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# SUMMARY OF HISTORICAL PUGET SOUND CONTAMINANT MASS LOADING ANALYSIS

SUBMITTED TO:

U.S. ENVIRONMENTAL PROTECTION AGENCY
REGION 10

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## 1.0 INTRODUCTION

Effective management decisions concerning the control of contaminant discharges into Puget Sound require identification of the contributing sources and the quantification of the contaminant mass loading associated with each source.

The objectives of this report are to:

- o Develop an updated summary of the available historical information generated by a number of recently completed studies.
- o Point out the differences and major difficulties encompassed in performing mass loading calculations.
- o Provide, to the extent possible, the reasons for the discrepancies in these studies.

The discussion which follows presents the mass loading summaries developed in these historical investigations and provides an interpretive evaluation of this information within the context of the objectives listed above.

## 2.0 POLLUTANT LOADING ESTIMATES DEVELOPED FOR PUGET SOUND

The discussion in this section summarizes the contaminant mass loading in Puget Sound estimated in three historical studies. The mass loading analysis presented in the following reports are discussed: Water Quality Management Program for Puget Sound (Jones and Stokes, 1983); Metals/Toxicants Pretreatment Planning Study (Romberg et al., 1984); and Toxic Chemicals and Biological Effects in Puget Sound (Quinlan et al., 1985).

### 2.1 WATER QUALITY MANAGEMENT PROGRAM FOR PUGET SOUND

This study presented wet season, dry season, and annual estimates of loadings associated with NPDES permitted municipal and industrial dischargers. Pollutant mass loadings associated with nonpoint sources were not reported.

Data were generally not available for all permitted discharges to a geographic basin. The information reported was primarily for conventional pollutants; priority pollutant data was sparse. Due to these limitations, total pollutant loading and the relative importance of each source was not assessed in the Jones and Stokes report. For these reasons no data from this report are presented in the summary.

### 2.2 TOXICANT PRETREATMENT PLANNING STUDY (TPPS)

In the TPPS report (Romberg et al. 1984), the central basin of Puget Sound was the primary focus of the contaminant mass balance estimates. Mass loading data were presented for both trace metals and synthetic organic components.

Estimates of heavy metals provided general information on the relative contribution of various sources. The mass balance for these constituents is presented in Table 1. By far the dominant mass of most metals was associated with the large amount of marine water that moves in and out of Puget Sound. Overall, little excess metal load from

## Table 1 ESTIMATED HEAVY METAL MASS BALANCE FOR CENTRAL PUGET SOUND

| Sources | Mass Loading in mt/year (percent of total in parenthesis) | | | | | | |
|---|---|---|---|---|---|---|---|
| | As | Cu | Pb | Hg | Ag | Zn | Total Metals |
| Inputs[a] | | | | | | | |
| Marine Waters/Advection | 390(80) | 75(39) | 50(33) | 0.6(67) | 3.33 | 510(71) | 1029(66) |
| Non-Point Source | | | | | | | |
| River Drainage | 28(6) | 49(25) | 30(20) | 0.2(22) | 2(22) | 89(12) | 198(13) |
| Shoreline Erosion | 58(12) | 12(6) | 7(5) | NDA[c] | <1(11) | 46(6) | 123 (8) |
| Atmospheric Inputs | 3(.6) | 6(3) | 40(26) | <0.1 | <0.1 ( 1) | 4 | 69(4) |
| Point Sources | | | | | | | |
| Industrial | 5(1) | 32(17) | 4(3) | 0.1(11) | 1(11) | 24(3) | 66(4) |
| Municipal | 1(.2) | 17(9) | 15(10) | <0.1 | 2(22) | 34(5) | 54(3) |
| CSOs | <0.1 | <1 | <1 | 0 | <0.1 | <0.1 | <2 |
| Dredge Disposal | <0.1 | 2(1) | 4(3) | <0.1 | <0.1 | 8(1) | 14(1) |
| TOTAL INPUTS | 485 | 193 | 151 | <1.2 | < 9 | 715 | 1554 |
| Outputs[a] | | | | | | | |
| Advection | 400(95) | 157(70) | 46(37) | 0.5(55) | 3(60) | 570(75) | 1176(76) |
| Sedimentation | 21(5) | 68(30) | 79(63) | 0.4(45) | 2(40) | 194(25) | 365(24) |
| TOTAL OUTPUTS | 421 | 225 | 125 | 0.9 | 5 | 764 | 1541 |
| VARIANCE[b] | +13 | -17 | +17 | +0.3 | +44 | -7 | +1 |

[a]All input and loss terms were estimated as discussed in the text.

