

Canadian Environmental Protection Act

Priority Substances List
Assessment Report

WASTE CRANKCASE OILS

Government of Canada
Environment Canada
Health Canada

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TABLE OF CONTENTS

Synopsis	v
Glossary	vii
1.0 Introduction	1
2.0 Summary of Information Critical to Assessment of "Toxic"	4
2.1 Identity, Production, and Uses	4
2.2 Entry into the Environment	6
2.3 Exposure-related Information	10
2.3.1 Fate	10
2.3.2 Concentrations	14
2.4 Effects-related Information	22
2.4.1 Dust Suppressant, Landfill, Land Disposal, and Spills	22
2.4.2 Re-refining, Fuel, and Sewers	25
3.0 Assessment of "Toxic" Under CEPA	26
3.1 CEPA 11(a) Environment	26
3.2 Conclusion	28
4.0 Recommendations for Research and Evaluation	29
5.0 References	30

LIST OF FIGURES

1	Estimated Quantities of Waste Crankcase Oils Generated in 1990 for Each Entry Scenario	7
2	Air Contaminant Concentrations in Stack Emissions and Downwind Concentrations from Combustion Units Using Waste Crankcase Oils as Fuel	17
3	Contaminant Concentrations Released in Runoff and to the Atmosphere from a Road Treated with Waste Crankcase Oils	21

Synopsis

The priority substance "waste crankcase oils" (WCOs) is defined as used lubricating oils removed from the crankcase of internal combustion engines. For the purpose of this assessment, the life cycle of WCOs was considered to begin at the point of collection. During collection, WCOs are frequently mixed with other waste oils. Therefore, the definition of WCOs also includes these mixed waste oils. In this assessment, an attempt was made to follow the life cycle through to their ultimate disposal. In so doing, seven use or disposal practices or scenarios were studied by which WCOs may enter the Canadian environment:

- (i) re-refining;
- (ii) burning as fuel;
- (iii) road-oiling as a dust suppressant;
- (iv) landfilling;
- (v) land disposal (*e.g.*, fields, pits);
- (vi) sewer disposal; and
- (vii) spills to the environment.

The composition of WCOs is difficult to characterize in chemical or other terms that would be useful for assessing the potential impact of these materials on the environment. It is recognized that the major components consist of aliphatic and aromatic hydrocarbons. Also present are organic and inorganic compounds of chlorine, sulphur, phosphorus, bromine, nitrogen, and metals such as zinc, magnesium, barium, and lead resulting from oil additives and contamination during use or disposal.

In 1990, the volume of recoverable WCOs was estimated to be 229.3×10^6 litres (L) or about 56% of the 413.3×10^6 L of crankcase oils sold in the automotive sector in Canada. The remainder was consumed during engine use, emitted from exhausts, and leaked from crankcases into the environment. The generation of WCOs from other sectors (*e.g.*, rail, marine and air transport, mining, forestry, and agriculture) could not be quantified, but is not believed to be as great as from the automotive sector.

Based on the available information regarding entry and fate, the following four of the seven scenarios by which WCOs enter the Canadian environment are of concern (percentages reported are 1990 estimates for automotive sector only):

- (i) re-refining (50.6%);
- (ii) burning as fuel (33.6%);
- (iii) road-oiling for dust suppression (3.0%); and
- (iv) land disposal (2.8%).

These scenarios were deemed to be of concern because they involved either direct releases to the environment (dust suppression and land disposal) or the volumes of WCOs involved were large (fuel and re-refining). The remaining scenarios were considered to be of less concern because the volumes involved were small (spills), or because entry to the environment was likely to be minimal (landfilling, sewer disposal).

Waste crankcase oils and their constituents may be released to air, water, and soil. Burning WCOs leads to air emissions of metals and polycyclic aromatic hydrocarbons (PAHs) (the constituents of WCOs of most concern) that are generally adsorbed to particulate matter and deposited to soil and water. Waste crankcase oils released to water initially lead to the formation of a surface film. Physical and chemical changes to the surface film release constituents of WCOs and their breakdown products to the environment via volatilization, emulsification, solubilization, partitioning to sediments, photodegradation, and biodegradation. Release of WCOs to soil leads to entry of its constituents to the environment via volatilization, adsorption to solid organic matter, leaching through soil to groundwater, or runoff to surface waters.

Insufficient information was available to estimate exposure of aquatic and terrestrial biota to WCOs entering the environment as described in the four scenarios of concern. No field effects data were available to assess the effects of WCOs on the Canadian environment.

There is insufficient information to estimate the exposure of humans to WCOs. In addition, information was not identified on the effects of WCOs on the environment on which human life depends. Therefore, detailed consideration of whether WCOs are "toxic" as defined under Paragraphs 11(b) and 11(c) of the *Canadian Environmental Protection Act* is not included in this assessment.

Therefore, based on these considerations, it has been determined that there is insufficient information to conclude whether waste crankcase oils are entering the environment in a quantity or concentration or under conditions that are having a harmful effect on the environment.

Glossary

Additives - substances that enhance and prolong the performance characteristics and life of the lubricating base oil; for automobiles, these additives include inorganics and aromatic organics.

Agglomeration - the action or process of oil constituents combining in a mass.

Asphalt Extenders - a material (such as distillation bottoms) that extends the properties of the asphalt.

