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TRANSPORT OF SOME CHLORINATED CONTAMINANTS BY THE WATER, SUSPENDED SEDIMENTS AND BED SEDIMENTS IN THE ST. CLAIR AND DETROIT RIVERS

by

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MANAGEMENT PERSPECTIVE

The total contaminant load transported by a river consists of dissolved contaminants carried by the water as well as contaminants in particulate form carried by the suspended sediments and sediments moving along the river bed. Knowledge of the relative importance of the different means of transport is necessary for the understanding of the pollutant pathways and for devising pollution control strategies.

In this report the measurements of river flow, sediment transport and contaminant concentrations have been used to evaluate the transport of contaminants at several locations on the St. Clair and Detroit Rivers. The results show that, along these rivers, there are more contaminants being transported with suspended sediments than with the water in dissolved state. This result will be useful for the control of pollution in the Upper Great Lakes Connecting Channels.

PERSPECTIVE - GESTION

La charge totale de contaminants que transporte un cours d'eau est constituée de contaminants dissous véhiculés par le courant et de contaminants sous forme de particules qui sont transportées dans les sédiments en suspension et les sédiments qui se déplacent dans le lit du cours d'eau. Il est nécessaire de connaître l'importance relative des différents moyens de transport des contaminants pour déterminer les divers modes de pollution et pour élaborer des stratégies de lutte contre la pollution.

Dans le présent rapport, nous avons mesuré le débit d'eau, le transport des sédiments et la concentration des contaminants pour évaluer de transport des contaminants à plusieurs endroits dans les rivières Ste-Claire et Détroit. Les résultats montrent que, dans ces cours d'eau, davantage de contaminants sont transportés avec les sédiments en suspension que sous forme dissous dans l'eau. Ces résultats seront utiles pour lutter contre la pollution des cours d'eau reliant la partie supérieure des Grands Lacs.

CONTAMINANT TRANSPORT IN ST. CLAIR AND DETROIT RIVERS

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Abstract - Measurements of water flow, sediment transport and concentrations of some chlorinated contaminants were used to calculate the transport of contaminants in the St. Clair and Detroit Rivers. The chemicals chosen were hexachlorobenzene, octachlorstyrene and polychlorinated biphenyls. From measurements on three transects in the St. Clair River and two transects in the Detroit River, it can be concluded that the suspended sediments transport the largest amount of contaminants. The amount transported in the soluble phase was of the same order of magnitude as that in the particulate phase. The transport by the bed sediments was negligible mainly because of a lack of supply of such sediments.

Keywords - Chlorinated contaminants Suspended sediments
Bed sediments River transport

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TRANSPORT DE CERTAINS CONTAMINANTS ORGANOCHLORÉS PAR L'EAU, LES SÉDIMENTS EN SUSPENSION ET LES SÉDIMENTS DU LIT DANS LES RIVIÈRES STE-CLAIRE ET DÉTROIT

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Résumé : Nous avons mesuré le débit d'eau, le transport des sédiments et la concentration de certains contaminants organochlorés pour calculer le transport des contaminants dans les rivières Ste-Claire et Détroit. Pour ce faire, nous avons choisi l'hexachlorobenzène, l'octachlorostyrène et des biphényles polychlorés. À partir des mesures effectuées sur trois transects de la rivière Ste-Claire et deux transects de la rivière Détroit, on peut conclure que les sédiments en suspension transportent la plus grande quantité de contaminants. La quantité transportées dans la phase soluble est du même ordre de grandeur que celle transportée dans la phase particulaire. Le transport des contaminants par les sédiments du lit est négligeable, principalement à cause de la rareté de tels sédiments.

Mots clé - Contaminants organochlorés, sédiments en suspension,
Sédiments du lit, transport par les cours d'eau

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INTRODUCTION

The St. Clair and Detroit Rivers, which connect Lake Huron to Lake Erie, receive very heavy contaminant loadings from industrial activities along their shores [1]. Elevated concentrations of a variety of inorganic and organic chemicals, both in the water and in the sediments, have been reported [2-7]. The contamination resulted in severe impairment of the benthic biological community living in the sediments in the St. Clair River [8,9] and have also had an adverse impact on the fisheries in the Lake St. Clair area [10].

