.36 | 15.08 | 13.99 | 16.23 | 25.38 | 5.88 | 4.87 | 12.83 | 7.38 | 9.30 | 10.95 |
| MIREX | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND |
| TRANS-NONACHLOR | 5.15 | 2.30 | 0.86 | 1.26 | 1.92 | 1.12 | 2.10 | 2.30 | 1.33 | 1.47 | 2.59 | 3.10 |
| CL2(08) | ND | ND | ND | ND | ND | 6.55 | ND | ND | ND | ND | ND | ND |
| CL3(18) | ND | ND | 9.61 | ND | ND | 1.41 | 1.92 | 1.38 | 1.17 | 0.85 | 10.76 | 7.52 |
| CL3(28) | ND | ND | 8.95 | ND | 2.09 | 2.11 | 4.05 | 4.38 | 4.75 | 5.46 | ND | ND |
| CL4(44) | ND | ND | 4.52 | 2.14 | 2.26 | 2.27 | ND | 0.59 | 1.47 | 1.19 | ND | ND |
| CL4(52) | ND | ND | 4.91 | 1.74 | 1.46 | 0.93 | 1.06 | 0.67 | 0.58 | 1.18 | 4.12 | 3.72 |
| CL4(66) | 1.02 | 0.88 | 3.88 | 0.46 | 0.54 | 0.78 | 2.42 | 1.74 | 0.80 | 1.79 | ND | ND |
| CL4(77) | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND |
| CL5(101) | 2.48 | 2.43 | 1.99 | 1.62 | 1.43 | 1.06 | 0.32 | 1.51 | 0.35 | 0.78 | NA | NA |
| CL5(105) | 1.78 | 1.41 | 1.34 | 1.15 | 0.61 | 0.58 | 2.81 | 3.30 | 3.72 | 3.82 | ND | ND |
| CL5(118) | 2.85 | 2.82 | 2.10 | 1.84 | 1.81 | 1.47 | 3.33 | 2.54 | 2.27 | 3.49 | 1.31 | 1.33 |
| CL5(126) | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND |
| CL6(128) | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND |
| CL6(138) | 9.42 | 10.49 | 2.07 | 2.47 | 1.66 | 1.53 | NA | NA | NA | NA | NA | NA |
| CL6(153) | 3.14 | 3.63 | 1.90 | 2.69 | 1.88 | 1.86 | 0.12 | 0.10 | ND | 1.11 | 0.78 | 1.22 |
| CL7(170) | ND | ND | ND | ND | ND | ND | NA | NA | NA | NA | ND | ND |
| CL7(180) | ND | ND | ND | ND | ND | ND | 16.70 | 17.94 | NA | NA | 1.43 | 0.81 |
| CL7(187) | 0.95 | 1.49 | 0.86 | ND | 0.94 | 0.88 | ND | ND | ND | ND | 0.36 | 0.61 |
| CL8(195) | ND | ND | ND | ND | ND | ND | ND | 4.37 | ND | ND | ND | ND |
| CL9(206) | ND | ND | ND | ND | ND | ND | 1.75 | 1.88 | 2.66 | 2.93 | ND | ND |
| CL10(209) | ND | ND | ND | ND | ND | ND | 1.30 | 1.24 | 2.16 | 2.09 | ND | ND |
| Total PCB | 21.63 | 23.14 | 42.11 | 14.11 | 14.66 | 21.42 | 35.78 | 41.63 | 19.92 | 24.68 | 18.75 | 15.21 |
| Total DDT | 56.74 | 61.49 | 43.63 | 49.62 | 43.15 | 45.72 | 4.85 | 4.74 | 5.79 | 8.73 | 55.03 | 64.92 |
| Total Chlordane | 14.07 | 7.34 | 2.29 | 3.21 | 4.89 | 3.22 | 7.11 | 3.80 | 3.83 | 4.51 | 41.37 | 74.31 |

ND = Not Detected
MI = Matrix Interference

MWRA Effluents: PCB/Pesticide Analysis
Data in ng/L

| Sample_ID | 39405747 | 39405748 | 39407459 | 39407462 | 39408814 | 39408815 | 39409914 | 39410840 | 39410841 | 39412306 | 39412307 |
|---|---|---|---|---|---|---|---|---|---|---|---|
| Date_sampled | 6/1/94 | 6/3/94 | 7/13/94 | 7/15/94 | 8/10/94 | 8/12/94 | 9/14/94 | 10/12/94 | 10/14/94 | 11/15/94 | 11/17/94 |
| Sample_size (L) | 2.01 | 2.01 | 2.01 | 2.02 | 2.10 | 0.51 | 2.15 | 2.01 | 1.98 | 2.28 | 1.98 |
| ALDRIN | ND | ND | ND | ND | ND | ND | 2.14 | 5.33 | 0.98 | ND | ND |
| CIS-CHLORDANE | 29.73 | 34.80 | 3.22 | ND | 4.86 | 4.83 | 1.41 | 1.37 | 1.10 | ND | ND |
| 2,4-DDD | 0.85 | 1.08 | 0.76 | 2.16 | 4.81 | 16.65 | ND | 1.00 | 1.14 | ND | ND |
| 2,4-DDE | 4.04 | 3.10 | 3.90 | 5.85 | 8.72 | 6.41 | ND | ND | ND | ND | ND |
| 2,4-DDT | ND | 42.57 | ND | ND | ND | ND | 84.88 | 39.37 | 48.89 | ND | ND |
| 4,4-DDD | 60.07 | 64.52 | 45.67 | 55.30 | 62.65 | 44.15 | 28.24 | 69.29 | 56.79 | ND | ND |
| 4,4-DDE | 9.45 | 8.29 | 12.47 | 11.65 | 8.76 | 23.69 | 2.36 | 2.57 | 2.58 | 12.62 | 8.49 |
| 4,4-DDT | 8.11 | 58.76 | 6.36 | 5.17 | 9.38 | 12.05 | 44.67 | 29.23 | 21.93 | ND | ND |
| DIELDRIN | MI | 3.10 | MI | 1.60 | 3.70 | MI | 1.19 | 1.51 | 1.04 | ND | ND |
| ENDRIN | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND |
| HEPTACHLOR | ND | ND | 2.20 | 4.58 | ND | ND | ND | 1.04 | 1.66 | ND | ND |
| HEPTACHLOR EPOXIDE | 0.95 | 1.67 | 2.58 | 5.81 | ND | ND | ND | 0.41 | ND | ND | ND |
| HEXACHLOROBENZENE | ND | ND | 1.07 | 3.27 | 1.21 | ND | 30.91 | 28.85 | 33.66 | ND | ND |
| LINDANE | 9.85 | 8.08 | 11.22 | 7.62 | 9.40 | 13.93 | 68.11 | 16.73 | 14.25 | ND | ND |
| MIREX | ND | ND | ND | ND | ND | ND | 10.43 | 9.54 | 9.39 | ND | ND |
| TRANS-NONACHLOR | 3.52 | 3.56 | ND | ND | 2.53 | 4.57 | 3.49 | 3.29 | 2.90 | ND | ND |
| CL2(08) | ND | ND | ND | ND | ND | ND | 8.60 | 5.07 | 3.82 | ND | ND |
| CL3(18) | ND | ND | 7.41 | 12.76 | ND | ND | 6.15 | 2.97 | 2.70 | MI | MI |
| CL3(28) | ND | ND | 20.60 | 23.57 | ND | ND | 16.13 | 12.71 | 11.61 | 38.49 | 42.40 |
| CL4(44) | 14.21 | 8.80 | 9.15 | 10.30 | 8.96 | 6.25 | 4.56 | 2.08 | 3.41 | 10.56 | 6.74 |
| CL4(52) | ND | ND | 3.55 | 6.62 | 2.02 | 5.57 | 2.82 | 1.48 | 2.59 | 5.07 | 5.35 |
| CL4(66) | 1.33 | 1.67 | ND | 3.35 | ND | ND | 4.48 | 1.44 | 1.80 | ND | ND |
| CL4(77) | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND |
| CL5(101) | NA | NA | 3.75 | 15.80 | 3.40 | 5.90 | 3.40 | 2.54 | 2.56 | 16.64 | 36.55 |
| CL5(105) | ND | ND | ND | ND | ND | ND | 4.38 | 1.51 | 1.32 | ND | ND |
| CL5(118) | 2.42 | 1.25 | 0.71 | 1.74 | 2.82 | ND | 5.64 | 4.92 | 5.07 | ND | ND |
| CL5(126) | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND |
| CL6(128) | ND | ND | ND | ND | ND | ND | 1.21 | 0.68 | 0.85 | ND | ND |
| CL6(138) | 14.50 | 11.13 | ND | ND | 12.05 | ND | 2.29 | ND | ND | 16.99 | 6.24 |
| CL6(153) | 0.82 | 0.67 | 3.34 | 0.52 | 3.72 | ND | 1.74 | 5.10 | 4.97 | 14.57 | 12.89 |
| CL7(170) | ND | ND | ND | ND | ND | ND | 2.28 | 5.45 | 13.97 | ND | ND |
| CL7(180) | ND | ND | ND | ND | ND | ND | ND | 12.43 | 13.26 | ND | ND |
| CL7(187) | 0.53 | 0.81 | ND | 0.91 | 1.32 | ND | 5.18 | ND | ND | ND | ND |
| CL8(195) | ND | ND | ND | ND | ND | ND | 2.24 | 8.30 | 7.52 | ND | ND |
| CL9(206) | ND | ND | ND | ND | ND | ND | 1.52 | 6.07 | 3.98 | ND | ND |
| CL10(209) | ND | ND | ND | ND | ND | ND | ND | 5.58 | 6.33 | ND | ND |
| Total PCB | 33.80 | 24.33 | 48.52 | 75.58 | 34.29 | 17.72 | 72.63 | 78.32 | 85.76 | 102.32 | 110.18 |
| Total DDT | 82.51 | 178.32 | 69.16 | 80.13 | 94.31 | 102.94 | 160.14 | 141.45 | 131.32 | 12.62 | 8.49 |
| Total Chlordane | 34.20 | 40.03 | 8.00 | 10.39 | 7.40 | 9.40 | 4.90 | 6.11 | 5.66 | 0.00 | 0.00 |

ND = Not Detected
MI = Matrix Interference

Table 3. Concentrations ($\mu$g/L) of trace metals in individual 24-h composte Deer Island effluent samples (June 1993 - November 1994).