Crankcase - the housing for the crankshaft of an engine, where, in the case of an automobile, oil from hot engine parts is collected and cooled before being pumped back to the engine.

Crankcase Oil - consists of virgin lubricating base oil and additives; it is used in the crankcase as a hydrodynamic lubricant to reduce friction, as a coolant, and to form a compression seal.

Demetallized Filter Cake - neutral phosphate solid waste that is a by-product of the demetallizing/vacuum distillation/hydrotreating re-refining process.

Distillation Bottoms - by-products of the distillation processes in re-refineries; these by-products have higher boiling points than the recovered lubricating oil and are nonvolatile.

Fleet Shop - a permanent maintenance location (garage) where a company's fleet of automobiles or trucks is repaired and where preventative maintenance (*e.g.*, oil changes) is carried out.

Gas Scrubbers - liquids that come into contact with gases to remove gaseous or liquid impurities by solubilization or by chemical combination.

Lubricating Base Oil - derived from selected fractions of refined petroleum or other oils; it is a complex mixture of hydrocarbons (80 to 90%) used together with performance-enhancing additives to make crankcase oil.

Off-Road Industry Fleet Shop - a maintenance location for off-road industry vehicles; its location is temporary and depends on where the company is working at the time.

Recoverable - the volume of oil that is not consumed in-use and that becomes a waste; this volume can be recovered for reuse or recycling purposes.

Sludge - residue left after acid treatment of petroleum oils; any semi-solid waste from a chemical process; sediment in a steam boiler; a precipitate from oils, such as the products from crankcase oils in engines.

Sootblow - ash and slag removed from the heat-absorbing surfaces of combustion units by a system of steam or air jets used to maintain cleanliness, efficiency, and capacity of heat-transfer surfaces.

Spent Acid - the residue from the sulphuric-acid treatment of petroleum lubricants; also known as sludge assay or waste acid.

Spent Clay - the residue from the acid/clay or vacuum distillation/clay re-refining processes.

Weathering - changes in the physical and chemical properties of oil exposed to environmental processes, such as evaporation, dissolution, biodegradation, photodecomposition, dispersion into the water column, emulsification, adsorption onto suspended particulate, agglomeration, sedimentation, and others.

1.0 Introduction

The *Canadian Environmental Protection Act* (CEPA) requires the Minister of the Environment and the Minister of Health to prepare and publish a Priority Substances List that identifies substances, including chemicals, groups of chemicals, effluents, and wastes, that may be harmful to the environment or constitute a danger to human health. The Act also requires both Ministers to assess these substances and determine whether they are "toxic" as defined under Section 11 of the Act which states:

"... a substance is toxic if it is entering or may enter the environment in a quantity or concentration or under conditions

- (a) having or that may have an immediate or long-term harmful effect on the environment;
- (b) constituting or that may constitute a danger to the environment on which human life depends; or
- (c) constituting or that may constitute a danger in Canada to human life or health."

Substances that are assessed as "toxic" as defined under Section 11 of the Act may be placed on the List of Toxic Substances in Schedule I of CEPA. Consideration can then be given to developing regulations, guidelines, or codes of practice to control any aspect of these substances' life cycle, from the research and development stage through manufacture, use, storage, transport, and ultimate disposal.

In this assessment, the priority substance waste crankcase oils (WCOs) is defined as used lubricating oils removed from the crankcase of internal combustion engines. For the purpose of this assessment, the life cycle of WCOs began at the point they were collected, and an attempt was made to follow through to their ultimate disposal. In so doing, seven use or disposal practices or scenarios were studied by which WCOs may enter the Canadian environment:

- (i) re-refining;
- (ii) burning as fuel;
- (iii) road oiling as a dust suppressant;
- (iv) landfilling;
- (v) land disposal (e.g., fields, pits);
- (vi) sewer disposal; and
- (vii) spills to the environment.

Since WCOs are frequently mixed with other waste oils during their collection, the assessment of other waste oils is included where appropriate.

Data relevant to the environmental portions of the assessment were identified through searches of commercial and government databases including: AQUALINE

(1988 to February 1993), Aquatic Information Retrieval (AQUIRE) (1977 to July 1990), Oil and Hazardous Materials/Technical Assistance Data System (OHMTADS) (1971 to December 1985), Aquatic Sciences and Fisheries Abstracts (ASFA) (1988 to January 1993), Toxicology Information Online (TOXLINE) (1988 to December 1992), Commonwealth Agricultural Bureau (CAB Abstracts) (1988 to January 1993), Environmental Fate (ENVIROFATE) (1976 to December 1992), Hazardous Substances Data Bank (HSDB) (1988 to January 1993), National Technical Information Service (NTIS) (1988 to January 1993), POLLUTION ABSTRACTS (1988 to November 1992), Integrated Risk Information System (IRIS) (1988 to January 1993), Chemical Carcinogenesis Research Information System (CCRIS) (1988 to December 1992), Registry of Toxic Effects of Chemical Substances (RTECS) (1988 to July 1992), and Directory of American Research Technology (DART) (1988 to January 1993). Additional information was identified in review documents.

The potential effects of WCOs on human health have not been widely studied. Based on a preliminary literature survey, it has been concluded that there are insufficient data to assess the degree of human exposure to WCOs. Information is available on the effects of several of the major constituents, such as PAHs, arsenic, cadmium, chromium, and nickel in experimental animals and humans. However, these substances are being addressed in separate Assessment Reports and their potential effects on human health will not be discussed in this report. No information was identified to indicate that WCOs affect the environment upon which human life depends. Therefore, detailed consideration of whether waste crankcase oils are "toxic" as defined under Paragraph 11(b) and 11(c) of the *Canadian Environmental Protection Act* is not included in this assessment.