Contaminants in a river can be transported downstream by the flow in several ways. They can move along with the water in dissolved state. They can also be transported in particulate form by the sediments which are carried in suspension or by the bed sediments which move along the river bottom, commonly referred to as the bedload. In order to study the fate of the contaminants it is important to know how the loading is distributed between these three phases. This paper describes the results of a study to determine the relative importance of the water, the suspended sediments and the bed sediments in the transport of organic contaminants in the St. Clair and Detroit Rivers.

About 50 halogenated chemicals were analysed but for simplicity only three chemicals will be discussed in detail since their behaviour is reasonably representative. The chemicals chosen were hexachloro-benzene (HCB) and octachlorostyrene (OCS) which are present in high concentrations in the St. Clair River and its sediments, and polychlorinated biphenyls (PCBs) which are present in the Detroit River [11].

MEASUREMENT PROCEDURES

The measurements were made at three transects across the St. Clair River and two transects on the Detroit River. Figure 1 shows the study area and the locations of the transects. The measurements were made over a three week period in May, 1986.

Two boats were used at all transects except the Port Lambton transect. From one boat, measurements of depth, velocity, suspended sediment concentration and bed sediment transport rate were made. From the other boat, whole water samples were centrifuged for chemical analysis. At the Port Lambton transect, the whole operation was carried out from one large research vessel, the CSS ADVENT. At each transect, measurements were made at a number of locations across the river. In the ADVENT, a radar device was used to measure the distance of the ship from the banks. At the other transects, the positions were determined using a sextant.

At each measurement station, an echo sounder was used to measure the water depth. A Price current meter was used to measure the velocities at two point located at 0.2 and 0.8 times the flow depth respectively from the water surface. The average velocity at that location was obtained by averaging those two velocities. The depth integrated suspended sediment concentration was measured using a U.S. P72 suspended sediment sampler. An Arnhem bedload sampler was used to collect samples of the bed sediment transport. More details on these measurements can be found elsewhere [12].

Water samples were pumped from a depth of 1 m with a March pump through teflon and stainless steel hose. The water was then passed through a Wesphalia continuous-flow centrifuge to remove the particulates and into a 200 L stainless steel extractor, and extracted on site with dichloromethane. The surrogate spikes 1,3-dibromobenzene; 1,3,5-tribromobenzene; 2,3,5,6-tetrachlorobiphenyl and octachloronaphthalene were added to the drum when the sample was collected and carried right through the extraction, cleanup and analytical procedure. Recoveries for the surrogate chemicals in these samples were in the 60%-80% range. Details of the concentration and cleanup procedures have been previously reported [13]. Very low detection limits, in the parts per quadrillion, are achieved by this technique.

The sediment samples were soxhlet extracted with acetone/hexane, back extracted to remove the acetone, and concentrated to the appropriate volume using Snyder and/or Kuderna-Danish condensers. Cleanup consisted of passage through a small pasteur pipette (8 mm ID) packed with 1 cm Na_2SO_4, 4 cm 40% H_2SO_4 silica gel, and 2 cm of Florisil (deactivated with 5% water). The verification of this methodology has been published [14].

Quantification was carried out using dual capillary columns (30 m DB5 and DB17) and electron capture detector (350°C) in a Varian 4600 gas chromatograph. The carrier gas was helium (linear velocity 20 cm/s) and an extremely slow program rate 50 to 250°C at 1°C per minute was used to optimize separations.

RESULTS

The five transects vary in width between 500 m and 2400 m and the average depth is about 10 m. At each transect, the river cross section was divided into eight to ten panels, depending on the number of measuring stations at the transect. Using the velocity and depth measurements, the water discharge through each panel could be calculated. Knowing the concentration of suspended sediments in each panel, the transport of suspended sediments through all the panels and thus the total transport through that transect could be obtained. Calculations of the bed material transport in each panel were also made using the Arnhem sampler data.

