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TOXIC CONTAMINANTS IN URBAN RUNOFF:
A CASE STUDY

by

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MANAGEMENT PERSPECTIVE

Evaluation of the environmental hazards posed by toxic contaminants requires determination of the significance of specific point and non-point sources of toxic contaminants discharged into receiving waters. One of such sources, urban runoff, is addressed in this paper. Selected toxic contaminants were studied in surface runoff from 12 Ontario municipalities. The results of these studies are summarized and presented in the form of contaminant occurrences, mean levels, and calculated loading partitioning between the water and sediment. This information should be of interest in inventory studies of toxic contaminants, comparative evaluations of their sources, considerations of control measures and general water quality studies in urban areas.

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PERSPECTIVE GESTION

Pour être en mesure d'évaluer les risques que les contaminants toxiques représentent pour l'environnement, il faut déterminer l'importance relative de sources ponctuelles et non ponctuelles spécifiques de contaminants toxiques qui se déversent dans des milieux récepteurs. Le présent document traitera de l'une de ces sources, c'est-à-dire le ruissellement urbain. Certains contaminants toxiques de l'écoulement de surface ont été étudiés dans douze municipalités de l'Ontario. Les résultats de ces recherches ont été résumés et sont présentés selon les critères suivants: présence des contaminants, niveaux moyens et charges calculées pour l'eau et pour les sédiments. Ces renseignements devraient servir au moment de dénombrer les contaminants toxiques, d'évaluer comparativement leurs sources, d'envisager des mesures de limitation et de faire des études générales sur la qualité des eaux en zone urbaine.

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Introduction

Concerns about adverse effects of toxic substances on the
environment and human health have increased in recent years as
a result of mounting experimental evidence indicating
carcinogenic, mutagenic and teratogenic impacts of these
substances throughout the biosphere. Such concerns have been
further heightened by the widespread distribution of toxics in
the environment and by indications of bioaccumulation and
biomagnification of many toxic substances. Although in many
cases the impacts of relatively low-level concentrations of
toxics are not yet fully understood, a conservative approach to
this problem and the need to improve the understanding of
underlying processes are generally advocated. Consequently,
the Canadian Department of Environment has initiated a research
program on toxic substances. The main goals of this program
include the compilation of inventories of toxics in the
environment; identification of their sources, pathways and
impacts; and, the development of control and remedial measures.

The problem of toxic substances in the Great Lakes Basin has
been addressed earlier by the International Joint Commission
(IJC) which noted recurring pollutional problems in some parts
of the basin. In these parts, which were designated as "areas
of concern", high levels of such toxic substances as heavy
metals, PCB's, organochlorine pesticides and industrial
organics have been found and identified as primary causes of
environmental degradation. These substances originated from
the following six sources identified by the Commission (7):

Municipal and industrial discharges
Waste disposal sites
Combined sewer overflows
Urban land runoff
Agricultural land runoff, and
In-place pollutants

To evaluate the above sources, a number of studies has been conducted in recent years. Preliminary results of one of these studies, which delt with toxics in urban runoff, are presented in the paper that follows.

Experimental Program

The main study effort focussed on extensive field investigations of selected toxic substances in urban runoff in the study area. The planning and conduct of these investigations differed from earlier studies of conventional pollutants in urban runoff and it is, therefore, desirable to explain such differences before proceeding with the description of the field program.

Conventional pollutants found in urban runoff, for example suspended solids or nutrients, originate mostly from local sources and occur in relatively high concentrations (10^{-5} - 10^{-3}) in which large variations during runoff events. It is feasible to design a program for the monitoring of pollutants in runoff by considering local sources of pollutants and variations in pollutant concentrations during runoff events. There are nos severe restrictions on the number of samples analyzed, because conventional analyses are relatively inexpensive. The data collected are fairly site specific, because they reflect the local composition of pollutant sources.

By contrast, toxic trace organics found in urban runoff typically originate from remote sources and occur in relatively low concentrations (10^{-12} - 10^{-9}). Sources of trace organics are rather dispersed and for many substances, fairly rare. To

some extent, urban runoff provides a transport mechanism (or a pathway) for toxics imported into the catchment mostly with wet precipitation. Consequently, observed concentrations of trace organics exhibit low variations when comparing data from various urban centres, unless strong point sources are present. Such sources can be readily identified from pollution source inventories (mostly industrial inventories) which are compiled by pollution control enforcement agencies. It follows from the above discussion that the trace organics data may be transferable to other areas without strong point sources of organics.