| | 1993 | | | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Collection Date: | 6/16/93 | 6/18/93 | 7/14/93 | 7/16/93 | 8/11/93 | 8/15/93 | 9/15/93 | 9/17/93 | 10/13/93 | 10/15/93 | 11/10/93 | 11/12/93 | 12/8/94 | 12/10/94 |
| MWRA ID: | 39307241 | 39307242 | 39308543 | 39308544 | 39310239 | 39310242 | 39312031 | 39312032 | 39313118 | 39313117 | 39314666 | 39314667 | 39315830 | 39315831 |
| Ag | 5.08 | 5.87 | 2.40 | 3.25 | 7.11 | 6.03 | 3.39 | 5.09 | 4.09 | 1.75 | 3.16 | 2.82 | 4.84 | 6.83 |
| Cd | 0.42 | 0.41 | 0.58 | 0.81 | 0.42 | 0.44 | 0.57 | 0.465 | 0.46 | 0.57 | 1.15 | 0.29 | 0.58 | 0.72 |
| Cr | 3.39 | 2.86 | 3.42 | 4.48 | 3.21 | 3.36 | 3.70 | 7.61 | 2.96 | 2.02 | 2.37 | 1.65 | 2.68 | 4.46 |
| Cu | 75.3 | 75.6 | 80.9 | 73.2 | 68.8 | 67.9 | 85.9 | 81.4 | 68.9 | 66.0 | 62.9 | 56.2 | 59.1 | 66.2 |
| Hg | 0.165 | 0.204 | 0.094 | 0.143 | 0.12 | 0.289 | 0.234 | 0.232 | 0.087 | 0.079 | 0.101 | 0.127 | 0.077 | 0.11 |
| Mo | - | - | - | - | - | - | - | - | - | - | - | - | 11.53 | 7.36 |
| Ni | 5.89 | 5.97 | 6.69 | 3.81 | 7.31 | 5.86 | 5.66 | 5.29 | 6.39 | 6.40 | 5.38 | 7.62 | 4.71 | 4.93 |
| Pb | 13.0 | 11.1 | 11.2 | 7.81 | 9.53 | 10.2 | 16.7 | 23.3 | 8.73 | 7.49 | 13.3 | 8.64 | 10.7 | 9.9 |
| Zn | 124 | 95.0 | 75.9 | 81.3 | 66.6 | 72.5 | 91.5 | 94.2 | 85.9 | 67.9 | 109 | 76.2 | 78.5 | 77.3 |

| | 1994 | | | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Collection Date: | 1/12/94 | 1/14/94 | 2/2/94 | 2/4/94 | 3/16/94 | 3/18/94 | 4/13/94 | 4/15/94 | 5/11/94 | 5/13/94 | 6/1/94 | 6/3/94 | 7/13/94 | 7/15/94 |
| MWRA ID: | 39400237 | 39400238 | 39401154 | 39401155 | 39402880 | 39402881 | 39404055 | 39404056 | 39405310 | 39405312 | 39405747 | 39405748 | 39407459 | 39407462 |
| Ag | 4.84 | 4.55 | 4.54 | 4.52 | 3.83 | 3.14 | 5.08 | 4.41 | 5.15 | 5.02 | 8.57 | 4.15 | 7.5 | 4.74 |
| Cd | 0.91 | 1.42 | 0.67 | 0.56 | 0.56 | 0.56 | 1.00 | 0.88 | 0.41 | 0.7 | 0.9 | 8.735 | 0.962 | 1.00 |
| Cr | 2.72 | 2.67 | 2.61 | 3.82 | 4.31 | 3.46 | 4.99 | 4.03 | 3.48 | 3.23 | 5.58 | 4.01 | 10.9 | 5.75 |
| Cu | 64.7 | 81.8 | 75.2 | 50.1 | 48.0 | 51.3 | 55.4 | 50.5 | 74.8 | 111 | 97.4 | 67.1 | 108 | 76.9 |
| Hg | 0.118 | 0.185 | 0.133 | 0.116 | 0.109 | 0.219 | 0.186 | 0.122 | 0.103 | 0.201 | 0.211 | 0.156 | 0.15 | 0.115 |
| Mo | 8.38 | 8.61 | 9.53 | 9.15 | 4.79 | 5.42 | 12.3 | 12.2 | 15.6 | 15.3 | 16.6 | 17.4 | 22 | 25.7 |
| Ni | 6.06 | 6.07 | 5.9 | 5.37 | 6.86 | 5.11 | 29.8 | 5.92 | 4.6 | 12.1 | 5.89 | 5.04 | 7.83 | 43.3 |
| Pb | 8.84 | 11.5 | 6.95 | 11.1 | 11.0 | 9.93 | 12.2 | 10.9 | 7.44 | 16.5 | 19.9 | 9.53 | 25.7 | 16.4 |
| Zn | 96.3 | 91.7 | 79.2 | 94.8 | 83.0 | 87.0 | 73.7 | 74.8 | 83.6 | 96.2 | 136 | 81.7 | 120 | 98.4 |

| Collection Date: | 8/10/94 | 8/12/94 | 9/14/94 | 9/16/94 | 10/12/94 | 10/14/94 | 11/15/94 | 11/17/94 |
|---|---|---|---|---|---|---|---|---|
| MWRA ID: | 39408814 | 39408815 | 39409914 | | 39410840 | 39410841 | 39412306 | 39412307 |
| Ag | 4.98 | 5.7 | 4.82 | No | 6.34 | 4.59 | 5.8 | 6.15 |
| Cd | 0.414 | 0.958 | 0.467 | samples | 0.445 | 0.983 | 0.392 | 0.613 |
| Cr | 4.62 | 4.07 | 3.51 | collected. | 5.55 | 3.65 | 3.82 | 4.56 |
| Cu | 80.7 | 83.2 | 108.6 | | 84.1 | 68.6 | 96 | 91.5 |
| Hg | 0.138 | 0.263 | 0.142 | | 0.177 | 0.118 | 0.144 | 0.117 |
| Mo | 20.8 | 18 | 24.1 | | 17.3 | 18.4 | 20.9 | 24.6 |
| Ni | 7.07 | 5.71 | 8.28 | | 8.79 | 6.4 | 5.89 | 7.09 |
| Pb | 11.1 | 9.5 | 11.8 | | 14.5 | 5.79 | 10.7 | 10.9 |
| Zn | 87.0 | 78.0 | 85.4 | | 77.6 | 69.8 | 84.3 | 70.4 |

|  |  | BIO- SI |  |  | SIO4 |  |  | POC |  |  |  | DOC |  |  | TOC |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
|  |  | uM |  |  | uM |  |  | mg/l |  |  |  | mgC/l |  |  | mgC/l |
| Col_date | Rep 1 | Rep 2 | Avg |  | Sum |  | Rep 1 | Rep 2 | Avg |  | Rep 1 | Rep 2 | Avg |  | Sum |
| 12/08/93 | 7.9 | 7.8 | 7.8 |  | 169.2 |  | 25.1 | 23.6 | 24.3 |  | 12.9 | 13.4 | 13.1 |  | 37.5 |
| 01/12/94 | 6.7 | 6.9 | 6.8 |  | 144.7 |  | 31.3 | 30.2 | 30.8 |  | 34.0 | 33.6 | 33.8 |  | 64.6 |
| 01/14/94 | 10.1 | 10.4 | 10.2 |  | 109.2 |  | 30.2 | 30.0 | 30.1 |  | 32.6 | 33.0 | 32.8 |  | 62.9 |
| 03/16/94 | 5.4 | 4.3 | 4.8 |  | 172.6 |  | 14.7 | 16.3 | 15.5 |  | 19.1 | 19.8 | 19.4 |  | 34.9 |
| 03/18/94 | 2.0 | 6.3 | 4.1 |  | 173.3 |  | 17.0 | 15.7 | 16.4 |  | 20.5 | 21.2 | 20.8 |  | 37.2 |
| 04/13/94 | 8.3 | 5.0 | 6.7 |  | 149.6 |  | 20.5 | 19.0 | 19.7 |  | 28.1 | 28.8 | 28.5 |  | 48.2 |
| 04/15/94 | 7.5 | 8.3 | 7.9 |  | 161.5 |  | 22.5 | 21.1 | 21.8 |  | 30.5 | 30.4 | 30.5 |  | 52.2 |
| 05/11/94 | 5.2 | 5.0 | 5.1 |  | 173.4 |  | 15.9 | 17.1 | 16.5 |  | 25.9 | 25.8 | 25.8 |  | 42.3 |
| 05/13/94 | 6.9 | 5.3 | 6.1 |  | 176.0 |  | 14.9 | 15.3 | 15.1 |  | 26.0 | 25.1 | 25.6 |  | 40.7 |
| 06/01/94 | 5.8 | 5.5 | 5.6 |  | 167.9 |  | 15.9 | 16.2 | 16.1 |  | 24.7 | 25.1 | 24.9 |  | 41.0 |
| 06/03/94 | 5.4 | 8.7 | 7.1 |  | 167.5 |  | 22.3 | 16.9 | 19.6 |  | 38.2 | 38.3 | 38.2 |  | 57.8 |
| 07/13/94 | 3.4 | 7.2 | 5.3 |  | 153.2 |  | 23.6 | 22.4 | 23.0 |  | 41.1 | 42.1 | 41.6 |  | 64.6 |
| 07/15/94 | 24.4 | 18.5 | 21.4 |  | 138.9 |  | 27.5 | 25.6 | 26.6 |  | 38.7 | 37.3 | 38.0 |  | 64.6 |
| 08/09/94 | 6.6 | 5.2 | 5.9 |  | 138.0 |  | 27.5 | 31.0 | 29.3 |  | 46.2 | 46.6 | 46.4 |  | 75.6 |
| 08/11/94 | 4.6 | 5.6 | 5.1 |  | 148.4 |  | 32.1 | 32.1 | 32.1 |  | 48.7 | 48.5 | 48.6 |  | 80.7 |
| 09/14/94 | 4.8 | 5.9 | 5.4 |  | 137.4 |  | 31.4 | 22.2 | 26.8 |  | 39.8 | e | 39.8 |  | 66.7 |
| 11/17/94 | 3.9 | 6.4 | 5.1 |  | 115.2 |  | 35.6 | 34.0 | 34.8 |  | 39.4 | e | 39.4 |  | 74.2 |
| 11/15/94 | 6.6 | 8.9 | 7.8 |  | 120.8 |  | 36.6 | 36.4 | 36.5 |  | 39.8 | e | 39.8 |  | 76.3 |

|  | NO3+N |  | NO2 |  | NO3 |  |  | PON |  |  |  | TDN |  |  | TN |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
|  | uM |  | uM |  | uM |  |  | uM |  |  |  | uM |  |  | uM |
| Col_dat | Avg |  | Avg |  | Avg |  | Rep 1 | Rep 2 | Avg |  | Rep 1 | Rep 2 | Avg |  | Sum |
| 12/08/93 | 21.3 |  | 8.9 |  | 12.4 |  | 1189.9 | 182.2 | 182.2 |  | 580.1 | 742.3 | 661.2 |  | 847.2 |
| 01/12/94 | 3.7 |  | 1.0 |  | 2.8 |  | 193.3 | 193.6 | 193.4 |  | 1092.6 | 971.6 | 1032.1 |  | 1225.5 |
| 01/14/94 | 3.0 |  | 0.8 |  | 2.3 |  | 220.1 | 190.6 | 205.4 |  | 1115.7 | 973.4 | 1044.6 |  | 1249.9 |
| 03/16/94 | 132.4 |  | 5.9 |  | 126.5 |  | 96.9 | 110.2 | 103.5 |  | 650.3 | 627.7 | 639.0 |  | 742.5 |
| 03/18/94 | 122.9 |  | 6.0 |  | 116.9 |  | 117.1 | 96.7 | 106.8 |  | e | e | e |  | NA |
| 04/13/94 | 10.6 |  | 4.9 |  | 5.7 |  | 216.1 | 172.7 | 194.9 |  | 947.1 | 961.3 | 954.2 |  | 1149.2 |
| 04/15/94 | 25.1 |  | 7.6 |  | 17.5 |  | 195.9 | 174.0 | 185.0 |  | 721.1 | 711.9 | 716.5 |  | 901.5 |
| 05/11/94 | 18.4 |  | 4.8 |  | 13.6 |  | 146.8 | 266.8 | 156.8 |  | 711.7 | 650.1 | 680.9 |  | 837.7 |
| 05/13/94 | 21.1 |  | 6.5 |  | 14.6 |  | 126.1 | 140.6 | 133.3 |  | 786.9 | 774.9 | 780.9 |  | 914.2 |
| 06/01/94 | 5.5 |  | 1.7 |  | 3.8 |  | 160.3 | 157.6 | 158.9 |  | 945.7 | 949.7 | 947.7 |  | 1106.7 |
| 06/03/94 | 7.8 |  | 3.3 |  | 4.6 |  | 195.1 | 166.7 | 181.0 |  | 1143.3 | 1081.3 | 1112.3 |  | 1324.2 |
| 07/13/94 | 9.0 |  | 5.8 |  | 3.2 |  | 267.1 | 255.6 | 261.3 |  | 1457.3 | 1493.8 | 1475.5 |  | 1736.9 |
| 07/15/94 | 3.2 |  | 1.3 |  | 1.9 |  | 260.0 | 234.6 | 247.3 |  | 1179.7 | 1097.5 | 1138.6 |  | 1385.9 |
| 08/09/94 | 6.3 |  | 1.6 |  | 4.8 |  | 242.4 | 251.8 | 247.1 |  | 1316.8 | 1411.6 | 1364.2 |  | 1611.3 |
| 08/11/94 | 4.8 |  | 1.2 |  | 3.6 |  | 256.1 | 256.1 | 256.1 |  | 83.28 S | e | S |  | NA |
| 09/14/94 | 4.4 |  | 1.0 |  | 3.3 |  | 291.1 | 220.0 | 255.6 |  | 402.47 S | 1364.1 | 1364.1 |  | 1619.6 |
| 11/17/94 | 6.3 |  | 6.8 |  | -0.5 |  | 248.9 | 238.3 | 243.6 |  | 1044.8 | 1039.2 | 1042.0 |  | 1285.6 |
| 11/15/94 | 5.6 |  | 0.9 |  | 4.6 |  | 307.1 | 299.4 | 303.2 |  | 1152.4 | 1034.6 | 1093.5 |  | 1396.7 |