The total sediment transport rate for each transect is given in Table 1. Details of the transport through each panel can be found in [12]. From Table 1 it can be seen that the bed sediment transport is three to four orders of magnitude smaller than the suspended sediment transport. This means that the transport of contaminants by the bedload is likely to be rather insignificant in comparison with the transport by the suspended sediments.

Table 2 shows the measured contaminant concentrations in the water, the suspended sediments and the bed sediments for the Imperial Oil transect, together with the calculated transport rates for the three chemicals. It can be seen that the transport by water and the transport by suspended sediments are of the same order. In comparison, the transport by bedload is insignificant. The concentration of contaminants in bed sediments is actually not vastly different from that in suspended sediments, even though the bed sediments consist of medium to fine sand in the 0.3 mm size range. However, the small bedload transport rate makes the loading from this source quite negligible.

For the Imperial Oil transect, the concentration of the various chemicals was considered to be fairly constant across the whole river and average concentration values were used to calculate the transport rates. For the other transects downstream, this was not the case. For example, the contaminant concentration distributions at the Sun Oil transect are given in Table 3. It can be seen that while the concentrations in the water do not vary widely, the concentrations in the suspended sediments from the location 10 m off the Canadian shore is very much higher than the other two locations. This is indicative of the sources of contaminants which exist along the Canadian shore. The existence of a contaminant plume along the Canadian shore of the St. Clair has been demonstrated by Chan et al [15]. For this transect, therefore, the contaminant transport from the suspended sediments was calculated by considering that the high concentration values measured at 10 m can be applied to a 20 m wide panel next to the Canadian shore while the lower concentration values apply to rest of the transect. The calculated contaminated transport rates are shown in Table 4. It can be seen that the transport by the bedload is again quite negligible compared with the total transport and that the particulate contaminants and dissolved contaminants are both important.

Similar assumptions were used to calculate the transport rates for the other three transects. The data show that the concentrations in the water were all relatively constant across each transect. Therefore, an average value for concentration in the water was used for each transect. For the suspended sediments, the concentration always had a higher value close to one shore before dropping to a relatively constant value away from the immediate vicinity of that shore. For the St. Clair River, the high values were along the Canadian shore while for the Detroit River, the high values were found close to the U.S. shore. This is to be expected in view of the locations of the industrial activity.

The total contaminant transport rate, the transport by the particulates and the transport by water at the various transects are plotted in Figs. 2, 3 and 4 for the three different contaminants. It can be seen that, in most instances, the suspended sediments carry a larger portion of the contaminant load than the water. As noted before, the portion carried by the bed sediment movement is quite negligible.

DISCUSSION

Contaminants which enter a river can be transported downstream either in the soluble phase with the water or in particulate phase with the suspended sediments or with the bed sediments which move as bedload. For the three organic contaminants being studied, it has been shown that the suspended sediments carry the largest portion of the loading most of the time. Thus the dynamics of these sediments become very important considerations when dealing with the fate of the contaminants. When the flow passes through sections with low velocities or into lakes, settling of the suspended sediments may significantly reduce the downstream transport of contaminants. However, resuspension by high flows or wave action will bring the contaminants back into circulation.

The data show that the amount of contaminants transported by the bed sediment was negligible. This was due mainly to the small rate of bed sediment transport. The concentration of contaminants in the bed sediments was actually quite significant, being comparable to the concentration in the suspended sediments. Calculations using sediment transport relationships [12] have shown that the rate of bed sediment transport measured in the St. Clair River is up to a hundred and fifty times less than the transport capacity of the river. This means that the river can actually transport a much larger bed sediment load and that the transport rate was small because of the scarcity of sediment supply from upstream. Therefore, the role of bed sediments in the transport of contaminants is not necessarily always negligible as in the present case in the St. Clair and Detroit Rivers.