Although trace organics are found in urban runoff in low con-centrations, these concentrations may be important because of high toxicity of many of these substances. Low concentrations and the nature of these substances lead to certain problems. In particular, special sampling procedures have to be used to avoid sample cross contamination and the analytical costs are rather high. The costs of sample collection and analysis are further increased by the fact that trace organics are transported by both water and sediment which may have to be investigated separately. High analytical costs then place a constraint on the number of samples collected in a particular study.

With the present state of knowledge, the interest in toxics in urban runoff is generally limited to their loadings for relatively long time intervals. For comparisons of various sources of toxics, monthly or even yearly loadings in urban runoff are adequate. Such loadings can be determined from mean event concentrations which are determined for composite event samples. Thus, there is no obvious need for costly sequential sampling of toxics in urban runoff.

The occurrence of toxic metals in urban runoff is similar to that of conventional pollutants. Metals originate mostly from local sources (e.g., traffic) and occur in relatively high concentrations (up to 10^{-6}). Their levels may be related to

local sources (e.g., land use) and in this sense, the data on toxic metals may be less readily transferable to other areas without observations. On the other hand, the data on metals in urban runoff are available from numerous sources (2, 4, 5, 8, 11 and 12) and that should help in transposition of data to other areas.

Recognizing the above discussed characteristics of toxic substances in urban runoff, a special field progrm for their monitoring was designed and conducted. A brief description of this program follows.

Toxic Substances Studied
The selection of toxic substances to be studied was initially based on the list of priority pollutants which was developed by the U.S. Environmental Protection Agency (17). This list was reduced to 50 persistent substances for which the samples could be analyzed in the supporting laboratories. These substances, which are listed in Table 1, can be summarized into the following five groups: Polychlorinated biphenyls (PCB's), organochlorine pesticides, polyaromatic hydrocarbons (PAH's), chlorinated benzenes, and trace elements.

Study area
The study area encompassed 12 large urban centres which, with two exceptions, are located in the Canadian part of the Lower Great Lakes Basin. Field investigations were conducted in 12 urban centres which are listed in Table 2 and their locations are shown in Fig. 1. In each centre, several sampling sites were established in areas with various urban land use. The types of land use sampled included residential, commercial, institutional and industrial land. In total, runoff and/or sediment samples were collected at more than 80 sites. At each site, from three to fifteen runoff events were sampled.

Sampling Procedures
Flow measurement and sampling methods for studies of urban runoff have been well established for conventional pollutants.

Table 1. <u>Toxic Substances Studied, Their Detection Limits and Frequencies of Detection</u>

Substance	Detection Limit Water (ppb)	Sediment (ppm)	Frequency of Detection (%)	
PCT's				
<u>Total PCB's</u>	.009	.09	46	85
Organochlorine Pesticides				
<u>Hexachlor benzene</u>	.0004	.004	45	64
α-BHC	.0004	.004	98	28
Lindane	.0004	.004	86	18
Heptachlor	.0004	.004	6	16
Aldrin	.0004	.004	1	10
Heptachlor epoxide	.0004	.004	27	35
γ-Chlordane	.0004	.004	20	35
α-Chlordane	.0004	.004	11	18
α-Endosulfan	.0004	.004	26	51
p,p' - DDE	.0004	.004	19	21
Dieldrin	.0004	.004	26	16
Endrin	.0004	.004	23	26
o,p' - DDT	.0004	.004	18	18
p.p' - TDE	.0004	.004	28	40
p,p' ddt	.0004	.004	22	3
β- Endosulfan	.0004	.004	26	10
Mirex	.0004	.004	3	10
Methoxychlor	.0004	.004	21	12
Polyaromatic Hydrocarbons				
<u>Indene</u>	.05	.05	2	13
1,2,3,4, Tetrahydro-naphthalene	.05	.05	2	8
2, Methylnaphthalene	.05	.05	19	0
Quinoline	.05	.05	4	17
1, Methylnaphthalene	.05	.05	9	1
β- Chloronaphthalene	.05	.05	15	3
Acenaphthylene	.05	.05	17	10
Acenaphthene	.05	.05	13	1
Fluorene	.05	.05	2	8
Phenanthrene	.05	.05	6	30
Fluoranthene	.05	.05	13	37
Pyrene	.05	.05	17	28
Chlorinated Benzenes				
<u>1,3 Dichlorobenzene</u>	.005	.05	18	11
1,4 Dichlorobenzene	.005	.05	25	13
1,2 Dichlorobenzene	.005	.05	48	26
1,3,5 Trichlorobenzene	.001	.005	15	30
1,2,4 Trichlorobenzene	.001	.005	21	31