Although much of the research on WCOs has been conducted outside Canada, available data on sources, fate and concentrations, and effects of WCOs on the Canadian environment were emphasized. All original studies that form the basis for determining whether WCOs are "toxic" under CEPA have been critically evaluated by the following Environment Canada staff:

R.L. Breton, Task Group Leader
F. Laperrière
D.R.J. Moore
W.M. Windle

In this report, a synopsis is presented that will appear in the *Canada Gazette*. A summary of technical information that is critical to the assessment is presented in Section 2.0. A Supporting Document that discusses the technical information in greater detail has also been prepared and is available upon request. The assessment of whether WCOs are "toxic" under CEPA is presented in Section 3.0.

As part of the review and approvals process established by Environment Canada for its contributions to Priority Substances List Assessment Reports, this report was reviewed by a number of experts from Environment Canada as well as the following external experts: Roger Lafleur (Canadian Petroleum Products Institute), David Black

(Energy Mines and Resources Canada), Jerry F. Payne (Fisheries and Oceans Canada), Rafael Vazquez-Duhalt (University of Alberta), William Stubblefield (ENSR Consulting and Engineering, Fort Collins, CO), and David Hoffman (U.S. Fish and Wildlife Service, Laurel, MD). The final Assessment Report was reviewed and approved by the Environment Canada/Health Canada CEPA Management Committee.

Copies of this Assessment Report and the unpublished Supporting Document are available upon request from:

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2.0 Summary of Information Critical to Assessment of "Toxic"

2.1 Identity, Production, and Uses

Waste crankcase oils (WCOs) are defined as used lubricating oils removed from the crankcase of internal combustion engines* (CCME, 1989a; CH2M HILL ENGINEERING LTD., 1992). Before they are used, crankcase oils consist of a base lubricating oil (a complex mixture of hydrocarbons, 80 to 90% by volume) and performance-enhancing additives (10 to 20% by volume) (Petro-Canada, 1987; Franklin Associates Ltd., 1985; Vazquez-Duhalt, 1989). Crankcase oils are altered during use because of the breakdown of the additives, contamination with the products of combustion, and the addition of metals from the wear and tear of the engine (CH2M HILL ENGINEERING LTD., 1992). Therefore, the composition of WCOs is variable and difficult to characterize. Nevertheless, WCOs generally consist of linear and branched aliphatic alkanes, cyclic alkanes, and mono- and polycyclic aromatic hydrocarbons such as phenol, naphthalene, benz(a)anthracene, benzo(a)pyrene, and fluoranthene. Other organic compounds include toluene, benzene, xylenes, and ethylbenzene. Also present are organic and inorganic compounds of chlorine, sulphur, phosphorus, bromine, nitrogen, and metals such as zinc, magnesium, barium, and lead (Hey, 1966; CPPI, 1990; CCME, 1989a).

During collection, waste crankcase oils are frequently mixed with other waste oils, such as industrial lubricating oils, hydraulic oils, metal working and cutting oils, heat transfer oils, oil storage tank bottoms, and oil/water mixtures from diverse sources (Byrne *et al.*, 1989; CCME, 1989a; U.S. EPA, 1992). Therefore, the definition of WCOs is expanded to include other waste oils, of which WCOs are a major fraction. Poor segregation practices during collection and transportation of WCOs may introduce contaminants such as chlorinated organics, spent solvents, and polychlorinated biphenyls (PCBs)(CCME, 1989a; Vazquez-Duhalt, 1989).

Waste crankcase oils are generated by the following sectors: automotive (cars and trucks); railway (diesel locomotives); marine and aviation transportation sectors (diesel-powered boats and piston-driven aircraft); and the transportation and operation of the mining and forestry (off-road vehicles and equipment) and agricultural (off-road machinery such as tractors) sectors (CCME, 1989a; Transport Canada, 1991, as cited in CH2M HILL ENGINEERING LTD., 1992; CH2M HILL ENGINEERING LTD., 1992). Recent data on sales of crankcase oils are available for the automotive, marine, and aviation sectors. Estimates of generation of WCOs, however, are available only for the automotive sector.

In 1990, the volume of crankcase oils sold in the automotive sector in Canada was estimated to be 413.3×10^6 L, of which 227×10^6 L was for gasoline engines and 186.3×10^6 L was for diesel engines (CPPI, 1993a). Private vehicles use approximately 75% (170.3×10^6 L) of the crankcase oils sold for gasoline engines, and light

* For definition of technical terms used in this report, see the Glossary.

commercial vehicles that run on gasoline or propane use the remaining 25% (56.8×10^6 L). Heavy, commercial on-road vehicles use 70% (130.4×10^6 L) of the crankcase oils sold for diesel engines, and industrial off-road vehicles use the remaining 30% (55.9×10^6 L) (CH2M HILL ENGINEERING LTD., 1992).

About half the volume of crankcase oils is burned and released from the exhaust during engine use (Elliot, 1986) and lost from crankcases as leaks into the environment (Mueller Associates Inc., 1987; 1989; Vazquez-Duhalt, 1989; CH2M HILL ENGINEERING LTD., 1992). It is estimated that direct oil emissions in the exhaust from engines in perfect technical condition range from 0.1 to 0.25 L/1000 km (Reinhardt, 1989).