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REFERENCES

1. Environment Canada and Ontario Ministry of the Environment. 1986. St. Clair River pollution investigation (Sarnia area) report, Ottawa, Ontario.
2. Water Resources Branch, Ontario Ministry of the Environment. 1977. Mercury content of sediments in the St. Clair River-Lake St. Clair system. Unpublished report.
3. Water Resources Assessment Unit (Southwestern Region), Ontario Ministry of the Environment. 1979. St. Clair River organics study biological surveys 1968 and 1977. OME report.
4. Chau, Y.K., P.S. Wong, G.A. Bengert, J.L. Dunn and B. Glen. 1985. Occurrence of alkylead compounds in the Detroit and St. Clair Rivers. J. Great Lakes Res. 11:313-319.
5. Pugsley, C.W., P.D.N. Hebert, G.W. Wood, G. Brotea and T.W. Obal. 1985. Distribution of contaminants in clams and sediments from the Huron-Erie corridor. I.-PCBs and octachlorostyrene. J. Great Lakes Res. 11:275-289.
6. Oliver, B.G. and K.L.E. Kaiser. 1986. Chlorinated organics in nearshore water and tributaries of the St. Clair River. Water Poll. Res. J. Canada, 21:344-350.

7. Oliver, B.G. and C.W. Pugsley. 1986. Chlorinated contaminants in St. Clair River sediments. Water Poll. Res. J. Canada 21:368-379.

8. Thornley, S. 1985. Macrozoobenthos of the Detroit and St. Clair Rivers with comparisons to neighbouring waters. J. Great Lakes Res. 11:290-296.

9. Kauss, P.B. and Y.S. Hamdy. 1985. Biological monitoring of organochlorine contaminants in the St. Clair and Detroit Rivers using clams, Elliptio complanatus. J. Great Lakes Res. 11:247-263.

10. Ontario Ministry of the Environment. 1984. Guide to eating Ontario sport fish. Southern Ontario Great Lakes 1984-85. Toronto, Canada.

11. Oliver, B.G. and R.A. Bourbonniere. 1985. Chlorinated contaminants in surficial sediments of Lakes Huron, St. Clair and Erie: implications regarding sources along the St. Clair and Detroit Rivers. J. Great Lakes Res. 11:366-372.

12. Lau, Y.L. and B.G. Krishnappan. 1987. Measurements of sediment loads in St. Clair and Detroit Rivers. NWRI contribution #87-15, National Water Research Institute, Burlington, Ontario, Canada.

13. Oliver, B.G. and K.D. Nicol. 1986. Field testing of a large volume liquid-liquid extraction device for halogenated organics in natural waters. Int. J. Environ. Anal. Chem. 25:275-285.

14. Oliver, B.G. and K.D. Nicol. 1982. Gas chromatographic determination of chlorobenzenes and other chlorinated hydrocarbons in environmental samples using fused silica capillary columns. Chromatographia. 16:336-340.

15. Chan, C.H., Y.L. Lau and B.G. Oliver. 1986. Measured and modelled chlorinated contaminant distributions in St. Clair River water. Water Poll. Res. J. of Canada 21:332-343.

Table 1. Transport rate of suspended sediments and bed sediments

Transect	Suspended sediment transport (kg/day)	Bed sediment transport (kg/day)
Imperial Oil	2.57×10^6	6.71×10^2
Sun Oil	3.00×10^6	3.04×10^3
Port Lambton	2.62×10^6	3.62×10^3
Rouge River	7.76×10^6	3.47×10^2
Gross Isle	8.78×10^6	1.32×10^2

Table 2. Contaminant concentrations and transport rates for the Imperial Oil transect

	Contaminant concentration			Transport rate			
Compound	Bed Material (ng/g)	Water (ng/l)	Suspended solids (ng/g)	Bedload (g/day)	Water (g/day)	Suspended solids (g/day)	Total (g/day)
HCB	6.1	0.044	3.0	0.004	24.4	7.7	32.1
OCS	2.3	0.003	0.8	0.002	1.7	2.1	3.8
PCBs	16	0.640	110	0.011	355	283	638