Table 1. (continued)

Substance	Detection Limit Water (ppb)	Sediment (ppm)	Frequency of Detection (%)	
1,2,3 Trichlorobenzene	.001	.005	5	21
1,2,4,5, + 1,2,3,5, Tetra-chlorobenzene	.001	.005	9	19
1,2,3,4 Tetrachlorobenzene	.001	.005	4	17
Pentachlorobenzene	.001	.005	14	53
Hexachlorobenzene	.0004	.004	19	50
Trace Elements				
Arsenic	.1	.05	87	100
Cadmium	1.0	10	12	70
Copper	1.0	10	93	94
Cobalt	1.0	10	27	58
Chromium	1.0	.5	44	91
Lead	1.0	.5	78	94
Mercury	.05	.1	66	80
Nickel	1.0	10	87	88
Selenium	.1	.05	86	84
Zinc	1.0	.1	98	100

Table 2. Study Sites

Urban Centre	Approximate Population	Annual Precipitation	Number of Sampling Sites
Burlington	115,000	800	2
Cornwall	48,000	680	8
Fort Erie	24,000	1000	2
Guelph	71,000	830	4
Hamilton	306,000	830	11
Kingston	53,000	900	5
Niagara Falls	71,000	940	4
Ottawa	310,000	660	6
Sarnia	51,000	890	14
Stratford	26,000	1030	4
Toronto (City)	600,00	800	12
Welland	45,000	940	9

cases, pollutant concentrations are fairly high and the possibility of sample contamination is rather limited. On the other hand, the corresponding methodology for toxic substances is not well established and some procedures as well as devices used in this study had to be developed on the basis of general recommendations found in the literature (16). Considering the high analytical costs and the interest in mean contaminant concentrations, which can be readily used to produce event loadings, it was desirable to collect flow-proportional composite samples for individual events. Descriptions of various sample collection methods follow.

Street runoff samples were collected by a simple custom made device referred to as the sewer inlet sampler. The sampler consists of a large stainless steel funnel, which fits under the inlet grate, and of a sample container. The funnel diverts a small fraction of the total inflow via a teflon tube into a 22-litre glass bottle which serves as the sample container (12).

Some runoff samples were collected by automatic wastewater samplers operated in the sequential mode. After each event, sequential samples were composed proportionately to the flow rates and volumes recorded by an electromagnetic flow recorder. The sampler employed was the ISCO model 2100 which has been re-commended for the monitoring of toxics (9). It is a sequential sampler with internal plumbing made of stainless steel or teflon, except for a short piece of tubing (0.6 m) leading through the peristaltic pump. This tubing has to be very flexible for good pump operation and, consequently, a medical-grade silicone rubber tubing is used for this purpose. This brand of tubing does not contribute any organics to the samples (9).

Collection of Sediment Samples
Sediment samples were collected by two methods. In the first one, suspended solids samples were obtained by filtration of runoff samples. The filtration process was aided by vacuum or,

for large volumes, by compressed gas. The pore size in the filter was 0.005 mm. To obtain a sufficient quantity of solids, from 5 to 15 litres of stormwater had to be filtered. Filtered solids were placed in glass jars and submitted for analysis. Samples of street surface sediments were collected by dry vacuuming. Some fractions of such samples were further analyzed to obtain a particle size distribution.

Preservation of Samples

Samples were removed from sampling devices as soon as possible after the sampled events and placed in glass bottles or jars with tops covered by aluminum foil. In the laboratory, the samples were transferred into laboratory bottles, preserved as required by the analytical laboratory (18) and submitted for analysis. Sediment samples were delivered in glass jars and subsequently frozen. Empty sample containers were washed with soap and hot water, rinsed with hot and distilled water and, after draining, further rinsed with analytical grade acetone and petroleum ether. The final rinse was made with pesticide residue grade ethyl acetate and hexane.

Analytical Methods

Details of analytical methods used can be found elsewhere (18). A brief summary of these methods follows.