|  |  | PARTP |  |  |  | TDP |  |  | PO4 |  | TP |  | NH4 |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
|  |  | uM |  |  |  | uM |  |  | uM |  | uM |  | uM |
| Col_dat | Rep 1 | Rep 2 | Avg |  | Rep 1 | Rep 2 | Avg |  | Avg |  | Avg |  | Avg |
| 12/08/93 | 24.7 | 23.9 | 24.3 |  | 25.0 | 30.1 | 27.6 |  | 32.8 |  | 51.9 |  | 765.5 |
| 01/12/94 | 21.3 | 18.1 | 19.7 |  | 59.9 | 54.7 | 57.3 |  | 54.1 |  | 77.0 |  | 1043.1 |
| 01/14/94 | 22.6 | 6.8 | 14.7 |  | 61.9 | 52.9 | 57.4 |  | 43.3 |  | 72.1 |  | 883.3 |
| 03/16/94 | 14.2 | 10.5 | 12.4 |  | 23.6 | 21.9 | 22.7 |  | 19.3 |  | 35.1 |  | 301.6 |
| 03/18/94 | 8.8 | 18.4 | 13.6 |  | e | e | e |  | 22.4 |  | NA |  | 328.8 |
| 04/13/94 | 20.2 | 21.4 | 20.8 |  | 49.8 | 49.2 | 49.5 |  | 47.5 |  | 70.3 |  | 786.0 |
| 04/15/94 | 20.0 | 17.2 | 18.6 |  | 36.5 | 35.5 | 36.0 |  | 43.0 |  | 54.6 |  | 578.0 |
| 05/11/94 | 19.6 | 22.6 | 21.1 |  | 38.3 | 37.2 | 37.8 |  | 44.1 |  | 58.8 |  | 626.0 |
| 05/13/94 | 15.1 | 18.9 | 17.0 |  | 37.8 | 39.3 | 38.6 |  | 42.0 |  | 55.6 |  | 664.0 |
| 06/01/94 | 22.7 | 22.6 | 22.7 |  | 62.7 | 53.5 | 58.1 |  | 50.4 |  | 80.8 |  | 775.0 |
| 06/03/94 | 21.4 | 21.0 | 21.2 |  | 74.7 | 69.9 | 72.3 |  | 54.8 |  | 93.5 |  | 932.0 |
| 07/13/94 | 31.9 | 23.9 | 27.9 |  | 89.8 | 87.2 | 88.5 |  | 68.4 |  | 116.4 |  | 1190.0 |
| 07/15/94 | 26.7 | 25.0 | 25.8 |  | 86.8 | 78.2 | 82.5 |  | 61.0 |  | 108.3 |  | 929.0 |
| 08/09/94 | 21.3 | 21.7 | 21.5 |  | 91.7 | 101.3 | 96.5 |  | 78.8 |  | 117.9 |  | 1094.0 |
| 08/11/94 | 15.5 | 23.0 | 19.2 |  | 91.1 | e | 91.1 |  | 86.0 |  | 110.3 |  | 1224.0 |
| 09/14/94 | 21.3 | 22.2 | 21.8 |  | 93.1 | 98.1 | 95.6 |  | 84.8 |  | 117.4 |  | 1054.0 |
| 11/17/94 | 18.4 | 15.6 | 17.0 |  | 75.8 | 70.2 | 73.0 |  | 71.2 |  | 90.0 |  | 683.0 |
| 11/15/94 | 19.1 | 23.6 | 21.3 |  | 259.2 | 153.6 | 206.4 |  | 81.2 |  | 227.7 |  | 854.0 |

Table x. Stable Isotope Ratios for individual 24-H composite Deer Island effluent (December 1993 - November 1994).

| Collection Date: | 12/8/93 | 1/12/94 | 2/2/94 | 3/16/94 | 4/13/94 | 5/11/94 | 6/1/94 | 7/13/94 | 8/10/94 | 9/14/94 | 10/12/94 | 11/15/94 |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| MWRA ID: | NA | 39400239 |  | 39402882 | 39404289 | 39405407 | 39405749 | 39407460 | 39408813 | 39409916 | 39410927 | 39412267 |
| Stable Nitrogen Isotope: | 1.2 | 1 | NR | 1.9 | 0.7 | 1.1 | 0.7 | 0 | lost | 1.2 | 1.8 | 1.6 |
| Stable Sulfur Isotope: | 5.7 | 6.1 | NR | too small | 8.4 | 5 | too small | 5.8 | lost | 5 | 4.5 | too small |

NA: Not assigned.
NR: Not requested.

Table x. *Clostridium perfringens* per 100mL for individual 24-h composite Deer Island effluent (December 1993 - November 1994).

| Collection Date: | 12/8/93 | 12/10/93 | 1/2/94 | 1/14/94 | 2/2/94 | 2/4/94 | 3/16/94 | 3/18/94 | 4/13/94 | 4/15/94 | 5/11/94 | 5/16/94 |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| MWRA ID: | NA | 39315831 | 39400237 | 39400238 |  |  | 39402880 | 39402881 | 39404211 | 39404054 | 39405310 | 39405371 |
| *C. perfringens*: | 4.6E+04 | 3.7E+04 | 2.0E+04 | SP | NR | NR | 1.4E+04 | SP | 2.5E+04 | 1.9E+04 | 1.1E+04 | 7.6E+03 |

| Collection Date: | 6/1/94 | 6/3/94 | 7/13/94 | 7/15/94 | 8/10/94 | 8/12/94 | 9/14/94 | 9/16/94 | 10/12/94 | 10/14/94 | 11/15/94 | 11/17/94 |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| MWRA ID: | 39405747 | 39405748 | 39407459 | 39407462 | 39408814 | 39408815 | 39409914 |  | 39410840 | 39410841 | 39412306 | 39412307 |
| *C. perfringens*: | 9.4E+03 | 1.0E+04 | 1.2E+04 | 2.4E+03 | 1.1E+04 | 6.9E+03 | 1.1E+04 | NS | 8.1E+03 | 9.5E+03 | 1.8E+04 | 9.1E+03 |

NA: Not assigned.
SP: Shipment problems, sample received after holding time, not analyzed.
NR: Not requested.
NS: No sample collected.

Battelle Ocean Meth_code: KP93PAH
MWRA Task Inst_code: GCMS
Sampling Eve Batch_no: 7
Batch #7 PAH Data in ng/L
File: A:\MWR PAH7

| Lab_sample_I | MY22 | MY23 | MY24 | OK79 | OK80 | OK81 | OK83 | OK84 | OK85 | OT49 | OT50 | OT51 |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Sample_ID | NA | NA | NA | 39405739 | 39405744 | 39405743 | 39405853 | 39405854 | 39405740 | 39407263 OR | 39407265 OR | 39407267 OR |
| Treatment_pla | Pilot Plant Effl | Pilot Plant Infl | Pilot Plant CE | Pilot Plant | Pilot Plant | Pilot Plant | Pilot Plant | Pilot Plant | Pilot Plant | Pilot Plant Infl | Pilot Plant Pri | Pilot Plant Sec |
| Date_sampled | 07-Dec-93 | 07-Dec-93 | 07-Dec-93 | 01-Jun-94 | 03-Jun-94 | 01-Jun-94 | 01-Jun-94 | 03-Jun-94 | 03-Jun-94 | 15-Jul-94 | 15-Jul-94 | 15-Jul-94 |
| Anal_date | 14-Dec-93 | 14-Dec-93 | 14-Dec-93 | 08-Jun-94 | 08-Jun-94 | 08-Jun-94 | 08-Jun-94 | 08-Jun-94 | 08-Jun-94 | 19-Jul-94 | 19-Jul-94 | 19-Jul-94 |
| Date_analyze | 07-Jan-94 | 07-Jan-94 | 07-Jan-94 | 22-Jun-94 | 22-Jun-94 | 22-Jun-94 | 22-Jun-94 | 22-Jun-94 | 22-Jun-94 | 04-Sep-94 | 04-Sep-94 | 04-Sep-94 |
| Sample_size ( | 2.01 | 2.01 | 2.00 | 2.00 | 2 00 | 2.02 | 2.00 | 1.83 | 2.00 | 2.000 | 2.005 | 2.010 |
| Unit_code | (ng/L) | (ng/L) | (ng/L) | | | | | | | | | |
| naphthalene | 959.97 | 1132.45 | 664.67 | 536.04 | 18.71 | 19.87 | 1465.77 | 1475.61 | 450.80 | 888.17 | 827.91 | 7.50 |
| C1-naphthale | 1465.65 | 1848.56 | 1005.68 | 631.29 a | a | | 1784.77 | 1753.33 | 426.00 | 1949.12 | 1643.85 a | |
| C2-naphthale | 2364.73 | 3323.48 | 1243.90 | 1083.56 a | a | | 2282.88 | 2935.34 | 746.36 | 4219.69 | 3145.96 a | |
| C3-naphthale | 2356.56 | 3381.11 | 928.08 | 1355.57 a | a | | 1802.26 | 3003.29 | 983.79 | 4118.23 | 2897.96 a | |
| C4-naphthale | 1418.31 | 2285.88 | 426.05 | 833.16 a | a | | 964.46 | 1693.39 | 473.12 | 2433.42 | 1530.68 a | |
| biphenyl | 171.32 | 224.50 | 112.43 | 89.83 a | a | | 177.11 | 196.08 | 86.48 | 284.62 | 237.27 | 10.11 |
| acenaphthyle | 7.51 | 11.58 | 5.52 a | a | a | a | a | a | | 10.84 a | | 4.65 |
| acenaphthen | 100.73 | 138.68 | 68.13 | 83.14 a | a | | 242.02 | 222.66 a | | 148.74 | 111.42 a | |
| dibenzofuran | 59.21 | 83.48 | 39.48 | 37.60 a | a | | 76.99 | 76.29 | 14.56 | 111.64 | 80.04 a | |
| fluorene | 136.18 | 204.14 | 79.05 | 113.76 a | a | | 230.28 | 275.95 | 103.83 | 284.60 | 200.49 | 1.72 |
| C1-fluorenes | 316.12 | 530.53 | 137.84 | 279.18 a | a | | 519.02 | 558.33 | 205.13 | 1027.43 | 657.88 | 39.08 |
| C2-fluorenes | 606.35 | 919.38 | 186.60 | 445.22 a | a | | 489.59 | 1002.19 | 343.60 | 1388.03 | 741.82 | 64.95 |
| C3-fluorenes | 603.55 | 927.76 | 171.49 | 686.82 a | a | | 686.16 | 949.89 | 408.08 | 1573.19 | 937.25 | 117.87 |
| phenanthrene | 261.80 | 414.44 | 111.02 | 262.69 a | | 11.93 | 457.02 | 658.62 | 199.51 | 641.44 | 406.82 | 3.66 |
| anthracene | 34.80 | 54.10 | 12.68 | 24.57 a | a | | 48.52 | 44.69 | 21.72 | 60.05 | 27.89 | 1.45 |
| C1-phenanthr | 573.22 | 842.80 | 174.30 | 616.66 a | a | | 812.57 | 1365.94 | 358.99 | 1735.96 | 860.22 | 11.26 |
| C2-phenanthr | 748.98 | 1113.79 | 218.21 | 855.78 | 109.99 | 233.00 | 1036.44 | 1688.74 | 430.20 | 2396.66 | 1085.95 | 27.12 |
| C3-phenanthr | 544.67 | 821.33 | 139.31 | 604.16 | 211.25 | 419.12 | 717.21 | 1416.59 | 276.70 | 1743.04 | 724.44 | 38.73 |
| C4-phenanthr | 271.89 | 396.79 a | | 319.36 | 71.89 | 180.92 | 325.45 | 791.92 | 125.84 | 953.69 | 295.60 a | |
| dibenzothioph | 56.85 | 84.51 | 25.17 | 33.17 a | a | | 55.92 | 68.90 | 22.35 | 113.31 | 73.69 a | |
| C1-dibenzothi | 198.77 | 302.34 | 64.57 | 161.83 a | a | | 185.92 | 355.84 | 137.14 | 449.67 | 210.14 a | |
| C2-dibenzothi | 329.81 | 508.19 | 95.85 | 226.94 a | a | | 286.17 | 683.12 | 213.07 | 697.84 | 372.17 a | |
| C3-dibenzothi | 300.86 | 471.82 | 88.31 | 197.22 | 104.07 | 187.96 | 233.89 | 703.60 | 175.55 | 573.52 | 299.50 a | |
| fluoranthene | 93.82 | 182.39 | 29.76 | 121.89 | 20.30 | 42.96 | 116.99 | 209.61 | 98.79 | 234.97 | 109.16 | 4.44 |