Table 3. Contaminant concentrations distribution at the Sun Oil Transect

	90 m from U.S. shore		150 m from Canadian shore		10 m from Canadian shore		
Compound	Water (ng/l)	Suspended solids (ng/g)	Water (ng/l)	Suspended solids (ng/l)	Water (ng/l)	Suspended solids (ng/g)	Bed Material (ng/g)
HCB	0.051	2.5	0.041	2.5	0.041	14000	300
OCS	0.012	0.9	0.007	0.4	0.050	99	72
PCBs	0.550	72	0.037	66	0.510	140	52

Table 4. Contaminant transport rates for the Sun Oil transect

Compound	Bedload (g/day)	Water (g/day)	Suspended solids (g/day)
HCB	0.9	22.4	106.8
OCS	0.22	11.7	2.7
PCBs	0.16	242	208

LIST OF CAPTIONS

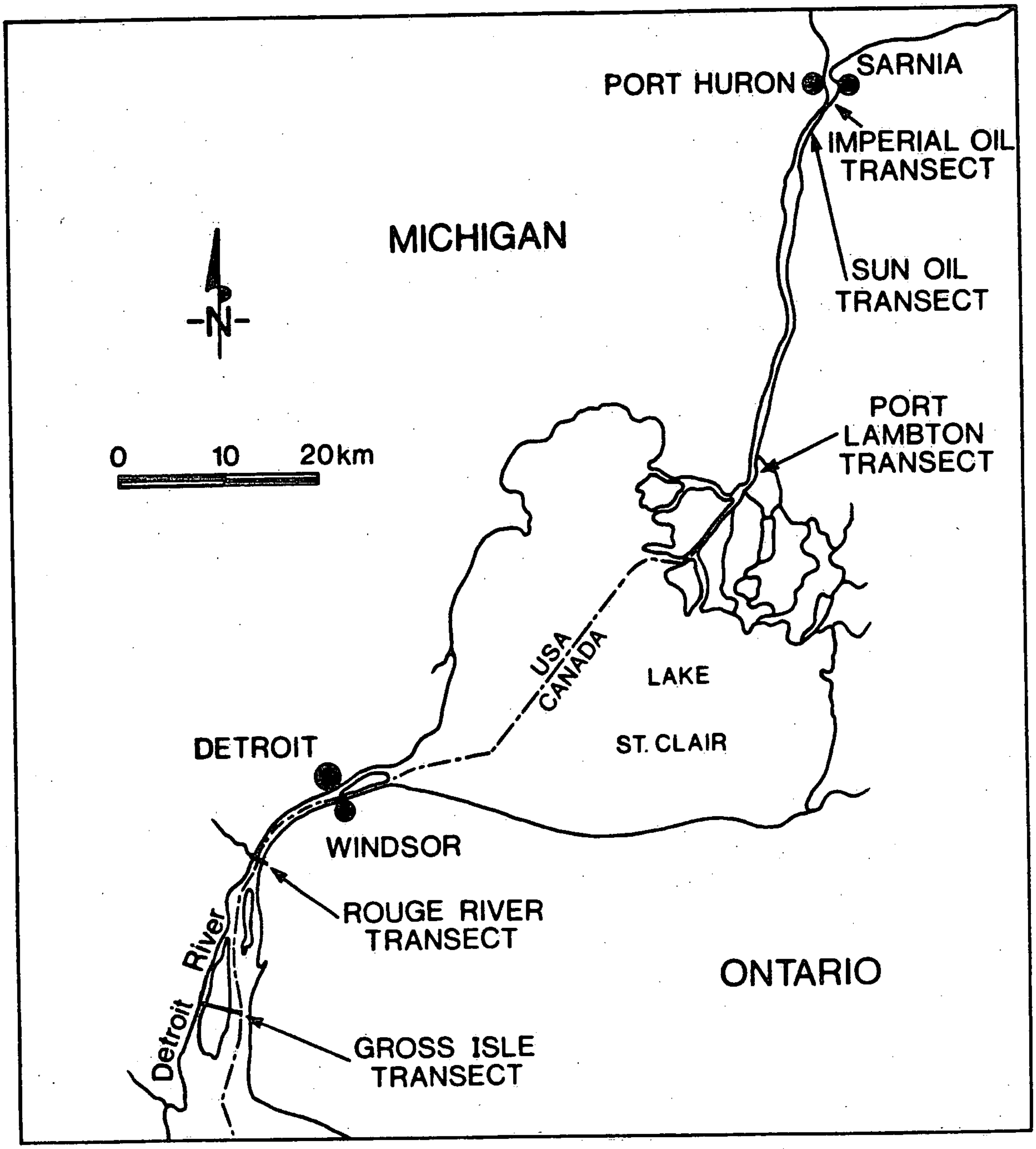

Figure 1 Map of study area and measurement transects.