Trace Organics - Water samples were extracted by the methylene chloride water extraction method. Sediment samples were extracted by ultrasonic extraction. Because of high amounts of coextracted interferring compounds present, an additonal cleanup step involving gel permeation was added. The analysis of extracts was done by gas chromatography. For PCB's and pesticide analysis, high-resolution chromatography with two columns was used. For the remaining substances, single-column chromatography was used. Two detectors were used - a flame ionization detector for PAH's and an electron capture detector for the remaining substances.

Trace Elements - Runoff samples were analyzed by atomic absorption spectroscopy. Sediment analyses were done by cold vapour atomic absorption for mercury, flameless atomic absorption for arsenic and selenium, and the bomb digestion method for the remaining elements.

Results and Discussion

The presentation of results starts with frequencies of detection, followed by mean concentrations and partitioning of loadings in water and sediment phases of runoff.

Frequency of Detection

The frequency of detection is a useful statistic which indicates prevalence of a particular substance in the medium studied. This statistic, however, is fully meaningful only in combination with the detection limit concentration which applies to the analytical method used. When less expensive and less sensitive methods are used, lower detection frequencies are obtained and vice versa.

The detection frequencies discussed below correspond to the detection limits shown in Table 1. It should be also noted that detection frequencies are reported here separately for runoff and sediment samples.

As a group, the trace elements were found to be the most prevalent toxic contaminants in urban runoff and sediment. For water samples, the detection limit was typically 1 ppb with the exception of arsenic, mercury and selenium. At this level, the most frequently detected elements were zinc (98% of all water samples), copper (93%), nickel (87%), and lead (78%). Such results agree quite well with those reported in the NURP program (2). For arsenic, mercury and selenium, the detection limit was substantially lower (0.1 ppb). At this level, the frequencies of detection varied from 66% to 87%.

The frequencies of detection of trace elements in sediment samples were higher than those found for water samples and typically ranged from 58% to 100%.

Among trace organics, the detection frequencies varied widely. Pesticides were the most prevalent group. Two substances, α-BHC and γ-BHC (lindane) were found in 98% and 86% of all water samples, respectively. This finding is in agreement with the earlier reported prevalence of these substances in rainwater (14). For the remaining substances, the detection frequencies in water samples varied from 1% to 45%. The two lowest frequencies were found for aldrin (1%) and mirex (3%). The highest frequency was found for hexachlor benzene (45%) and the remaining frequencies varied from 6% to 28%. The detection frequencies reported here were generally higher than those found in the NURP program, but the general trends were quite similar. The above differences were possiblycaused by different detection limits used in both programs.

The detection frequencies in sediment samples were more uniformly distributed. At the detection level of 0.04 ppm, the frequencies varied from 3% to 64%. The highest frequencies were found for hexachlor benzene (64%) and α-endosulfan (51%), the lowest for p,p'-DDT (3%). The frequency of detection of total PCB's was 46% and 85% for water and sediment samples, respectively.

The detection frequencies of chlorinated benzenes varied from 4% to 48% in water samples and from 1% to 53% in sediment samples. The least prevalent group were PAH's, particularly in water samples. The frequencies of PAH's varied from 2% to 19% in water samples and from 1% to 37% in sediment samples. These results were affected by somewhat higher detection limits used in PAH's analyses.

Mean Concentrations

The mean concentrations reported here were defined as arithmetic means of mean concentrations determined for composite event

samples. The decision to use the arithmetic mean as opposed to the sometimes used geometric mean was based on limited variations in mean event concentrations.

For data below the detection limit, the concentration was set equal to 0.5 of the detection limit. This expedient barely affected the final results for substances with high detection frequencies and low detection limits. The only group where the above assumption may have caused significant uncertainties in the final results were PAH's. In their case, the detection limit was somewhat higher and the detection frequencies were therefore somewhat lower. For reasons of brevity, only the salient data are presented here. A complete listing of mean concentrations can be found elsewhere (12).

The highest concentrations were found for trace elements as a group. Among the individual elements, the highest mean concentrations were found for zinc (440 ppb in water, 400 ppm in sediment), lead (90 ppb in water, 470 ppm in sediment), copper (19 ppb in water, 67 ppm in sediment), and nickel (16 ppb in water, 50 ppm in sediment). Such values are generally consistent with those reported earlier by others (4, 5, 8, and 11).