In a survey of automobile owners by CH2M HILL ENGINEERING LTD. (1992), it was estimated that 60% of crankcase oils was recoverable as WCOs from gasoline engines and 50% of crankcase oils was recoverable as WCOs from diesel engines. Based on these estimates, generation of WCOs in 1990 from the volume of crankcase oils sold for gasoline and diesel engines was estimated to be 136.2×10^6 L and 93.1×10^6 L, respectively. Therefore, an estimated total of 229.3×10^6 L of WCOs was generated from the automotive sector in 1990. The generated amount was either recycled through re-refining or re-processing; burned as fuel in boilers, space heaters, diesel engines, and cement kilns; applied to roads as a dust suppressant; disposed of by landfilling; indiscriminately dumped on land (e.g., off-road industry fleet shops, backyards, alleys, small pits, fields, and drainage ways); dumped into sewers; and accidentally spilled (Victor and Burrell *et al.*, 1988; CCME, 1989a; CPPI, 1990; CH2M HILL ENGINEERING LTD., 1992).

CH2M HILL ENGINEERING LTD. (1992) could not estimate the quantity of crankcase oils used in railway locomotives. However, they reported that most of the WCOs generated (quantity not specified) are reprocessed on-site for reuse in locomotives or are used directly by the railways as fuel for boilers and incinerators.

CH2M HILL ENGINEERING LTD. (1992) estimated that 2.2×10^6 L of crankcase oils are used in marine vessels. A re-refinery in British Columbia collects approximately 80 000 L/yr of WCOs from fishing vessels and marine shops, while another re-refinery in Nova Scotia collects most of the WCOs from fishing vessels in the Maritimes (quantity not specified). Waste crankcase oils can be used as fuel in some marine vessels and as heating fuel for shops and fish plants (Environment Canada, 1993a). Owners of small marine boats that do not have a storage facility available to them may dispose of their WCOs on land or in landfills (Weinstein, 1974). Waste crankcase oils from tanker diesel engines are stored and collected at the oil terminals together with other waste oils such as cargo oil spills, bilge and ballast waters, and tanker washings (Weinstein, 1974). A large contract hauler collects waste oil from shipping companies in the Great Lakes (CH2M HILL ENGINEERING LTD., 1992).

In 1990, it was estimated that 0.2×10^6 L of crankcase oils were used in piston-driven aircraft in Canada. Re-refineries in British Columbia and Ontario have

reportedly collected WCOs from airports (quantities not specified) (CH2M HILL ENGINEERING LTD., 1992).

Off-road industries, such as mining and forestry companies, also generate WCOs. For most companies, their management program for WCOs depends on the location of the site, the volume of WCOs produced, the equipment on site, and the agreement between the supplier of the crankcase oils and the off-road company (CH2M HILL ENGINEERING LTD., 1992). Re-refineries in Canada have reported collecting large volumes (quantities not specified) of WCOs from mines and logging sites (CH2M HILL ENGINEERING LTD., 1992). A British Columbia re-refinery reported that an average-sized mine site generates 250 000 L/yr of WCOs (Mohawk Lubricants, 1991, as cited in CH2M HILL ENGINEERING LTD., 1992)).

Little information is available on the generation of WCOs from the agricultural sector. From a survey conducted in Alberta in 1979, it was reported that on average, 182 L/yr of WCOs are generated per farm (Mackenzie, 1984).

2.2 Entry into the Environment

As outlined in the following text, there are seven major entry scenarios by which WCOs and their constituents may enter the Canadian environment. The volume of WCOs generated for each entry scenario is shown in Figure 1.

Re-refining. Re-refining of WCOs involves removing the contaminants (*e.g.*, metals, PAHs) to levels suitable for re-use as re-refined lubricating base oil. The performance of re-refined crankcase oils is considered equivalent to virgin crankcase oils (Goetzinger *et al.*, 1975; Armstrong, 1983; CPPI, 1990; CH2M HILL ENGINEERING LTD., 1992). Re-refining WCOs generates air emissions, liquid effluents, and solid wastes (Mueller Associates Inc., 1987; 1989). The types of emissions, effluents, and wastes generated vary depending on the re-refining technology used, the environmental control methods adhered to, and techniques used to mitigate the releases (Mueller Associates, 1987; 1989).

The principal sources of air emissions are vents from process and wastewater treatment units, and storage tanks. These vents may be discharged to a furnace where the vented combustible materials are burned (U.S. EPA, 1974).