Battelle Ocean
MWRA Task
Sampling Eve
Batch #7 PAH
File: A:\MWR

| Lab_sample_I | OU89 | OU93 | OU96 |
|---|---|---|---|
| Sample_ID | 39407918 OR | 39407920 OR | 39407922 OR |
| Treatment_pla | Pilot Plant Infl | Pilot Plant Pri | Pilot Plant Se |
| Date_sampled | 29-Jul-94 | 29-Jul-94 | 29-Jul-94 |
| Anal_date | 02-Aug-94 | 02-Aug-94 | 02-Aug-94 |
| Date_analyze | 15-Sep-94 | 15-Sep-94 | 15-Sep-94 |
| Sample_size ( | 1.900 | 2.240 | 2.480 |
| Unit_code | | | |
| | | | |
| naphthalene | 2251.48 | 973.07 | 15.35 |
| C1-naphthale | 5983.05 | 1809.02 | 15.72 |
| C2-naphthale | 14952.74 | 3189.44 | 15.27 |
| C3-naphthale | 15773.23 | 2972.80 | 38.82 |
| C4-naphthale | 10242.50 | 1518.15 a | |
| biphenyl | 639.33 | 261.48 | 1.57 |
| acenaphthyle | 90.44 | 9.67 | 5.15 |
| acenaphthen | 380.32 | 190.82 | 1.58 |
| dibenzofuran | 221.53 | 93.80 | 1.99 |
| fluorene | 641.75 | 240.97 | 1.68 |
| C1-fluorenes | 1765.93 | 580.70 | 19.48 |
| C2-fluorenes | 3360.43 | 794.44 | 62.12 |
| C3-fluorenes | 3800.57 | 1034.01 | 168.10 |
| phenanthrene | 2424.32 | 443.59 | 1.92 |
| anthracene | 238.84 | 54.54 | 0.98 |
| C1-phenanthr | 3550.25 | 1026.37 | 7.75 |
| C2-phenanthr | 4442.76 | 1200.80 | 29.80 |
| C3-phenanthr | 2808.85 | 762.05 | 97.21 |
| C4-phenanthr | 1652.34 | 391.67 | 50.79 |
| dibenzothioph | 347.39 | 96.60 | 0.92 |
| C1-dibenzothi | 1006.61 | 328.75 | 10.23 |
| C2-dibenzothi | 1563.37 | 360.19 | 22.92 |
| C3-dibenzothi | 1353.32 | 294.35 | 28.66 |
| fluoranthene | 2243.38 | 196.14 | 3.76 |

Battelle Ocean Meth_code: KP93PAH
MWRA Task Inst_code: GCMS
Sampling Eve Batch_no: 7
Batch #7 PAH Data in ng/L
File: A:\MWR PAH7

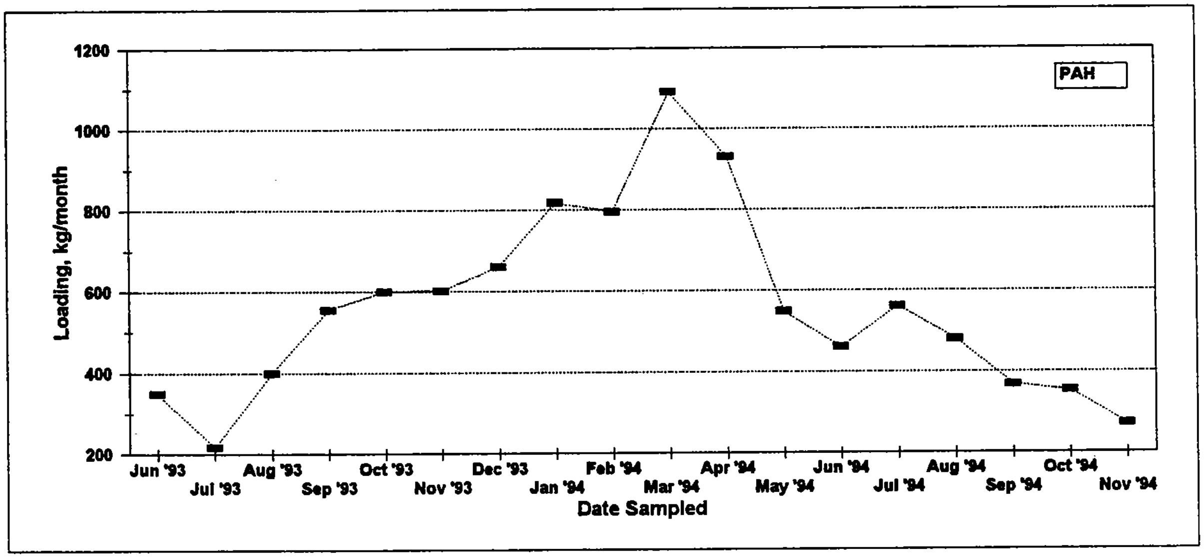
| Lab_sample_I | MY22 | MY23 | MY24 | OK79 | OK80 | OK81 | OK83 | OK84 | OK85 | OT49 | OT50 | OT51 |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Sample_ID | NA | NA | NA | 39405739 | 39405744 | 39405743 | 39405853 | 39405854 | 39405740 | 39407263 OR | 39407265 OR | 39407267 OR |
| Treatment_pla | Pilot Plant Effl | Pilot Plant Infl | Pilot Plant CE | Pilot Plant | Pilot Plant | Pilot Plant | Pilot Plant | Pilot Plant | Pilot Plant | Pilot Plant Infl | Pilot Plant Pri | Pilot Plant Sec |
| Date_sampled | 07-Dec-93 | 07-Dec-93 | 07-Dec-93 | 01-Jun-94 | 03-Jun-94 | 01-Jun-94 | 01-Jun-94 | 03-Jun-94 | 03-Jun-94 | 15-Jul-94 | 15-Jul-94 | 15-Jul-94 |
| Anal_date | 14-Dec-93 | 14-Dec-93 | 14-Dec-93 | 08-Jun-94 | 08-Jun-94 | 08-Jun-94 | 08-Jun-94 | 08-Jun-94 | 08-Jun-94 | 19-Jul-94 | 19-Jul-94 | 19-Jul-94 |
| Date_analyze | 07-Jan-94 | 07-Jan-94 | 07-Jan-94 | 22-Jun-94 | 22-Jun-94 | 22-Jun-94 | 22-Jun-94 | 22-Jun-94 | 22-Jun-94 | 04-Sep-94 | 04-Sep-94 | 04-Sep-94 |
| Sample_size ( | 2.01 | 2.01 | 2.00 | 2.00 | 2.00 | 2.02 | 2.00 | 1.83 | 2.00 | 2.000 | 2.005 | 2.010 |
| Unit_code | (ng/L) | (ng/L) | (ng/L) | | | | | | | | | |
| | | | | | | | | | | | | |
| pyrene | 116.44 | 215.85 | 37.58 | 151.31 | 62.80 | 111.76 | 142.67 | 309.14 | 101.41 | 331.55 | 156.95 | 17.71 |
| C1-fluoranthe | 149.71 | 229.26 | 49.77 | 230.57 | 78.79 | 141.29 | 242.02 | 439.76 | 78.83 | 596.49 | 246.38 | 21.08 |
| benz[a]anthra | 31.32 | 63.90 | 12.37 | 73.26 | 26.03 | 38.02 | 58.93 | 96.46 | 43.28 | 66.24 | 26.40 | 4.91 |
| chrysene | 44.49 | 92.30 | 17.27 | 116.60 | 36.61 | 61.77 | 84.49 | 168.67 | 59.15 | 95.84 | 39.05 | 6.46 |
| C1-chrysene | 70.01 | 104.19 | 20.06 | 261.30 | 94.98 | 118.03 | 264.70 | 338.50 | 80.41 | 215.74 | 72.71 | 5.07 |
| C2-chrysene | a | 110.62 | a | 371.87 | 102.60 | 166.26 | 368.97 | 459.22 | 95.39 | 277.21 | 93.38 | a |
| C3-chrysene | a | a | a | 189.79 | 56.34 | 89.47 | 230.92 | 329.11 | a | 134.67 | 54.91 | a |
| C4-chrysene | a | a | a | a | a | a | a | a | a | a | a | a |
| benzo[b]fluor | 28.64 | 75.20 | 10.23 | 81.60 | 36.96 | 56.10 | 45.76 | 117.92 | 58.84 | 61.95 | 23.11 | 6.20 |
| benzo[k]fluora | 16.66 | 35.70 | 5.11 | 28.26 | 13.43 | 18.85 | 14.26 | 40.60 | 21.59 | 19.19 | 6.68 | 3.51 |
| benzo[e]pyren | 20.89 | 46.13 | 6.76 | 48.83 | 22.66 | 34.82 | 31.34 | 69.14 | 33.48 | 40.40 | 15.71 | 7.34 |
| benzo[a]pyren | 21.50 | 56.02 | 8.23 | 59.57 | 26.86 | 36.19 | 37.17 | 85.13 | 33.35 | 46.86 | 15.67 | 4.94 |
| perylene | 5.54 | 12.62 | 1.39 | 21.89 | 16.67 | 12.26 | 14.62 | 34.38 | 11.91 | 17.86 | 6.59 | 8.96 |
| indeno[1,2,3- | a | 54.03 | a | 56.75 | 21.00 | 28.00 | 40.00 | 73.09 | 41.98 | 25.70 | 9.71 | 4.78 |
| dibenz[a,h]ant | a | a | a | 15.10 | a | a | a | 14.60 | 8.13 | 5.17 | 4.84 | 2.40 |
| benzo[g,h,i]pe | 14.09 | 38.93 | 5.98 | 37.37 | 17.82 | 24.29 | 13.43 | 58.46 | 21.78 | 40.79 | 17.25 | 13.62 |
| Total PAH | 14500.95 | 21338.78 | 6202.85 | 11343.52 | 1149.75 | 2032.86 | 16586.69 | 24764.08 | 6991.15 | 30013.55 | 18267.44 | 439.52 |
| | | | | | | | | | | | | |
| 1-phenyl deca | 1495.75 | 1955.79 | 448.85 | 708.41 | 521.32 | 392.97 | 1016.27 | 1008.48 | 1451.87 | 603.57 | 572.32 | 200.90 |
| 1-phenyl und | 5447.85 | 6646.05 | 1570.89 | 2539.29 | 2030.60 | 1446.53 | 3250.27 | 3296.06 | 6111.35 | 2716.16 | 2495.44 | 366.88 |
| 1-phenyl dod | 6010.05 | 7290.91 | 1843.37 | 2925.70 | 2179.47 | 1544.12 | 3760.09 | 3854.64 | 6921.36 | 2659.20 | 2222.06 | 507.71 |
| 1-phenyl tride | 2932.78 | 3529.93 | 894.74 | 1611.45 | 1432.62 | 1094.31 | 2220.75 | 1836.50 | 3813.38 | 1427.19 | 1358.07 | 438.26 |
| 1-phenyl tetra | 1042.64 | 1274.28 | 343.56 | 1235.95 | 549.27 | 772.13 | 997.29 | 1370.73 | 1532.89 | 802.14 | 615.34 | a |
| Total LAB | 16929.07 | 20696.96 | 5101.41 | 9020.82 | 6713.27 | 5250.06 | 11244.66 | 11366.40 | 19830.85 | 8208.27 | 7263.23 | 1513.76 |