The remaining substances were found in significantly lower (by several orders of magnitude) concentrations. The highest values were found for PAH's, but these may have contained relatively significant uncertainties caused by their low frequencies of detection and many readings below the level of detection. The remaining trace organics were found in water samples in mean concentrations ranging from .001 ppb to 0.04 ppb. The highest concentrations were found for 1,2 dichlorobenzene (.04 ppb), α-BHC (.02 ppb) and the total PCB's (.014 ppb). In sediment samples, the highest concentration was found for PCB's (1 ppm). Other concentrations varied from for several chlorinated benzenes, chlordane, and some derivatives of DDT.

Water/Sediment Partitioning of Loadings

The division or partitioning of contaminant loadings into the adsorbed and dissolved components is of interest for the planning of future studies and control measures. In general, such a division depends on numerous physico-chemical factors and may vary with time. Two approaches are commonly used to obtain water/sediment partitioning - a theoretical approach based on equations of the sorption process and an empirical approach based on separate analyses of water and sediment components of collected samples. Both approaches have some disadvantages. In the former cae, several simplifying assumptions have to be made. In the latter case, an equilibrium distribution may not have been reached. Considering these factors, the empirical approach was considered more appropriate and therefore adopted in this study.

The division of water/sediment loadings was calculated for a reference concentration of suspended solids of 20 mg/L which corresponds to the mean concentration established in an earlier study (15). The calculated divisions of loadings needed to be further evaluated. In this connection, the substances whose loadings were strongly associated with either water or sediment were of particular interest. Considering the uncertainties involved in this evaluation, the strong association was defined somewhat conservatively as the case where 80% or more of the total loading was associated with either water or sediment. Using this definition, loading partitionings were evaluated for all 50 substances studied. It was noted that the results obtained for PAH's were not meaningful, because they were strongly influenced by data below the detection limits. Consequently, PAH's were eliminated from this analysis. Among the remaining 38 substances, 12 exhibited loadings strongly associated with either water or sediment. These substances are listed in Table 3. For the remaining 26 substances, loading divisions were more uniform.

Although the concentrations of toxics in sediment were greater than those in water by a factor ranging from 10^2 to 10^5, the

Table. 3. Partitioning of Selected Toxic Loadings Between the
Liquid and Solid Phase of Runoff

Substance Loadings Associated with the Liquid (% of total)		Substance Loadings Associated With the Sediment (% of total)	
α-BHC	95%	Hexachlor benzene	95%
γ-BHC	90%	α-chlordane	84%
Mercury	99%	α-endosulfan	92
Selenium	96%	p,p'-DDE	83%
Zinc	85%	o,p'-DDT	88%
		p,p'-DDT	90%
		PCB's	93%

loadings calculated for five substances (see Table 3) were
carried mostly by water. Because two of these substances,
mercury and zinc, are known for their affinity for suspended
solids (17), it is unlikely that the calculations reflect
equilibrium conditions.   Under   such   conditions,   both
substances, BHC isomers and selenium, are known for their low
affinity for suspended solids (17) and the calculated results
are therefore plausible. All seven substances whose loadings
were carried mostly by sediment are known for their high
affinity for suspended solids (17) and this is correctly
reflkected by the calculated resutls in Table 3.

Sources of Toxic Contaminants in Urban Runoff
The most prevalent group, trace elements, have been studied
most extensively among all the contaminants investigated in
this study. This is particularly true for the most commonly
occurring metals - zinc, lead and copper. An extensive
discussion of sources of these metals in runoff can be found
elsewhere (11).   Only a brief listing of common sources
follows.

The most significant sources of zinc in urban runoff include atmospheric fallout, corrosion processes (particularly in galvanized metal sewers), tires, pavement wear, automobile exhausts, exterior paint, road salt and possibly some terrestrial sources (11). The sources of lead include gasoline products and by-products of their combustion, and exterior paints and stains. The sources of copper include corrosion of copper plumbing, electroplating wastes, some algicides, brake linings and asphalt pavement wear (11).

PCB's were used extensively in many industrial applications, particularly in fire-resistant transformers and insulating condensers. Although their use has been recently restricted, they are commonly found in the environment.

Many organochlorine pesticides were found in runoff samples. The two most prevalent pesticides, α-BHC and γ-BHC, are used commonly in soil treatment to eliminate nematodes and other pests. The remaining pesticides are much less prevalent and were found in low concentrations. Some of these substances have been banned for use in Ontario and their residues came either from atmospheric sources or from soil residues. The composition of rainwater in the Great Lakes region (14) indicated that PCB's, α-BHC and γ-BHC were most prevalent and occurred in concentrations which exceeded those of other pesticides by an order of magnitude. Similar trends were reflected in the composition of water in the Lower Great Lakes (13).