[b]Variance is defined as: $\frac{\text{Total Input} - \text{Total Output}}{\text{Total Input}} \times 100$.

[c]NDA=No data available.

land-based sources was carried out of the Sound. The majority of the land-originating metals appeared to be retained in the central basin via sedimentation. These land-based sources were dominated by rivers and shoreline erosion. The total anthropogenic inputs to the central basin represent the following relative contribution to the total annual metal loadings: 43 percent for silver, 42 percent for lead (probably much higher if the surface runoff is combined with the riverine discharges), 16 percent for copper, 11 percent for mercury, 10 percent for zinc, and 2 percent for arsenic.

Attempts to estimate a mass balance for organic compounds in the central basin were unsuccessful. In virtually all cases, estimated inputs were extremely small, even insignificant in comparison with the estimated output. This extreme variance was unexpected since the same method was used for calculating both the metal and organic mass balances. Possible explanations are:

(1) The organics data were far more variable than the metals data, due to large environmental patchiness; this indicates that more sampling is required to obtain a representative population of the ambient concentrations under various spatial and temporal coverage;

(2) that assumptions about compound stability, sedimentation, and water transport were in error; and

(3) that there was some large unknown source of organic toxicants.

The preliminary organic chemical loading estimates and mass balances prepared using arithmetic and geometric means are presented in Tables 2 and 3.

The TPPS loading estimates were also based upon limited data, especially for nonpoint sources. As stated above, data were incomplete for NPDES permitted dischargers, particularly for the priority

TABLE 2 ESTIMATED ORGANIC MASS BALANCE FOR CENTRAL PUGET SOUND USING ARITHMETIC MEANS (ROMBERG ET AL., 1984)

| SOURCES | Acid | Base | Neutrals | | | | | | Pesticides | | | Volatiles |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | | PAH | CPAH | CLA | CBD | Phth | Di-Octyl | DDT | PCB | MISC. | |
| INPUTS | | | | | | | | | | | | |
| Advection (Effection Oceanic Loading) | .024 | | 6.16 | -- | -- | -- | 59.4 | 2424 | .066 | .0028 | .132 | |
| Non-Point Sources | | | | | | | | | | | | |
| River Drainage | .211 | -- | .416 | .463 | .009 | -- | .009 | 10.24 | .021 | .024 | .042 | .54 |
| Shoreline Erosion | -- | -- | -- | -- | -- | -- | -- | -- | -- | -- | -- | -- |
| Atmospheric Inputs | -- | -- | | | -- | -- | -- | -- | -- | -- | -- | -- |
| Point Sources | | | | | | | | | | | | |
| Industrial | .08 | -- | .039 | -- | .001 | .0009 | .004 | -- | -- | -- | -- | 1.8 |
| Municipal | .66 | 0.13 | 1.62 | .115 | .1904 | -- | 11.62 | 3.78 | .0008 | .057 | -- | 17.74 |
| CSOs | .003 | -- | .004 | -- | -- | .069 | .069 | .015 | .00005 | .001 | -- | .234 |
| Dredge Disposal | .0004 | .0005 | .031 | .192 | .0026 | .00015 | .0068 | .058 | .020 | .011 | .00018 | .024 |
| Subtotal Estimated Inputs | .978 | .0135 | 8.27 | 1.105 | .203 | .07005 | 17.1088 | 2348.09 | .1078 | .0958 | .1742 | 20.338 |
| Unknown/Unaccounted for[c] | 12.05 | 11.16 | 82.36 | 29.69 | 11.10 | -- | 137.58 | -- | -- | 2.794 | -- | 136079.66 |
| Advection | 12.99 | 11.05 | 88.8 | 27.11 | 11.27 | -- | 206.83 | 183.03 | .00157 | 2.49 | .066 | 136100. |
| Sedimentation | .04 | .13 | 1.83 | 3.69 | .03 | .006 | 1.85 | 12.2 | .005 | .4 | .0031 | .49 |
| Total Outputs | 13.03 | 11.18 | 90.63 | 30.80 | 11.30 | .006 | 208.68 | 195.23 | .0066 | 2.89 | .0691 | 136100. |
| Variance (%)[b] | Lge- | Lge- | Lge- | Lge- | Lge- | Lge+ | Lge- | Lge+ | Lge+ | Lge- | Lge+ | Lge- |

[a]All units in $mt/yr^{-1}$

[b]Variance is defined as: $\frac{\text{Total Input - Total Output}}{\text{Total Input}} \times 100$

[c]Unknown/unaccounted for term is employed to attempt a balance with estimated outputs.