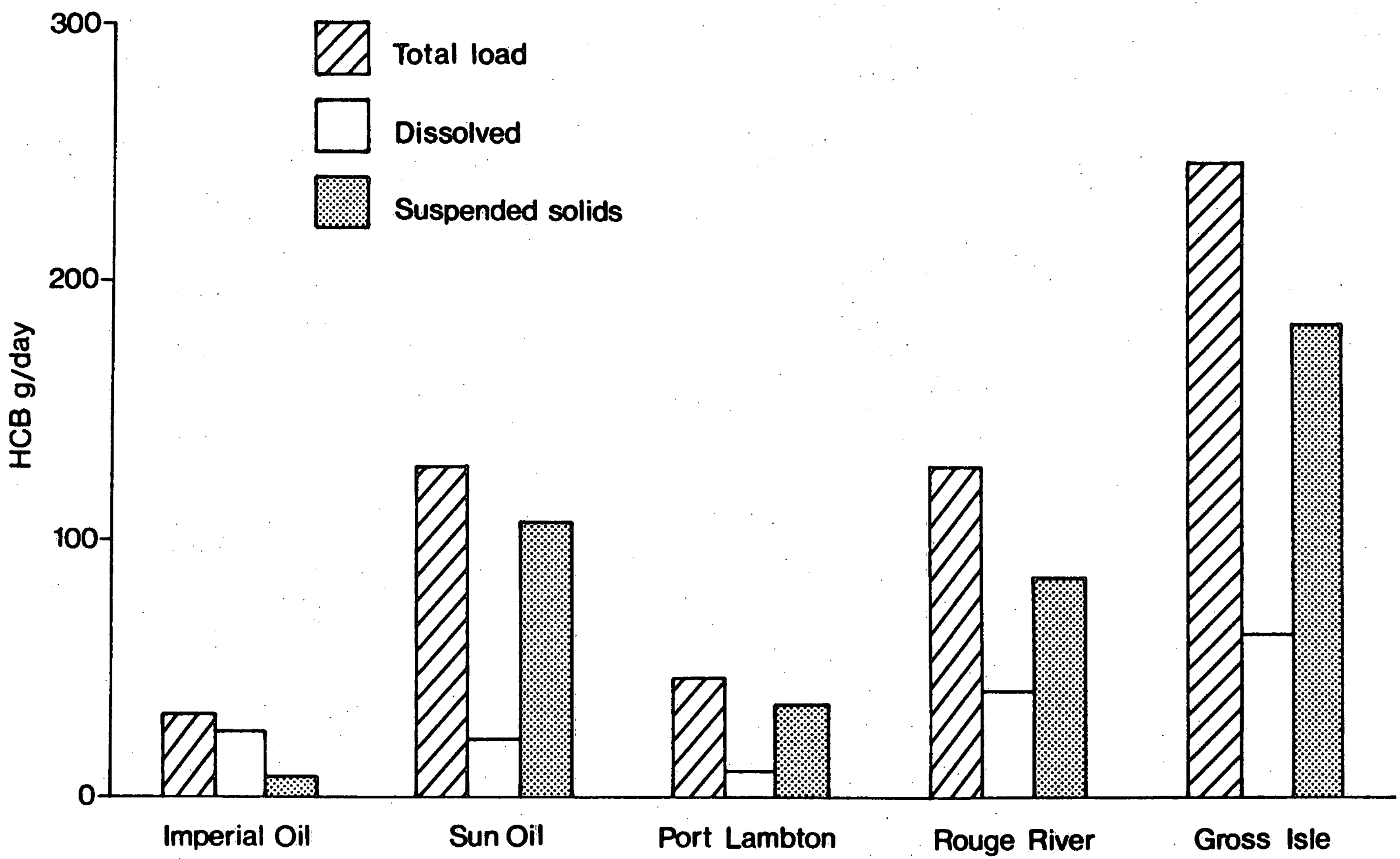

Figure 2 Distribution of HCB transport between the soluble and particulate phases.