Battelle Ocean
MWRA Task
Sampling Eve
Batch #7 PAH
File: A:\MWR

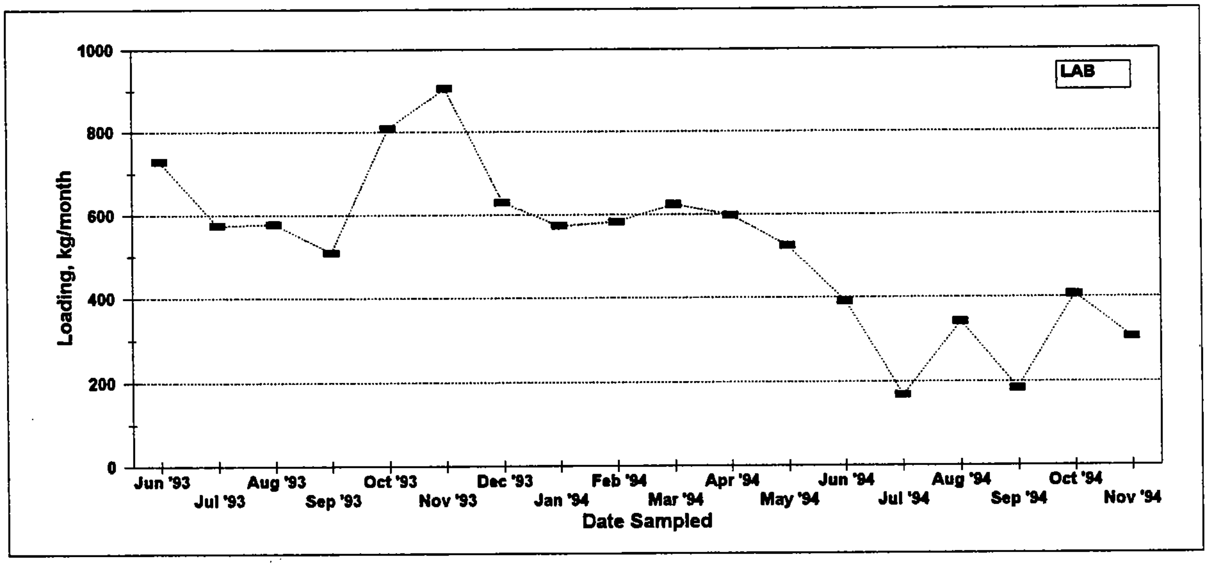
| Lab_sample_I | OU89 | OU93 | OU96 |
|---|---|---|---|
| Sample_ID | 39407918 OR | 39407920 OR | 39407922 OR |
| Treatment_pla | Pilot Plant Infl | Pilot Plant Pri | Pilot Plant Se |
| Date_sampled | 29-Jul-94 | 29-Jul-94 | 29-Jul-94 |
| Anal_date | 02-Aug-94 | 02-Aug-94 | 02-Aug-94 |
| Date_analyze | 15-Sep-94 | 15-Sep-94 | 15-Sep-94 |
| Sample_size ( | 1.900 | 2.240 | 2.480 |
| Unit_code | | | |
| | | | |
| pyrene | 2216.45 | 220.33 | 36.92 |
| C1-fluoranthe | 1511.44 | 291.86 | 44.17 |
| benz[a]anthra | 623.69 | 60.34 | 5.18 |
| chrysene | 1346.29 | 87.15 | 8.57 |
| C1-chrysene | 896.40 | 147.49 | 20.14 |
| C2-chrysene | 854.59 | 199.69 | 24.49 |
| C3-chrysene | a | 116.60 | 12.79 |
| C4-chrysene | a | a | a |
| benzo[b]fluor | 867.49 | 61.01 | 6.87 |
| benzo[k]fluora | 1061.48 | 17.89 | 2.29 |
| benzo[e]pyren | 561.52 | 37.35 | 3.92 |
| benzo[a]pyren | 503.72 | 38.71 | 4.20 |
| perylene | 159.72 | 13.08 | 48.84 |
| indeno[1,2,3- | 775.43 | 29.07 | 2.75 |
| dibenz[a,h]ant | 167.00 | 5.85 | 0.92 |
| benzo[g,h,i]pe | 546.99 | 33.55 | 2.51 |
| Total PAH | 93826.96 | 20183.40 | 826.31 |
| | | | |
| 1-phenyl deca | 1585.95 | 852.90 | 228.47 |
| 1-phenyl und | 4173.88 | 2132.21 | 457.63 |
| 1-phenyl dod | 2885.65 | 2027.02 | 289.06 |
| 1-phenyl tride | 2148.44 | 1306.80 | 487.25 |
| 1-phenyl tetra | 882.58 | 574.96 | a |
| Total LAB | 11676.50 | 6893.90 | 1462.41 |

# APPENDIX B

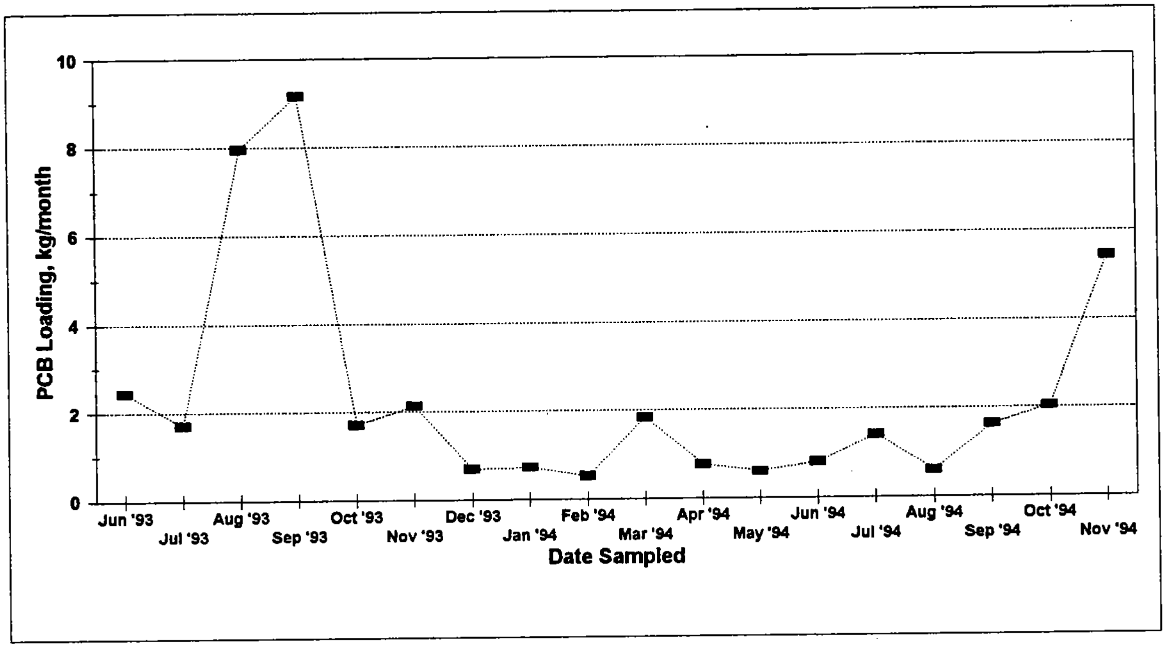
## Monthly Contaminant and Nutrient Loading Plots

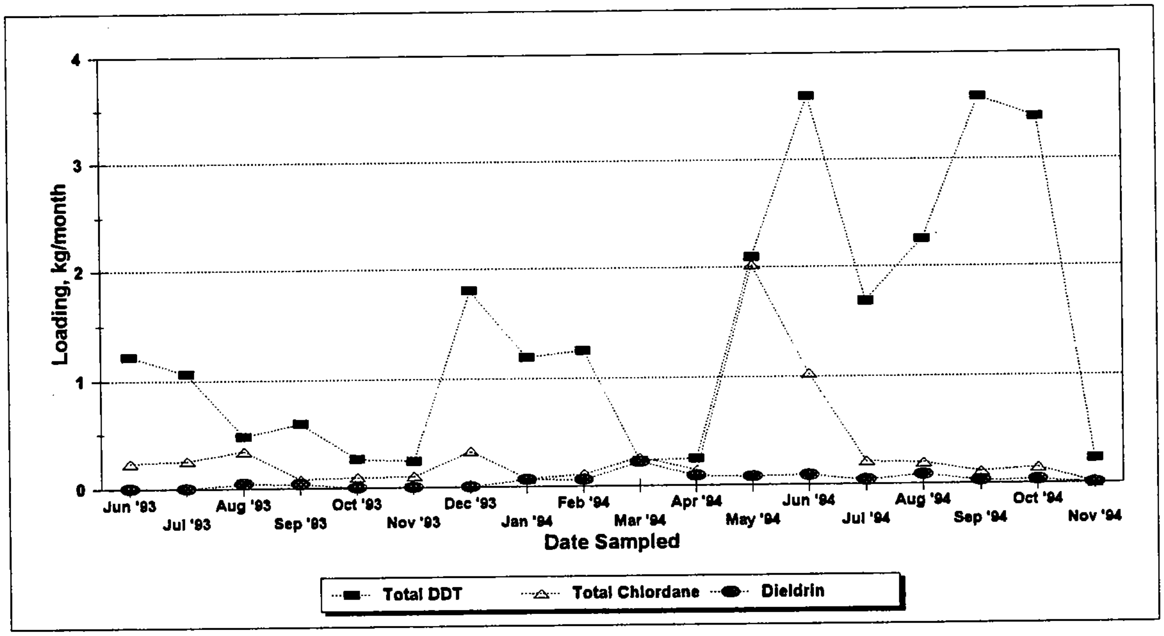


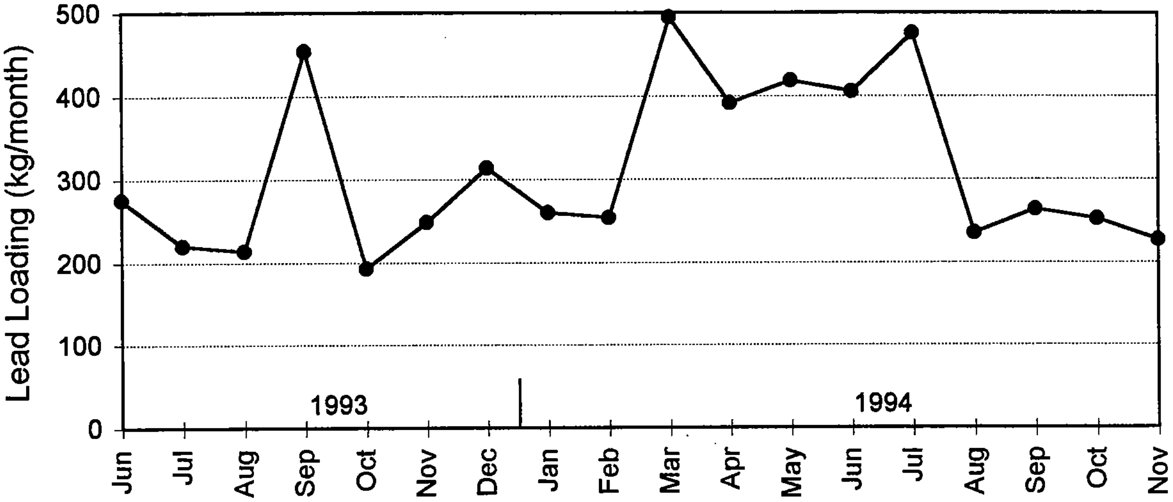
PAH
Loading, kg/month
1200
1000
800
600
400
200
Jun '93
Jul '93
Aug '93
Sep '93
Oct '93
Nov '93
Dec '93
Jan '94
Feb '94
Mar '94
Apr '94
May '94
Jun '94
Jul '94
Aug '94
Sep '94
Oct '94
Nov '94
Date Sampled