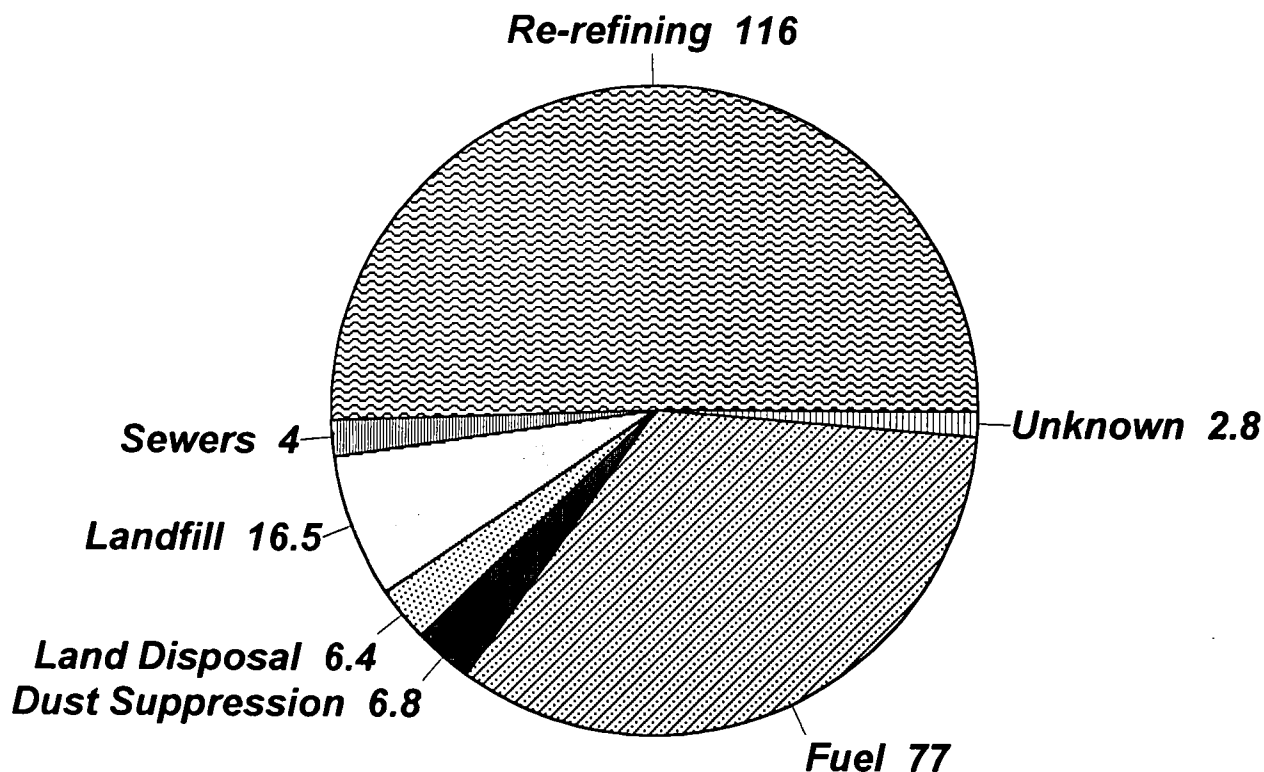
Liquid effluents originate from several sources:

- water separated from WCOs;
- cooling water from heat exchangers;
- contaminated cooling water;
- water from condensed steam that contacts the oil;
- plant runoff water; and

- water from vent gas scrubbers (U.S. EPA, 1974).

Before it is discharged, the wastewater may be treated on-site or at a local sewage treatment plant. After on-site treatment, the treated water could be used for cooling water, or be discharged to a sewer system or to the environment (Mueller Associates Inc., 1987; 1989).

The types of solid wastes generated in re-refining are settled sludge, distillation bottoms, acid and solvent sludges, spent clay, and other wastes. Some of the most common constituents of these solid wastes are metals, chlorinated solvents, PAHs, and other organics. Most of these wastes are disposed of in landfills or lagoons, or used as asphalt-extenders and surfacing material (Weinstein *et al.*, 1982; Mueller Associates Inc., 1987; 1989). Sludge and spent clay may also be reused as fuel, or treated for acid recycling or lead recovery (Weinstein *et al.*, 1982).



The quantities of waste crankcase oils (millions of litres) recycled in re-refineries, used for fuel and as a dust suppressant, and disposed of to land, landfills, and sewers in 1990 in Canada. In addition, Environment Canada (1993b) reported 35 spill events of waste crankcase oils from 1981 to 1992 which ranged from <1 L to 2273 L.

Figure 1 Estimated Quantities of Waste Crankcase Oils Generated in 1990 for Each Entry Scenario

There are nine re-refineries operating in Canada (CH2M HILL ENGINEERING LTD., 1992; Safety-Kleen Canada Inc., 1993; CPPI, 1993b; Manitoba Environment, 1993). In 1990, approximately 116×10^6 L or 50% of the estimated recoverable WCOs from the automotive sector were re-refined (Figure 1) (CH2M HILL ENGINEERING LTD., 1992). The products of re-refining include: re-refined lubricating oil base stock (74% of total), and a distilled light-end fuel oil fraction (7% of total), some of which is used on-site for heating. The by-products that have marginal value (11% of total) include distillation bottoms (used as an asphalt-extender or in fuel oil blending) and demetallized filter cake (used as road base material). The remainder (8% of total) consists of residues and wastes, such as acid sludge, spent clay, centrifuge sludge, and process waste directed to treatment and/or disposal (Franklin Associates Ltd., 1985; CCME, 1989a).

Fuel. Waste crankcase oils are burned as a mixture with other fuel oils or by themselves in a variety of combustion units including boilers, space heaters, engines, furnaces, incinerators, and cement kilns (Yates, 1981; Mueller Associates Inc., 1987; 1989; CH2M HILL ENGINEERING LTD., 1992; U.S. EPA, 1992). During burning, noncombustible compounds such as metals are released to the environment as atmospheric emissions, and PAHs are formed as combustion products (Skinner, 1974; Mueller Associates Inc., 1987; 1989). The products of combustion of WCOs may also be released during soot-blowing (generally limited to large boilers), or during furnace and boiler cleaning (Mueller Associates Inc., 1987; 1989).