TABLE 3 ESTIMATED ORGANIC MASS BALANCE FOR CENTRAL PUGET SOUND USING SOME GEOMETRIC MEANS (ROMBERG ET AL., 1984)

| Sources | Mass Loadings in mt/year | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|
| | | | Neutrals | | | | | Pesticides/PCBs | | | |
| | Acids | Bases | PAHs | CPAHs | CLAs | PHTHs | DI-OCTYL | DDTs | PCBs | Misc | Volatile |
| Inputs[a] | | | | | | | | | | | |
| Marine Waters/Advection[d] | .022 | -- | 0.0022 | -- | -- | 8.4 | 1400 | 0.022 | 0.0022 | 0.044 | 748 |
| Non-Point Sources | | | | | | | | | | | |
| River Drainage | .211 | --- | .416 | .463 | .009 | .009 | 10.2 | .021 | .024 | .042 | .54 |
| Shoreline Erosion | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- |
| Atmospheric Inputs | --- | --- | --- | .335 | --- | --- | --- | --- | --- | --- | --- |
| Point Sources | | | | | | | | | | | |
| Industrial | 0.08 | --- | .039 | --- | .001 | .004 | --- | --- | --- | --- | 1.8 |
| Municipal | .66 | .013 | 1.62 | .115 | .190 | 11.6 | 3.78 | .0008 | .057 | --- | 18. |
| CSOs | 0.0003 | --- | .004 | --- | --- | .069 | .015 | .00005 | .001 | --- | .23 |
| Dredge Disposal | 0.0004 | .0005 | .031 | .192 | .0026 | .0068 | .058 | .020 | .011 | .00018 | .024 |
| Subtotal Estimated Inputs | <1 | <.02 | 2.11 | 1.1 | .203 | 20.1 | 1414 | .064 | .095 | .086 | 769 |
| Unknown/Unaccounted for[b] | 10 | 2.8 | 6 | 5 | 3 | --- | --- | --- | .55 | --- | --- |
| Outputs[a] | | | | | | | | | | | |
| Advection[d] | 11.0 | 2.87 | 7.96 | 2.87 | 3.31 | 14.1 | 89.7 | .00066 | .464 | .00082 | 287 |
| Sedimentation[d] | .022 | .0066 | .246 | 3.39 | .0068 | .524 | 2.93 | .0023 | .185 | .011 | .0046 |
| TOTAL OUTPUTS | 11.02 | 2.88 | 8.21 | 6.26 | 3.32 | 14.6 | 92.6 | .0030 | .649 | .012 | 287 |
| VARIANCE (%)[c] | Lge- | Lge- | Lge- | Lge- | Lge- | Med+ | Lge+ | Lge+ | Lge- | Lge+ | Lge+ |

[a]All input and loss terms are estimated based on available data and scientific assumptions.

[b]Unknown/Unaccounted for term is employed to attempt a balance with estimated outputs.

[c]Variance is defined as: Subtotal Input-Total Output x 100.

[d]Values based on geometric mean values for whole water and sediments. All other loadings are same as the original detailed values used to develope the simplified version presented in Table 41 of the main text.

pollutants. However, in the TPPS program, detailed data were obtained for the METRO municipal discharges. Incorporation of these data and efforts to estimate nonpoint source contributions resulted in substantially improved estimates of pollutant loading to central Puget Sound over the Jones and Stokes report.

## 2.3 TOXIC CHEMICALS AND BIOLOGICAL EFFECTS IN PUGET SOUND

Quinlan et al. 1985 developed mass loading estimates for five source categories and three major classes of chemical contaminants, including trace metals, polynuclear aromatic hydrocarbons (PAHs) and polychlorinated biphenyls (PCBs). Sources included: rivers, shoreline erosion, atmospheric deposition, municipal sewage effluents and industrial waste effluents. Smaller sources, including combined sewer overflows and storm drains, small industrial dischargers and other nonpermitted discharges and spills were not included. The loading estimates computed for five Puget Sound subregions are presented in Tables 4 and 5.