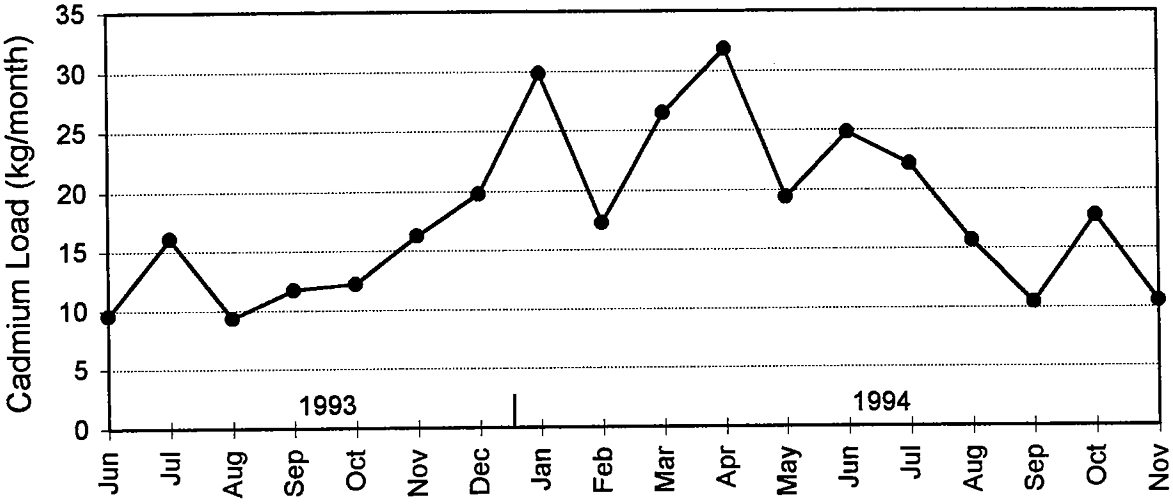
LAB
Loading, kg/month
1000
800
600
400
200
0
Jun '93
Jul '93
Aug '93
Sep '93
Oct '93
Nov '93
Dec '93
Jan '94
Feb '94
Mar '94
Apr '94
May '94
Jun '94
Jul '94
Aug '94
Sep '94
Oct '94
Nov '94
Date Sampled

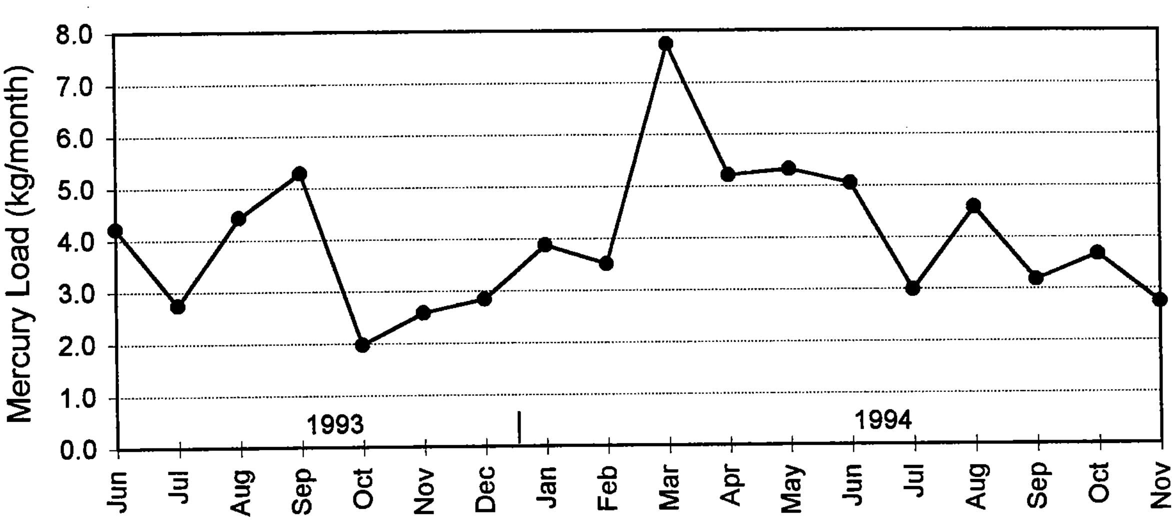

PCB Loading, kg/month
10
8
6
4
2
0
Jun '93
Jul '93
Aug '93
Sep '93
Oct '93
Nov '93
Dec '93
Jan '94
Feb '94
Mar '94
Apr '94
May '94
Jun '94
Jul '94
Aug '94
Sep '94
Oct '94
Nov '94
Date Sampled

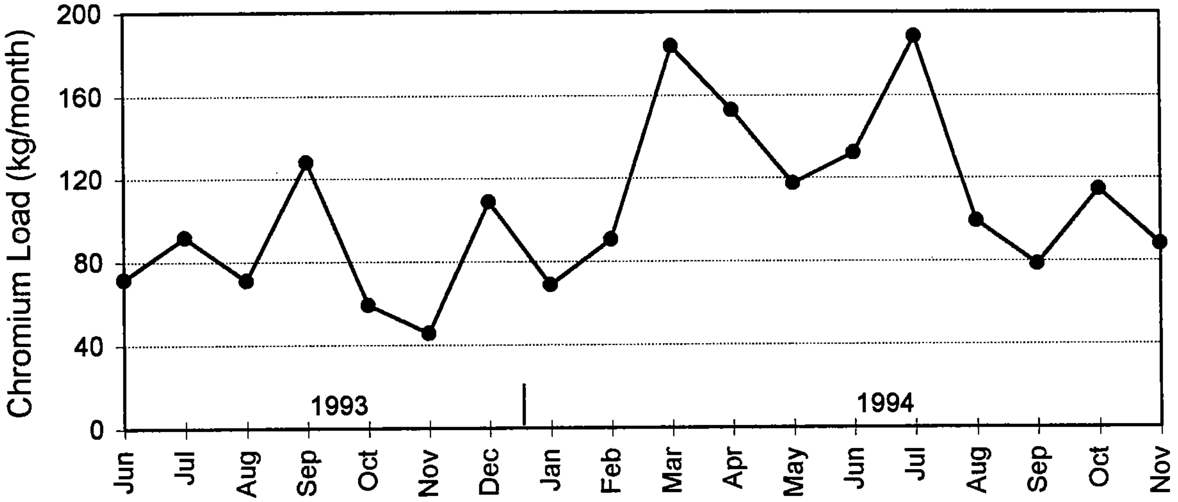

Loading, kg/month
4
3
2
1
0
Jun '93
Jul '93
Aug '93
Sep '93
Oct '93
Nov '93
Dec '93
Jan '94
Feb '94
Mar '94
Apr '94
May '94
Jun '94
Jul '94
Aug '94
Sep '94
Oct '94
Nov '94
Date Sampled
Total DDT
Total Chlordane
Dieldrin



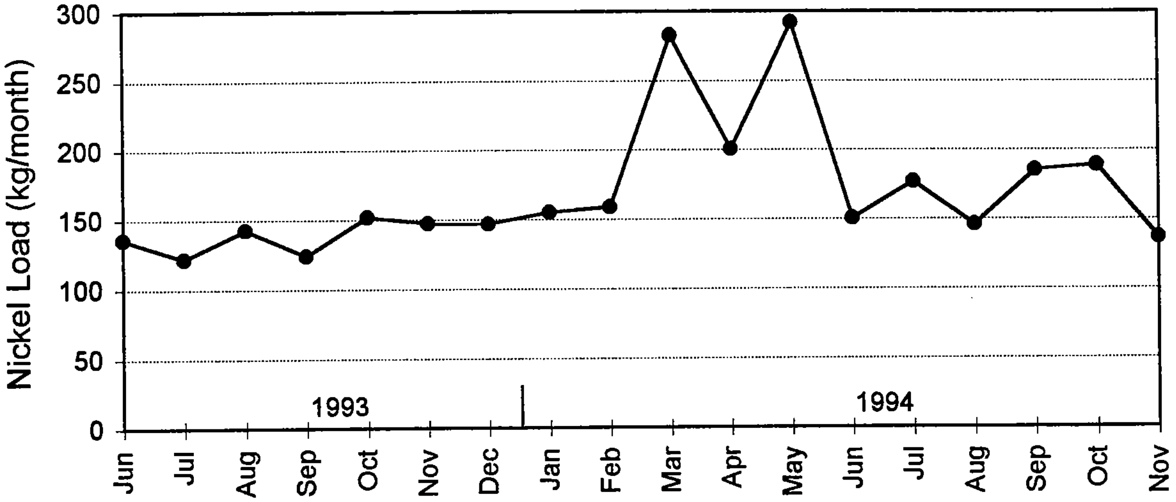
Lead Loading (kg/month)
500
400
300
200
100
0
1993
1994
Jun
Jul
Aug
Sep
Oct
Nov
Dec
Jan
Feb
Mar
Apr
May
Jun
Jul
Aug
Sep
Oct
Nov

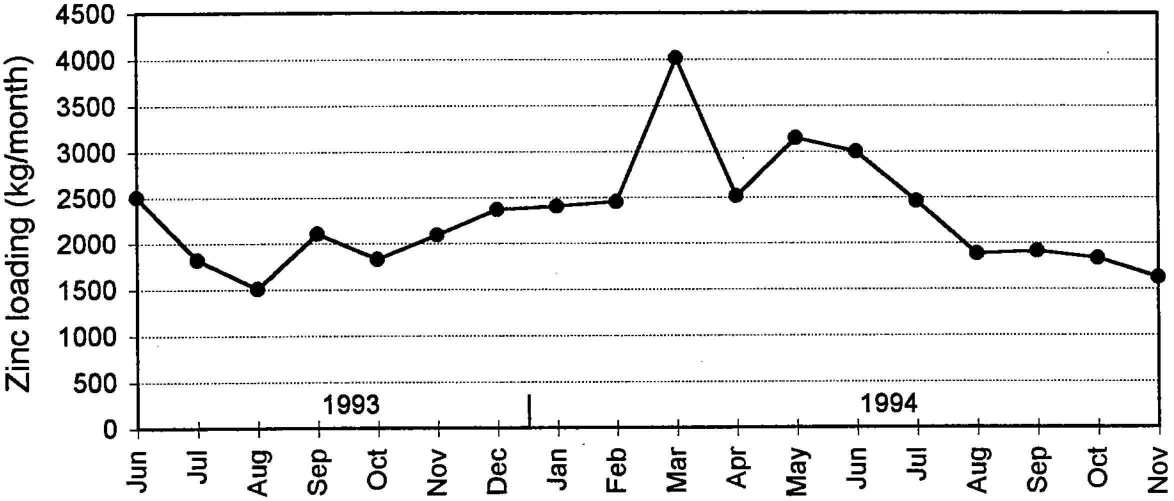

Cadmium Load (kg/month)
35
30
25
20
15
10
5
0
1993
1994
Jun
Jul
Aug
Sep
Oct
Nov
Dec
Jan
Feb
Mar
Apr
May
Jun
Jul
Aug
Sep
Oct
Nov