It is estimated that a total of 77×10^6 L of WCOs from the automotive sector was burned as a fuel in Canada in 1990 (Figure 1) (CH2M HILL ENGINEERING LTD., 1992). Waste crankcase oils were burned in boilers (70.5×10^6 L), space heaters (4.8×10^6 L), and diesel engines (1.7×10^6 L) (CH2M HILL ENGINEERING LTD., 1992). Canadian data are not available on burning of WCOs in furnaces, cement kilns, and incinerators. The number of combustion units in Canada fired with WCOs is unknown.

The combustion of WCOs also produces oxides of nitrogen (NO_x) and sulphur (SO_x) compounds that contribute to acid rain (Vazquez-Duhalt, 1989). In Canada in 1990, total emissions from combustion of WCOs for NO_x and SO_x were estimated to be 174.5 and 569.3 tonnes/yr, respectively (Environment Canada, 1993c). By comparison, emissions were 695 000 tonnes/yr of SO_x from a major Canadian industrial plant and 1 180 000 tonnes/yr of NO_x from the transportation sector (Environment Canada, 1993c).

Dust Suppressant. Waste crankcase oils are used as dust-suppressants on roads in Canada and the United States (CCME, 1989b; Mueller Associates Inc., 1987; 1989; CH2M HILL ENGINEERING LTD., 1992). Typically, the oils used are WCOs from service stations, fleet shops, and off-road industry fleet shops (such as mining and forestry) (Franklin Associates Ltd., 1985; I.D. Systems Ltd., 1989; CCME, 1989b). These WCOs may be mixed with industrial oils that contain substances such as polychlorinated biphenyls (PCBs) and tetrachlorodibenzo-dioxins (TCDD) and -furans (TCDF) (Franklin Associates Ltd., 1985; CCME, 1989b; Vazquez-Duhalt, 1989). Due to

the possible presence of these and other contaminants, the provinces of British Columbia (*Waste Management Act*, Special Waste Regulation 1988, Amended 1992), Saskatchewan (*Environmental Management and Protection Act*, 1989), Ontario [*Environmental Protection Act*, Regulation 347 amended 1992 (formerly Regulation 309, January 1, 1989)], Quebec (*Environment Quality Act*, Hazardous Waste Regulation, 1985), Nova Scotia (*Dangerous Goods and Hazardous Waste Management Act*, Waste Oil Regulations, revision 1990), Prince Edward Island (*Environmental Protection Act*, Used Oil Handling Regulation, 1992), and Newfoundland [*The Waste Material (Disposal) Act*, Waste Oil Recycling Regulations, draft] have banned the use of WCOs for dust suppression (CH2M HILL ENGINEERING LTD., 1992; British Columbia Ministry of the Environment, Lands, and Parks, 1993; Newfoundland Department of Environment and Lands, 1993; Prince Edward Island Department of the Environment, 1993; Nova Scotia Department of the Environment, 1993; Ontario Ministry of the Environment, 1993; Saskatchewan Department of the Environment and Public Safety, 1993; Quebec Ministry of the Environment, 1993). In 1990, it was estimated that 6.8×10^6 L/yr of WCOs from the automotive sector were used for dust suppression in provinces and territories practicing road oiling (Figure 1) (CH2M HILL ENGINEERING LTD., 1992).

Landfilling. Landfill disposal of WCOs is a common practice of individuals ("do-it-yourselfers") who change the oil in their own vehicles (CPPI, 1990; CH2M HILL ENGINEERING LTD., 1992). Waste crankcase oils are often disposed of with other household wastes that eventually end up in landfills. Although the disposal of liquid wastes in landfills is usually prohibited, the individual quantities of WCOs disposed of in landfills are small and usually go unnoticed (CCME, 1989a; 1989b; CPPI, 1990; CH2M HILL ENGINEERING LTD., 1992). In 1990, it was estimated that 16.5×10^6 L/yr of WCOs from the automotive sector were disposed of in landfills in Canada (Figure 1) (CH2M HILL ENGINEERING LTD., 1992).

Land Disposal. Disposal of WCOs directly on land is also practiced by "do-it-yourselfers" (Gottlieb, 1981; CH2M HILL ENGINEERING LTD., 1992). In urban areas, backyards and alleys are used while in rural areas, small pits, fields, and ditches are often used (CCME, 1989b). Off-road industry fleet shops also dispose of WCOs in designated areas of land on their own property (CH2M HILL ENGINEERING LTD., 1993). In 1990, it was reported that "do-it-yourselfers" and off-road industry fleet shops disposed of about 0.2×10^6 L and 6.2×10^6 L, respectively, of WCOs directly on land in Canada (Figure 1) (CH2M HILL ENGINEERING LTD., 1992).