Although available data for the selected contaminant groups are sufficient to develop quantitative loading estimates, a number of limitations to the data were identified. For the trace metals, literature values for mass inputs exist for most of the sources considered; however, samplings of many of these sources are very limited.

For the PAHs, data are available for many of the sources, providing a usable data set, but the majority of this data was unsupported by replicate samplings to allow for the establishment of precision and temporal consistency of measurements. In addition, because many of the PAH measurements were made at or very near the detection limits of the instrumentation available, considerable uncertainty must be accorded the PAH source data.

TABLE 4

ESTIMATED TRACE METAL INPUTS INTO PUGET SOUND (mt/yr)
(excluding advective fluxes)

| Source Type | Rivers | Shoreline | Atmospheric | Municipal | Industry |
|---|---|---|---|---|---|
| METAL | | | | | |
| As | 64 | 34 | 11 | 1.5 | 63 |
| Cd | 19 | 17 | 0.5 | 1.5 | 2 |
| Cr | 89 | 68 | ND 1/ | 16 | 18 |
| Cu | 108 | 75 | 32 | 24 | 56 |
| Pb | 55 | 54 | 121 | 25 | 15 |
| Hg | 4 | 3 | 0.1 | 0.2 | 0.1 |
| Ag | 4 | 1 | 0.1 | 3 | 2 |
| Zn | 384 | 305 | 27 | 51.0 | 47 |
| TOTAL METALS | 726 | 557 | 192 | 119 | 203 |

1/ ND = no data.

SOURCE: Quinlan et al. 1985, Table 23, p. 74.

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TABLE 5

ESTIMATED IMPACTS OF SELECTED ORGANIC CONTAMINANTS INTO PUGET SOUND (mt/yr)

5a: ESTIMATED CPAH INPUTS TO PUGET SOUND (mt/yr) (excluding advective fluxes)

| | Whidbey Basin | Main Basin A | Main Basin B | Southern Sound | Hood Canal | Straits |
|---|---|---|---|---|---|---|
| Riverine | 1.69 | 0.43 | 0.46 | 0.10 | 0.09 | 2.49 |
| Shoreline | 0 | 0 | 0 | 0 | 0 | 0 |
| Atmospheric | 0.17 | 0.28 | 0.34 | 0.76 | 0.62 | 0.50 |
| Municipal | 0.011 | 0.33 | 0.12 | 0.012 | 0 | 0.024 |
| Industrial | NQ | NQ | NQ | NQ | NQ | NQ |

5b: ESTIMATED PCB INPUT TO PUGET SOUND (mt/yr) (excluding advective fluxes)

| | Whidbey Basin | Main Basin A | Main Basin B | Southern Sound | Hood Canal | Strait of Juan de Fuca inner | Strait of Juan de Fuca outer |
|---|---|---|---|---|---|---|---|
| Riverine | 0.053 | 0.009 | 0.024 | 0.004 | 0.003 | 0.003 | 0.047 |
| Municipal | 0.019 | 0.282 | 0.06 | 0.021 | negligible | 0.014 | 0.019 |

1/ Total dissolved and particulate.

NQ Insufficient data available to quantify loading.

SOURCE: A - Quinlan et al., 1985, Tables 24 and 25, p. 76-77.
B - Romberg et al., 1984

For the PCBs, measured values are available for only a few rivers and some municipal discharges. PCBs, like the PAHs, occur at very low levels, and most source measurements have not used the sophisticated analytical procedures necessary to achieve adequate quantification. As a result, PCBs may be present in many additional sources but have not yet been identified. Additionally, the result that estimated inputs of CPAH from rivers were the largest overall source calculated by Quinlan et al. appears to be questionable given the lack of major known sources to the rivers themselves (Quinlan et al. 1985, page 76). A similar caution seems warranted for the atmospheric inputs which also appear to be large in nonurban areas. These limitations reported by Quinlan et al. (1985) are consistent with the discussion provided by Romberg et al. (1984) and provide additional rationale for explaining the large variance observed in the mass balance estimates attempted in the TPPS study.

## 3.0 INTERPRETIVE EVALUATION

The total Puget Sound metals loading data reported by Quinlan et al. (1985) indicate that metal inputs are dominated by riverine and shoreline erosion consistent with the findings of Romberg et al. (1984).