Mercury Load (kg/month)
8.0
7.0
6.0
5.0
4.0
3.0
2.0
1.0
0.0
1993
1994
Jun
Jul
Aug
Sep
Oct
Nov
Dec
Jan
Feb
Mar
Apr
May
Jun
Jul
Aug
Sep
Oct
Nov

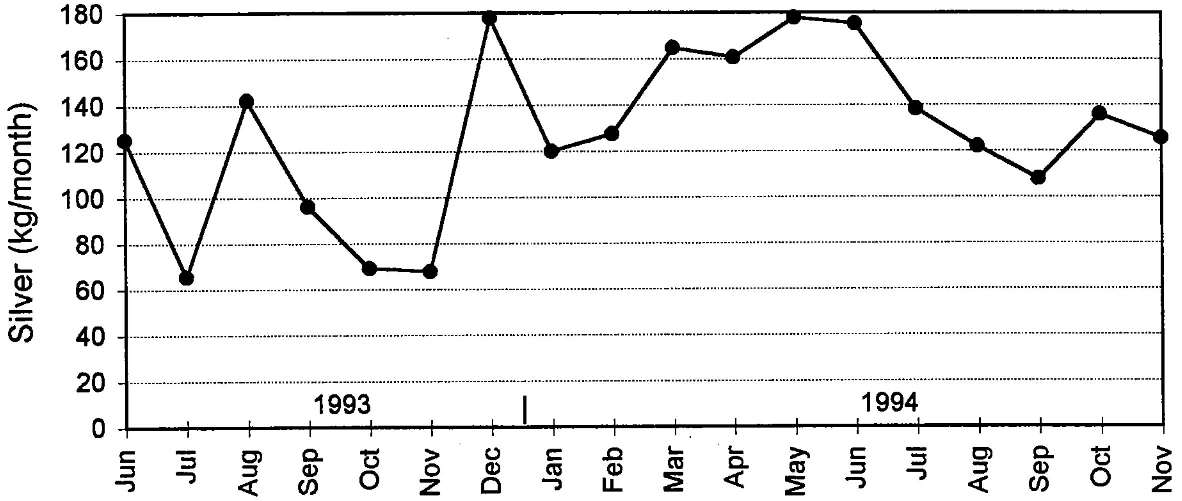

Chromium Load (kg/month)
200
160
120
80
40
0
1993
1994
Jun
Jul
Aug
Sep
Oct
Nov
Dec
Jan
Feb
Mar
Apr
May
Jun
Jul
Aug
Sep
Oct
Nov

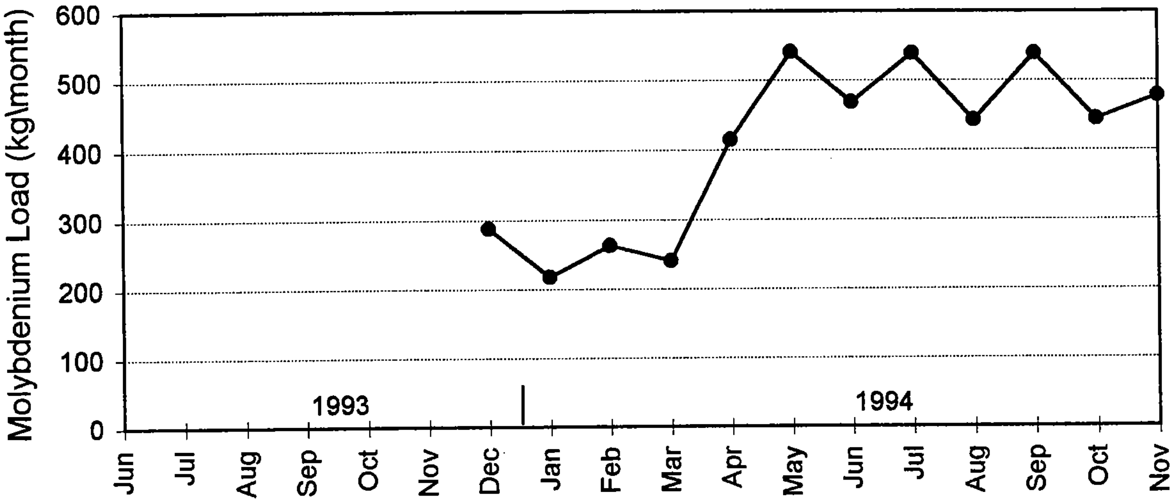
00021


Nickel Load (kg/month)
300
250
200
150
100
50
0
1993
1994
Jun
Jul
Aug
Sep
Oct
Nov
Dec
Jan
Feb
Mar
Apr
May
Jun
Jul
Aug
Sep
Oct
Nov


Zinc loading (kg/month)
4500
4000
3500
3000
2500
2000
1500
1000
500
0
1993
1994
Jun
Jul
Aug
Sep
Oct
Nov
Dec
Jan
Feb
Mar
Apr
May
Jun
Jul
Aug
Sep
Oct
Nov

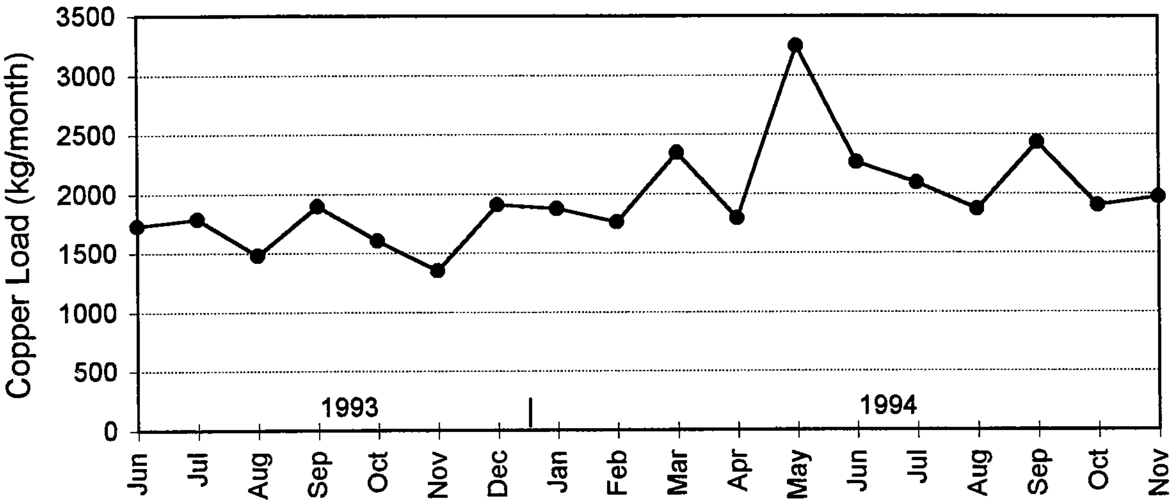
00023

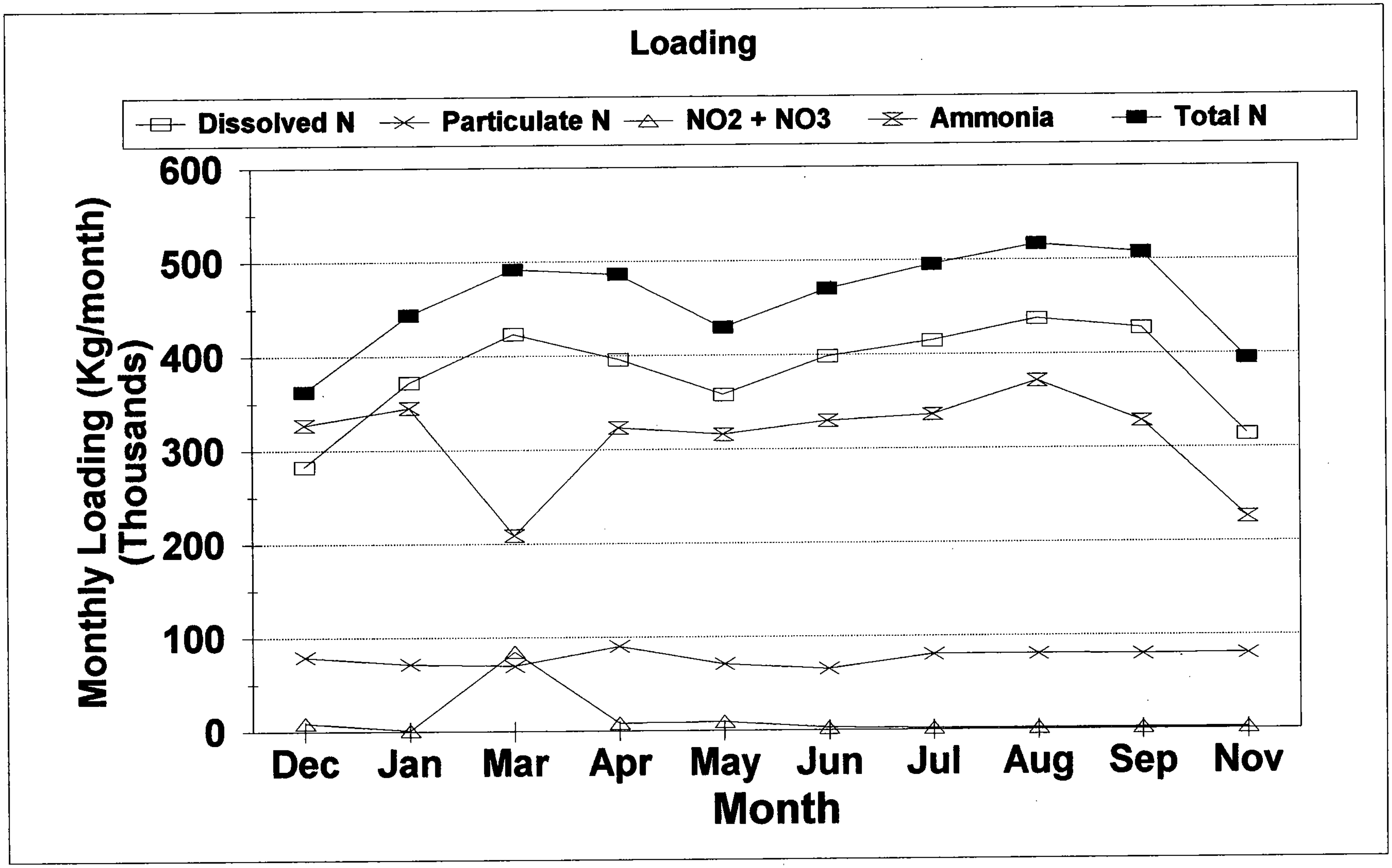

Silver (kg/month)
180
160
140
120
100
80
60
40
20
0
1993
1994
Jun
Jul
Aug
Sep
Oct
Nov
Dec
Jan
Feb
Mar
Apr
May
Jun
Jul
Aug
Sep
Oct
Nov