Sewers. A significant portion of automotive WCOs disposed of by "do-it-yourselfers" ends up in sewer systems (Tanacredi, 1977; Gottlieb, 1981; CH2M HILL ENGINEERING LTD., 1992). Waste crankcase oils disposed of in a sanitary or combined storm and sanitary sewer are most likely to be treated at a wastewater treatment plant. In contrast, WCOs disposed of to a separate stormwater system would likely be transported directly to surface water without treatment (CH2M HILL ENGINEERING LTD., 1992). Cities in Canada have various combinations of storm drainage systems, including combined and separate sanitary and storm sewers, storm

relief sewers, and open storm drains (Marsalek and Ng, 1989). The presence of WCOs and metal salts can upset the operation of a wastewater treatment plant (Mueller Associates Inc., 1987; 1989). Petroleum hydrocarbons have been detected in several wastewater treatment plant effluents and their receiving surface waters (Farrington and Quinn, 1973; Tanacredi, 1977). In 1990, it was estimated that 4.0×10^6 L of WCOs were disposed of in sewers in Canada (Figure 1) (CH2M HILL ENGINEERING LTD., 1992).

Waste crankcase oils or their constituents may also indirectly contribute to loadings to the sewer system as a result of water runoff after application of WCOs as a dust suppressant, disposal of WCOs to land, asphaltting with asphalt containing WCOs, use as fuel, leaching from landfills, and airport runoff (Weinstein, 1974; Hunter *et al.*, 1979; for reviews, see Surprenant *et al.*, 1983; Mueller Associates Inc., 1987; 1989; Vazquez-Duhalt, 1989).

Spills. As with other petroleum products, accidental spills can occur during storage and transportation of WCOs (CH2M HILL ENGINEERING LTD., 1992). Environment Canada (1993b) reported 35 spill events of WCOs from 1981 to 1992. Spill quantities for WCOs ranged from <1 to 2273 L. The total quantity of WCOs spilled during this period could not be estimated because of the number of events for which quantities were unknown (14/35). For the remainder (21/35), the total amount spilled was approximately 8100 L. The spills involving WCOs are small compared to other releases of petroleum products because WCOs are stored and transported in small drums and small tanker trucks. In addition, spills of WCOs occur on roads and may subsequently be recovered (CH2M HILL ENGINEERING LTD., 1992).

2.3 Exposure-related Information

2.3.1 Fate

The fate of WCOs in the environment is governed to a large extent by the entry scenario that led to its release. Due to the complexity of reactions and diversity of substances involved, the fate of WCOs and related groups of substances in WCOs (*e.g.*, metals, PAHs) is discussed in general terms for each entry scenario.

Re-refining. Little is known about the composition and, therefore, the fate of air emissions, liquid effluents, and solid wastes generated by the re-refining of WCOs in Canada or elsewhere (Mueller Associates Inc., 1987; 1989).

Booth *et al.* (1983) suggest that hydrocarbons are likely emitted to air, although no monitoring data were identified in Canada to confirm this prediction. If hydrocarbons are emitted, they would likely be transported through air with particulate and eventually be deposited on land and water (Stephens *et al.*, 1981; Manahan, 1991). In air, hydrocarbons are susceptible to photo-oxidation. Following deposition, the hydrocarbons may undergo biodegradation, photodegradation, adsorption to particulate, solubilization in water, and transport via rainfall runoff (L.S. Love and Associates

Canada Ltd., 1978; 1979; Stephens *et al.*, 1981; Surprenant *et al.*, 1983; Payne and Phillips, 1985; Manahan, 1991; CH2M HILL ENGINEERING LTD., 1992).

As with air emissions, little is known about the composition of liquid effluents from the re-refining of WCOs. Waste crankcase oils and their constituents discharged with liquid effluents initially form a liquid film that can undergo solubilization and sorption to particulate. Constituents adsorbed to particulate can then be carried to the bottom sediments (Hansen, 1975; Surprenant *et al.*, 1983; Payne and Phillips, 1985). Hydrocarbons can also biodegrade, photodegrade, and volatilize (Atlas, 1981; Stephens *et al.*, 1981; Surprenant *et al.*, 1983; Payne and Phillips, 1985; Leahy and Colwell, 1990).

(For more detail, see text on Sewers and on Spills later in this subsection.)

The fate of WCOs in solid waste disposed of on land or in landfills is related to the amount of WCOs that adsorb to solid matter, leaching via runoff percolating through the refuse or soil, biodegradation, and migration to groundwater (CH2M HILL ENGINEERING LTD., 1992). (For more detail, see text on Landfill and Land Disposal later in this subsection.)

Fuel. The quantities of particulate, metals, organics, sulphur dioxide, nitrogen oxides, and acid halides emitted to the atmosphere vary according to the composition of the feed (*i.e.*, WCOs or other waste oils), and the type of combustion unit. Test burns in combustion units, such as commercial boilers, have shown that 20 to 100% of lead and zinc in the original feed oils are emitted to the atmosphere from the stack, primarily in association with particulate (Broeker and Gliwa, 1979; Hall *et al.*, 1983; Surprenant *et al.*, 1983; Mueller Associates Inc., 1987; 1989; Vazquez-Duhalt, 1989). A significant quantity of the metals emitted (56 to 73% for zinc and 76 to 90% for lead) is associated with particles that are submicron in size ($<2 \mu\text{m}$) (Chansky *et al.*, 1974; Fennelly *et al.*, 1984). Metals and organic compounds emitted to the atmosphere are transported by wind currents and eventually deposited on land and water via wet or dry deposition (Stephens *et al.*, 1981; Manahan, 1991).