Comparison of the central basin metal loading estimates of Quinlan et al. (1985) and Romberg et al. (1984) are shown in Table 6 indicate that for most metals, loadings computed in the two studies are comparable. The discrepancies for arsenic and mercury loadings calculated for industrial sources appear to be due to the use of different data sources and assumptions regarding the distribution between the dissolved and particulate phase. For the loading estimates developed by Quinlan et. al., specific industrial source values were generally from more recent surveys. These data were considered to be more reliable than past summary data, and were used in the industrial loading estimates. With no data available for comparison, but assuming the same general geochemical reactions occurred, metals in industrial effluents were assumed to be fractionated in Puget Sound in a manner similar to those from municipal effluents and rivers.

Atmospheric loading estimates are comparable because the same methodology was employed in both studies. The approach used to estimate riverine and shoreline erosion metal concentrations was different for the two studies; thus reported metal loadings was also different, but are within a factor of two except for arsenic. The relatively large difference in arsenic loading between the two studies is due to the fact that the reported soils arsenic concentration of 100 ug/g reported by Dexter et al. (1981), was used by Romberg et al. (1984), whereas Quinlan et al. (1985) used a concentration of 10 ug/g based upon literature values for average earth's crust composition and observed street dust concentrations.

TABLE 6

COMPARISON OF METAL LOADINGS CALCULATED
FOR CENTRAL PUGET SOUND

| Metal | Municipal Discharge Loading (mt/yr) | | Industrial Discharge Loading (mt/yr) | | Riverine Loading | | Shoreline Erosion | | Atmospheric Loading | |
|---|---|---|---|---|---|---|---|---|---|---|
| | METRO 1/ | URS 2/ | METRO 1/ | URS 2/ | METRO 1/ | URS 2/ | METRO 1/ | URS 2/ | METRO 1/ | URS 2/ |
| As | 1 | 1.3 | 5 | 62 | 28 | 12 | 58 | 8 | 3 | 2.9 |
| Cu | 17 | 21.2 | 32 | 51 | 49 | 24 | 12 | 17 | 6 | 12.0 |
| Pb | 15 | 22.2 | 4 | 5.79 | 30 | 13.3 | 7 | 12.7 | 40 | 31.1 |
| Hg | 0.1 | 0.19 | 0.1 | 0.01 | 0.2 | 0.905 | NDA | 0.8 | 0.1 | 0.02 |
| Ag | 1 | 2.3 | 1 | 0.42 | 2 | 0.6 | 1 | 0.3 | 0.1 | 0.03 |
| Zn | 24 | 34 | 24 | 27.5 | 89 | 74 | 46 | 69 | 4 | 6.8 |

1/ Romberg et al. 1984.

2/ Quinlan et al. 1985.

NDA = No Data Available.

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The loadings of organic constitutents computed in the two studies presented in Table 5 indicate that for the CPAHs, the agreement is good between the two studies; however, for PCB's the difference in loading estimates computed in the two studies vary in a range of two to five times. For the municipal inputs, the discrepancy appears to be due to different flow estimates and concentrations used by Quinlan et al. Similarly, an average PCB value was applied to all Puget Sound rivers to compute the loadings presented by Quinlan et al. 1985. The TTPS values are probably more accurate because actual flow and concentration data were used.

## Summary

Available data have been used to compute preliminary contaminant mass loading to Puget Sound. These estimates are based upon best available data, however, they must be regarded only as approximate loading values. The computations do indicate the relative contributions from different sources and are graphically presented in Figures 1 and 2.

Where comparisons are possible among the different studies, mass loading evaluations, study findings and limitations appear to be consistent. However, data are generally not available to quantify, with accuracy, the loadings from contaminant sources to Puget Sound. The difficulty lies both in our ability to characterize the quantity and quality of non-point source contributions and the limitations associated with data available for point source discharges.