PAH's are widely distributed in the environment. Besides their natural sources (some forms of biosynthesis in phytoplankton, algae and plants; natural forest fires (1)), there are anthropogenic sources associated with combustion of fossil fuels. PAH's were reported in urban runoff studies undertaken in Great Britain (1, 8), Norway (3, 10), Sweden (11) and USA (2). It appears that PAH's are commonly found in highway runoff and their origin can be traced to combustion byproducts. PAH's tend to accumulate in soils (8, 10) and snowbanks (10) along highways. Typical dustfall deposition rates of PAH's along

highways vary from 0.3 ng/day/m^2 to 12 ng/day/m^2. PAH's accumulated in snowbanks are suddenly released to the receiving waters during the snowmelt period and create a shock loading (10).

Chlorinated benzenes originate primarily from industrial sources. No other information on their occurrence in urban runoff has been found in the literature.

Environmental Implications

The significance of the reported levels of toxic substances needs to be evaluated in terms of environmental criteria. Such criteria may be based on a whole variety of considerations, including the human health, drinking water standards and toxicity to aquatic life. From these considerations, general criteria for water quality in the receiving water bodies are developed. In the study described here, the water quality criteria used were established by the International Joint Commission and referred to as water quality objectives for the Great Lakes (6). The discussion that follows is based on those objectives.

IJC established water quality objectives for the seven trace elements listed in Table 4. It is apparent from this table that such objectives were exceeded by the mean concentrations of four elements - cadmium, lead, mercury and zinc. The reported exceedances are highly significant, because the mean observed concentrations varied from 3.6 to 17 times the objective values. Considering the fact that the reported levels represent means of event means, temporary exceedances for limited durations will be even higher than indicated in the table below.

A PCB's concentration of 0.01 ppb has been suggested as an objective on the basis of their bioaccumulation in fish (6). Such an objective was slightly exceeded (by 40%) by the mean concentration reported here. This concentration reported for urban runoff (0.014 ppb) compared quite well with the values reported for the rainwater in the study area - 0.11-0.031 ppb

TABLE 4.   Comparison of Observed Trace Element Levels With
            the IJC Water Quality Objectives

Element	IJC Objective (ppb)	Observed Level (ppb)	Objective Exceeded
Arsenic	50	1.7	No
Cadmium	.2	1.3	Yes
Chromium	50	6.4	No
Lead	25	90	Yes
Mercury	.2	3.4	Yes
Selenium	10	1.6	No
Zinc	30	440	Yes

(14). It would appear that the above objective for PCB's would
be exceeded even by the levels reported for the rainwater.

Water quality objectives for eight organochlorine pesticides
were also developed by IJC and listed in Table 5. Such ob-
jectives were exceeded only in the case of heptachlor epoxide.
Temporal exceedances, in some locations, can be expected for
aldrin/dieldrin, ΣDDT, endosulfan and lindane. No objectives
were available for the most prevalent pesticide - α-BHC. This
pesticide was found in the NURP study (2) to exceed the EPA
criteria for the protection of human life from carcinogenesis
at the 10^{-5} risk level.

Conclusions

Among the toxic contaminants studied, trace elements and
particularly heavy metals were the most prevalent. The highest
levels were found for lead and zinc. Four elements were found
at levels which exceeded the ICJ water quality objectives. The
next group in terms of levels were PAH's. Although they were
infrequently detected in water samples (partly because of their
detection limit of .001 ppb), they seem to be quite widespread

Table 5. Comparison of Observed Pesticide Concentrations
Levels With the IJC Water Quality Objectives

Element	IJC Objective (ppb)	Mean Observed Concentration (ppb)	Objective Exceeded
Aldrin/Dieldrin	.001	.0006	No
Chlordane	.060	.0012	No
ΣDDT	.003	.0012	No
Endosulfan	.003	.0011	No
Endrin	.002	.0008	No
Heptachlor Epoxide	.001	.0011	Yes
Lindane	.010	.0065	No
Methoxychlor	.040	.0015	No

in sediments in urban areas. Among the pesticides studied, α-BHC and γ-BHC occurred most frequently and at the highest levels. Another pesticide, heptachlor expoxide, was found at the level exceeding the IJC water quality objective. PCB's were detected rather frequently and their mean levels also exceeded the IJC objective. Finally, chlorinated benzenes were found at the levels comparable to those reported for pesticides. Their occurrence was related to industrial sources.

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