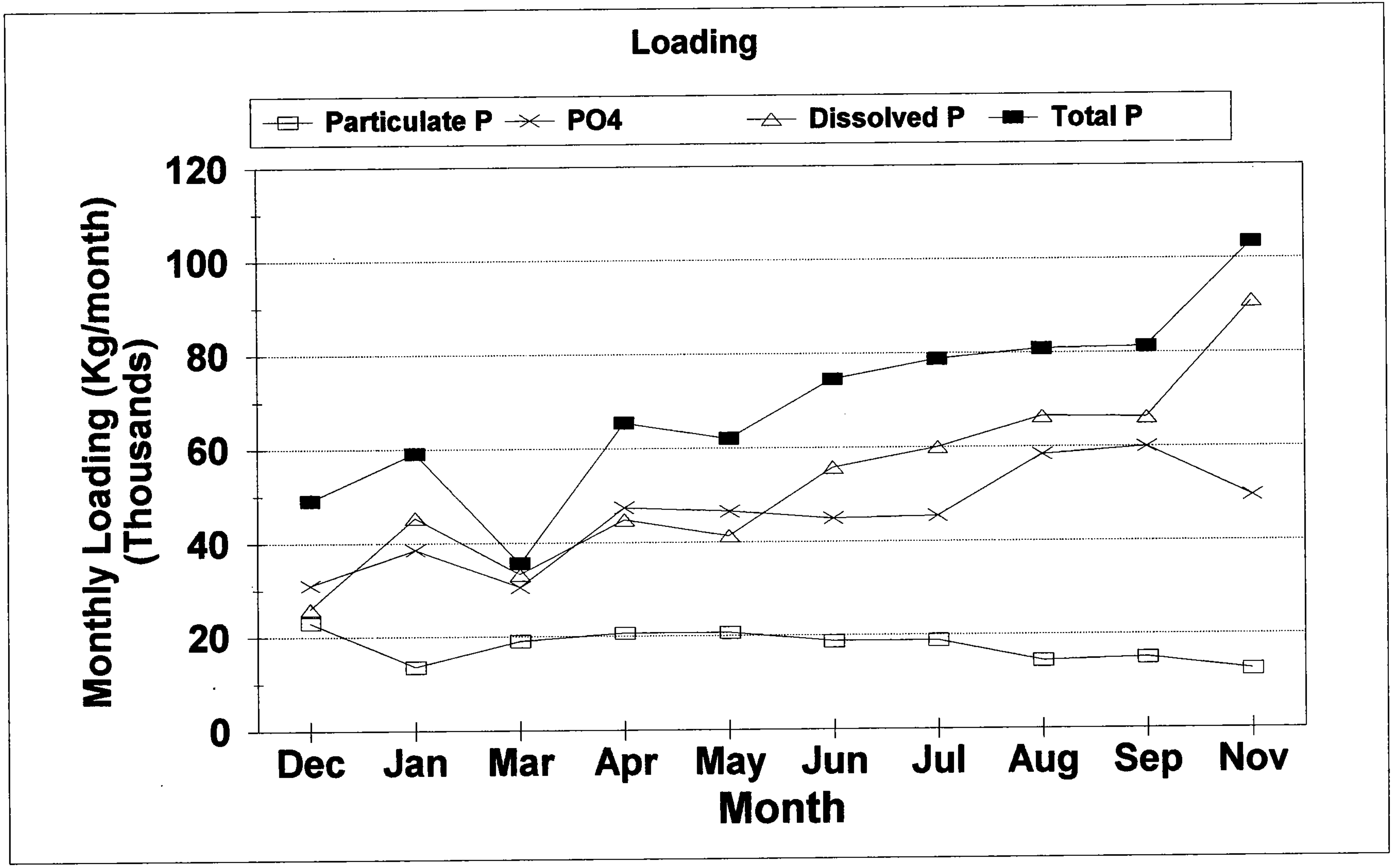


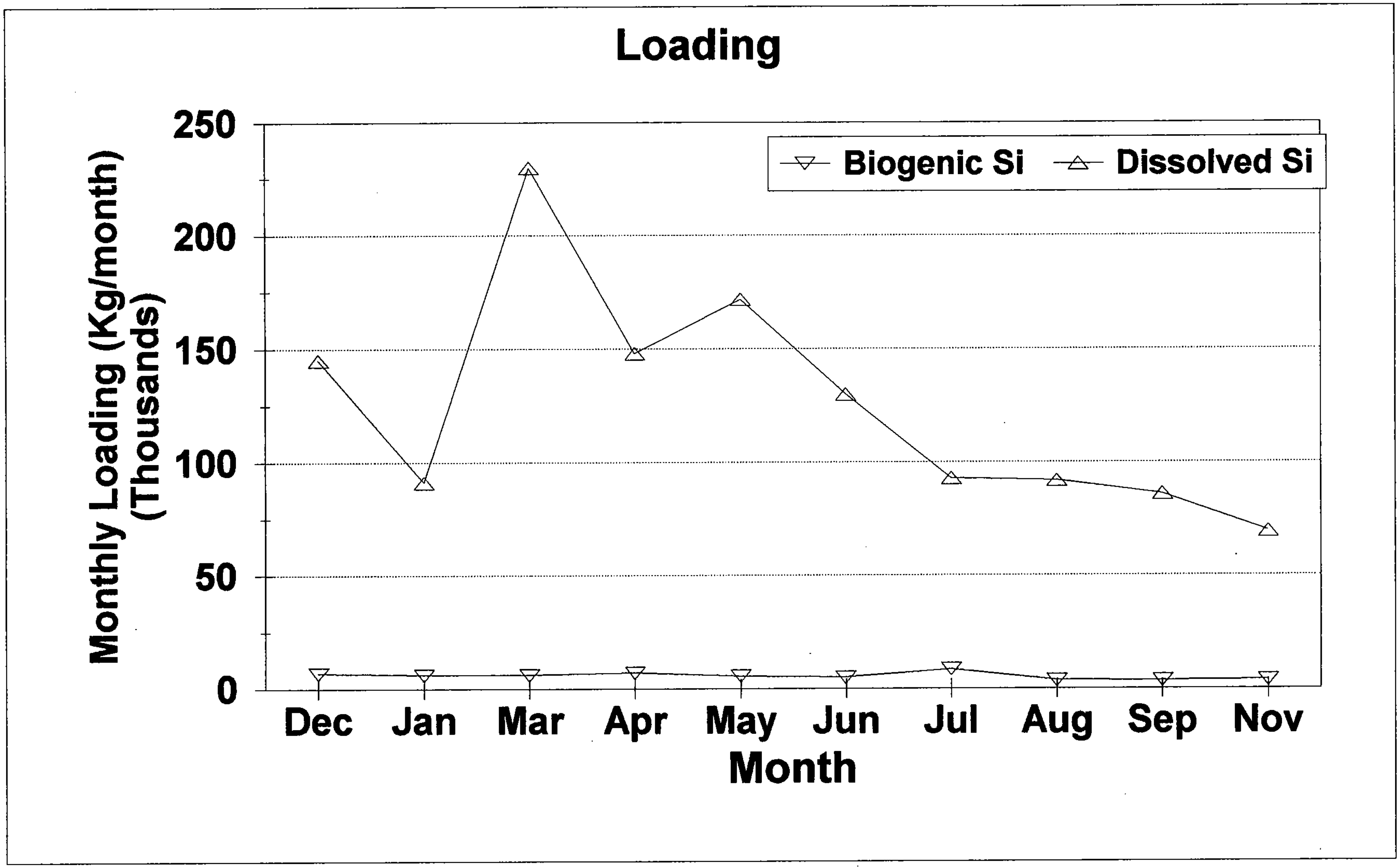
Molybdenum Load (kg\month)
600
500
400
300
200
100
0
1993
1994
Jun
Jul
Aug
Sep
Oct
Nov
Dec
Jan
Feb
Mar
Apr
May
Jun
Jul
Aug
Sep
Oct
Nov

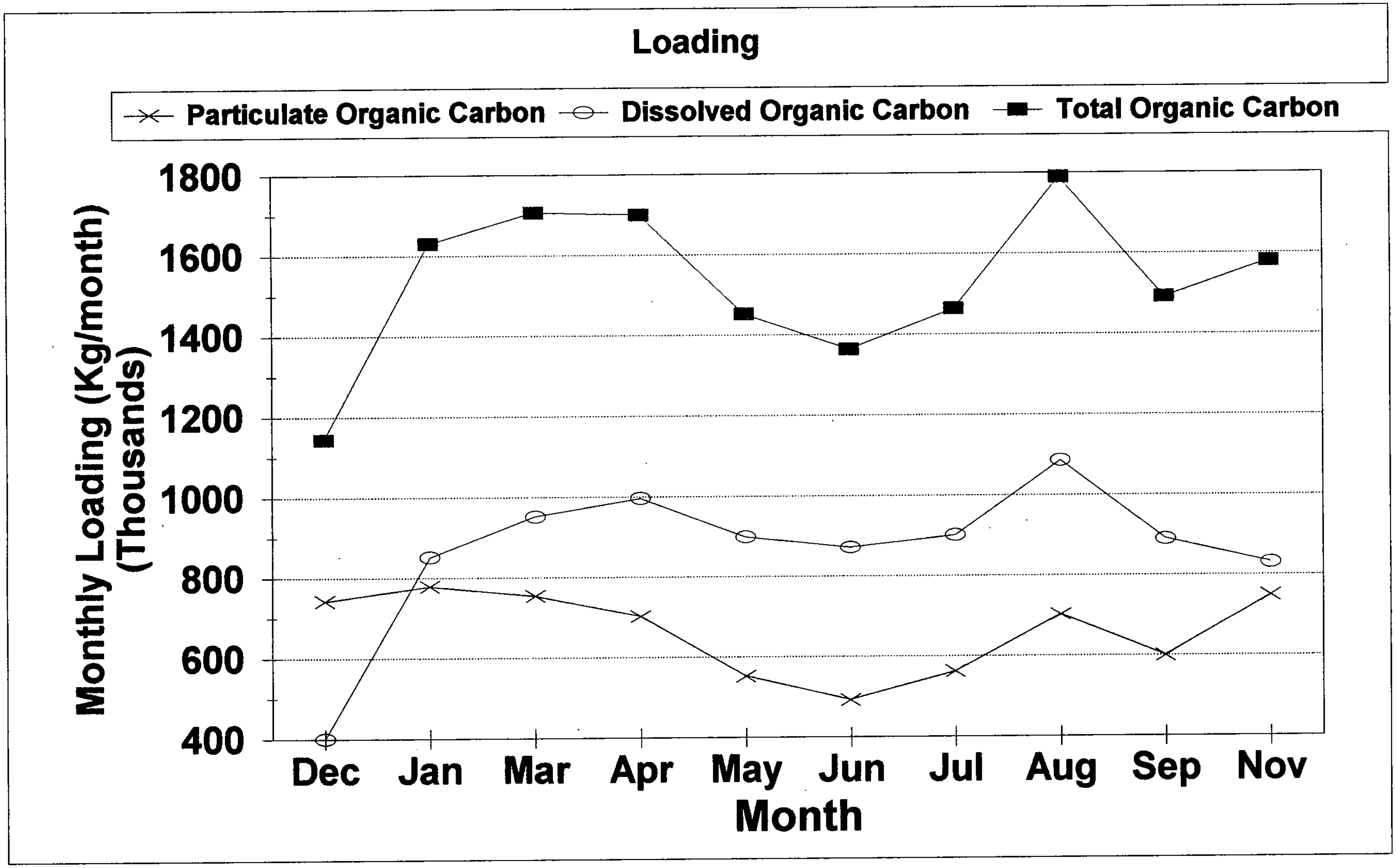
00025


Copper Load (kg/month)
3500
3000
2500
2000
1500
1000
500
0
1993
1994
Jun
Jul
Aug
Sep
Oct
Nov
Dec
Jan
Feb
Mar
Apr
May
Jun
Jul
Aug
Sep
Oct
Nov


Loading
Dissolved N
Particulate N
NO2 + NO3
Ammonia
Total N
Monthly Loading (Kg/month) (Thousands)
600
500
400
300
200
100
0
Dec
Jan
Mar
Apr
May
Jun
Jul
Aug
Sep
Nov
Month


Loading
Particulate P
PO4
Dissolved P
Total P
Monthly Loading (Kg/month) (Thousands)
120
100
80
60
40
20
0
Dec
Jan
Mar
Apr
May
Jun
Jul
Aug
Sep
Nov
Month


Loading
Biogenic Si
Dissolved Si
Monthly Loading (Kg/month)
(Thousands)
250
200
150
100
50
0
Dec
Jan
Mar
Apr
May
Jun
Jul
Aug
Sep
Nov
Month


Loading
Particulate Organic Carbon
Dissolved Organic Carbon
Total Organic Carbon
Monthly Loading (Kg/month) (Thousands)
1800
1600
1400
1200
1000
800
600
400
Dec
Jan
Mar
Apr
May
Jun
Jul
Aug
Sep
Nov
Month

The Massachusetts Water Resources Authority
Charlestown Navy Yard
100 First Avenue
Charlestown, MA 02129
(617) 242-6000