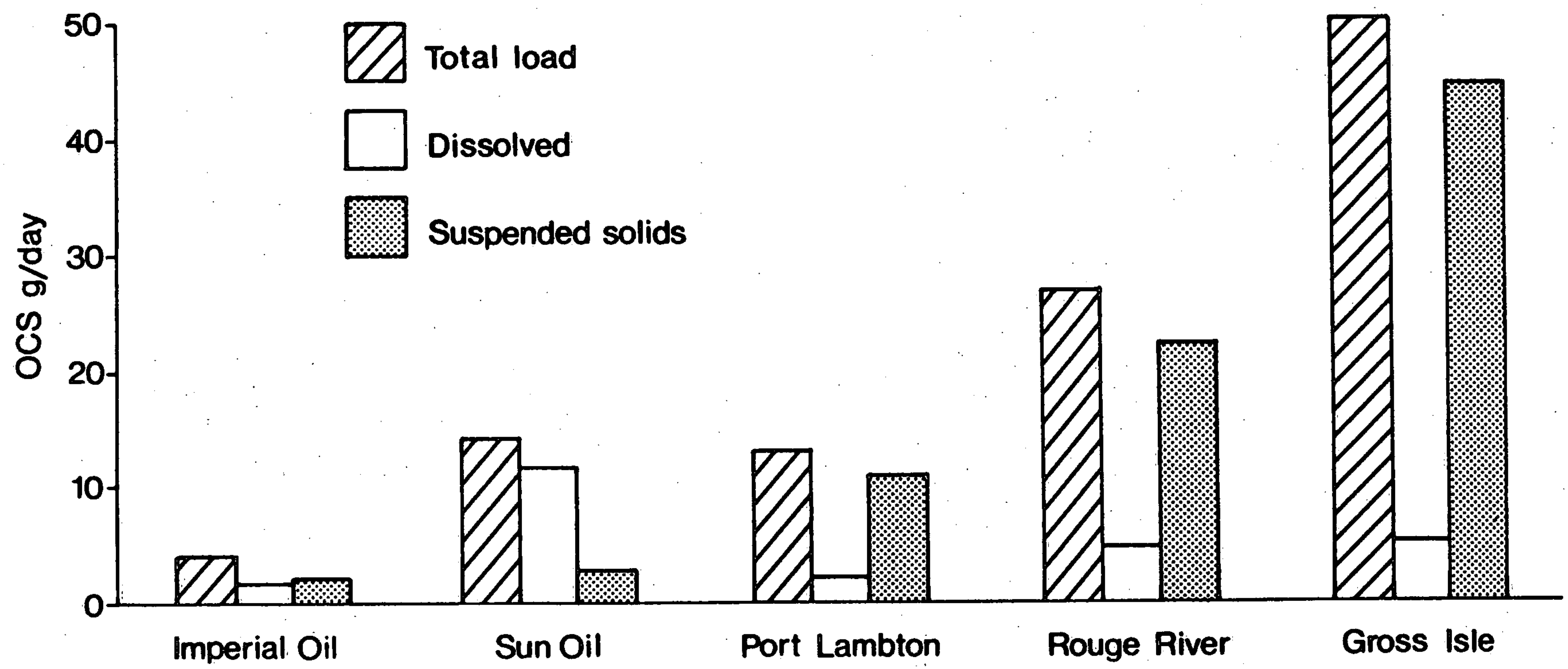

Figure 3 Distribution of OCS transport between the soluble and particulate phases.