FIGURE 1

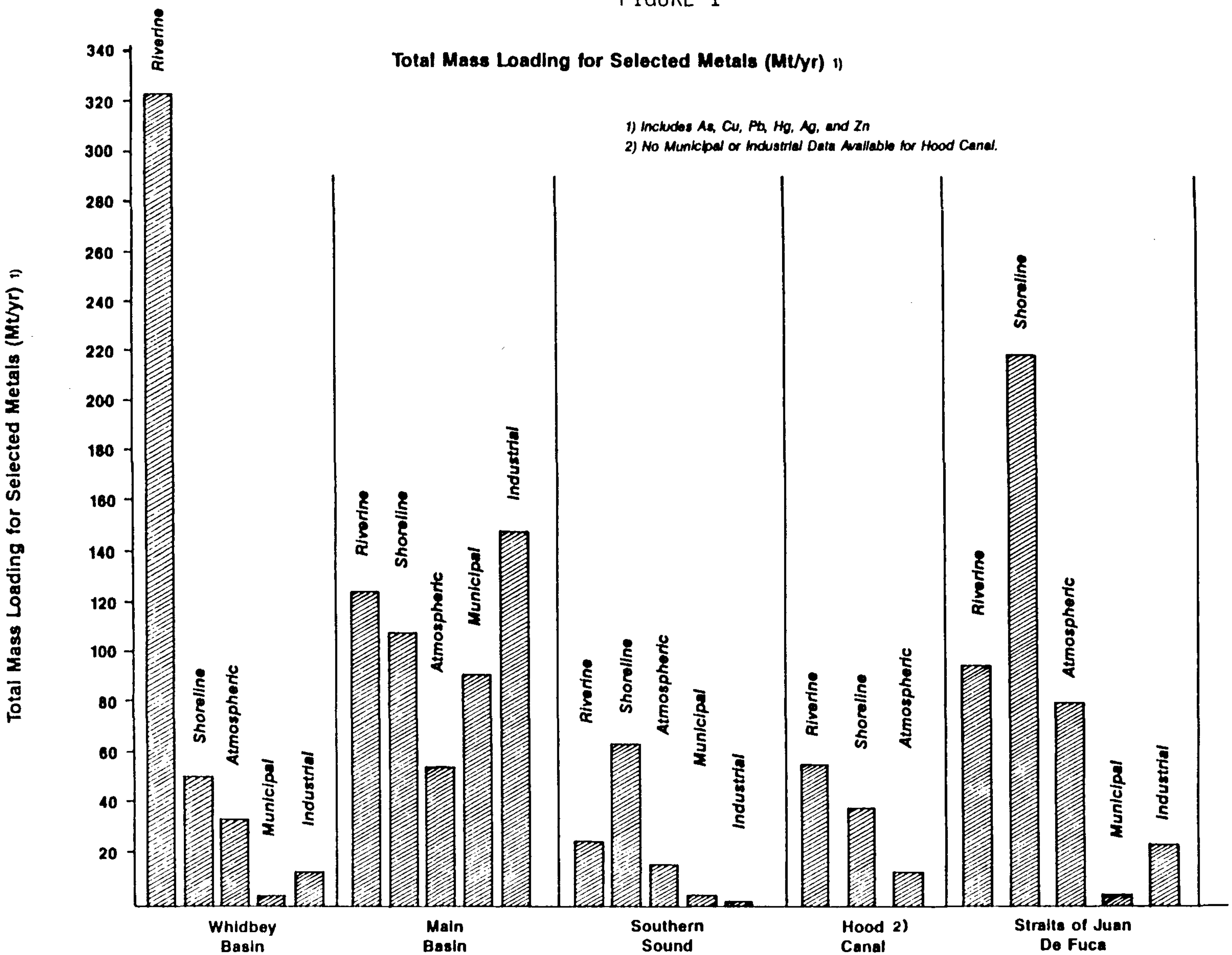
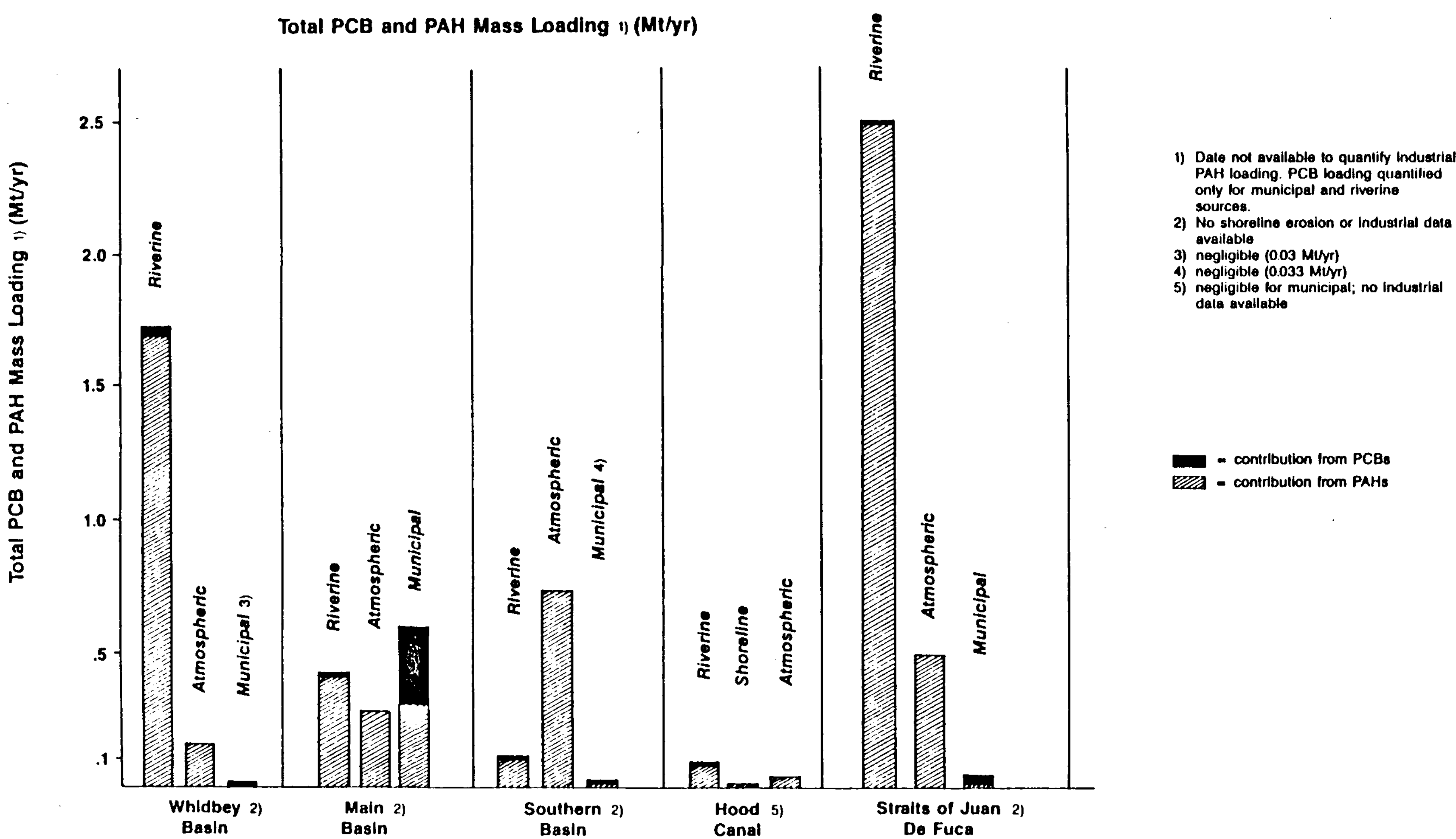

Total Mass Loading for Selected Metals (Mt/yr) 1)
1) Includes As, Cu, Pb, Hg, Ag, and Zn
2) No Municipal or Industrial Data Available for Hood Canal.
Total Mass Loading for Selected Metals (Mt/yr) 1)
340
320
300
280
260
240
220
200
180
160
140
120
100
80
60
40
20
Riverine
Shoreline
Atmospheric
Municipal
Industrial
Whidbey Basin
Main Basin
Southern Sound
Hood 2) Canal
Straits of Juan De Fuca

FIGURE 2


Total PCB and PAH Mass Loading 1) (Mt/yr)
Total PCB and PAH Mass Loading 1) (Mt/yr)
2.5
2.0
1.5
1.0
.5
.1
Riverine
Atmospheric
Municipal 3)
Riverine
Atmospheric
Municipal
Riverine
Atmospheric
Municipal 4)
Riverine
Shoreline
Atmospheric
Riverine
Atmospheric
Municipal
Whidbey 2) Basin
Main 2) Basin
Southern 2) Basin
Hood 5) Canal
Straits of Juan 2) De Fuca
1) Date not available to quantify industrial PAH loading. PCB loading quantified only for municipal and riverine sources.
2) No shoreline erosion or industrial data available
3) negligible (0.03 Mt/yr)
4) negligible (0.033 Mt/yr)
5) negligible for municipal; no industrial data available
= contribution from PCBs
= contribution from PAHs