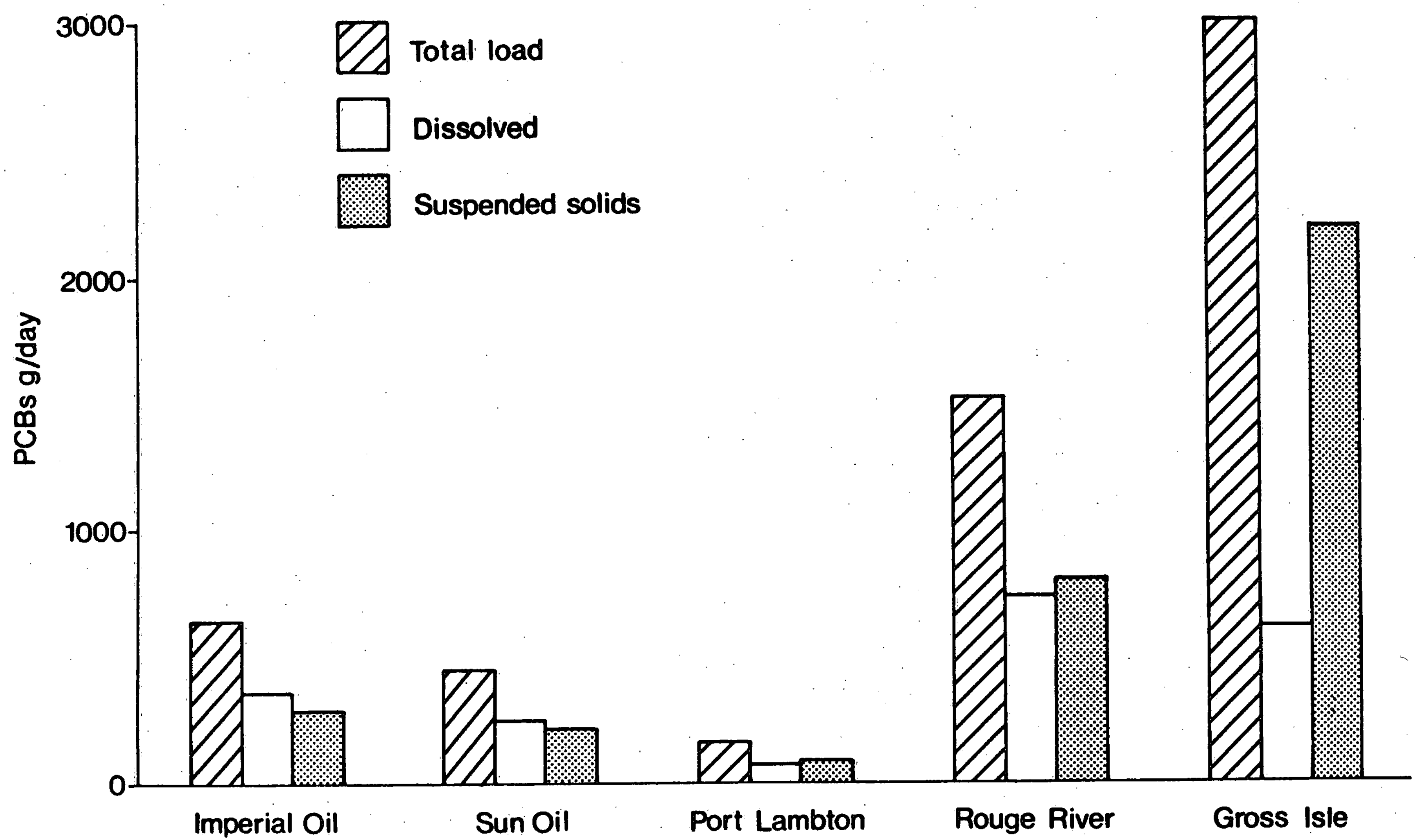

Figure 4 Distribution of PCBs transport between the soluble and particulate phases.