In contrast to metals, most organic compounds (99.4 to 99.99%) in WCOs are destroyed during combustion in commercial boiler systems (Fennelly *et al.*, 1984). Under certain conditions, however, detectable levels of polychlorinated dibenzofuran and polychlorinated dibenzodioxin compounds can be formed during the combustion of WCOs (Fennelly *et al.*, 1984). Photodegradation half-lives for several PAHs that could potentially be emitted from stacks, including fluorene, naphthalene, acenaphthene, anthracene, benzo(a)pyrene, phenanthrene, and pyrene, range from 0.37 hours to 550 days based on single substance experiments conducted under laboratory conditions (Environment Canada, 1993d). Mixtures of PAHs and particulate-bound PAHs are more resistant to photodegradation, particularly in the presence of other organic compounds (Gubergrits *et al.*, 1972; Pitts, 1979; van Cauwenberghe *et al.*, 1979; Korfmacher *et al.*, 1980a; 1980b). Limited data are available concerning the fate of non-metallic inorganic substances such as sulphur, nitrogen, phosphorus, and halogens that are emitted to the atmosphere following combustion of WCOs.

Indiscriminate disposal of unburned residues (ashes) contaminated with metals and PAHs from the combustion of WCOs could lead to significant environmental releases of these compounds (Williams, 1977; Hall *et al.*, 1983; Surprenant *et al.*, 1983). However, no information was identified regarding the disposal and eventual fate of contaminated ashes.

Dust Suppressant. Constituents of waste crankcase oils applied to road surfaces enter the surrounding environment by volatilization to air; transport of windborne dust to air and subsequent transfer to land and water; and runoff to adjacent soil or drainage ditches and eventually to local water streams (L.S. Love and Associates Canada Ltd., 1978; 1979; Stephens *et al.*, 1981; Surprenant *et al.*, 1983).

The compounds associated with windborne dust (*e.g.*, metals and hydrocarbons) may be solubilized in water or surficial runoff following deposition to land and water (Stephens *et al.*, 1981). Photodegradation and biodegradation occur during or following transport of WCOs and their constituents to local water streams. (For more details, see text on Spills later in this subsection.)

Freestone (1972) and Surprenant *et al.* (1983) observed that 10 to 12% of the oil applied to road surfaces was lost by volatilization in the initial 15- to 30-day period following application. Low molecular weight PAHs and volatile compounds, such as the mono-aromatics and various halogenated alkyl substances, comprise the largest fraction of WCOs lost by volatilization (Stephens *et al.*, 1981; Metzler and Jarvis, 1985).

The amount of WCOs lost by runoff is variable and estimates range from 3 to 5% (Surprenant *et al.* 1983) to $\geq 20\%$ (Freestone, 1972; L.S. Love and Associates Canada Ltd., 1978; 1979). In general, high runoff rates are expected when roads are made of non-porous materials such as clay (Bell, 1976; Rudolph, 1980), when the roads are in poor condition (Stephens *et al.*, 1981), and following periods of heavy rainfall (Freestone, 1972; L.S. Love and Associates Canada Ltd., 1978; 1979). The compounds detected in runoff of WCOs include metals such as zinc, aluminum, sodium, and calcium, and organic compounds such as phenol and chlorophenol (Surprenant *et al.*, 1983). Compounds in runoff of WCOs may be in the water-soluble fraction, or may be adsorbed to particles in the runoff (Metzler and Jarvis, 1985).

The portion of WCOs retained in the road surface layer may be removed by adhesion to vehicles, and by chemical and biological degradation (Freestone, 1972; Raymond *et al.*, 1976; Rudolph, 1980; Surprenant *et al.*, 1983; Mueller Associates Inc., 1987; 1989).

Landfill and Land Disposal. In general, the fate of WCOs disposed of on land (*e.g.*, in backyards, alleys, pits, fields, and drainageways) or to landfills is related to the amount of WCOs that adsorbs to solid matter, leaching via runoff percolating through the refuse or soil, and biodegradation (CH2M HILL ENGINEERING LTD., 1992). When large quantities of WCOs are disposed of on land or in landfills, a separate liquid phase would be generated (Villaume, 1985). In such situations, the fate of WCOs would be

similar to that of WCOs accidentally spilled on land. (For more detail, see text on Spills later in this subsection.)

Waste crankcase oils disposed of with large amounts of organic matter are expected to remain with the refuse in the landfill due to adsorption of the constituents to cellulose, hemicellulose, and other organic matter (CH2M HILL ENGINEERING LTD., 1992). A similar situation is expected for WCOs disposed of on land with a high soil organic content (Raymond *et al.*, 1976). In contrast, at sites with little adsorbent material and permeable soils, there is a greater potential for constituents of WCOs to migrate to groundwater, particularly those constituents and degradation products that are water-soluble (Raymond *et al.*, 1976).

Field studies have shown that 55 to 82% of hydrocarbons in WCOs from cars and 23 to 53% of hydrocarbons in WCOs from diesel trucks are biodegraded in soils of varying composition over a period of one year following a single application (Raymond *et al.*, 1976). After approximately 300 days, up to 60% of waste crankcase oils applied to Canadian soils were biodegraded (*i.e.*, by weight) (Parker *et al.*, 1983). Similarly, aged oily sludges applied to field plots had half-lives ranging from 270 to 410 days (Loehr *et al.*, 1992). In general, the half-life of alkanes (C₁₂-C₂₆), naphthalenes, and other aromatics was less than 30 days. However, 20 to 25% of the applied sludge (typically high molecular weight substances) was slow to degrade and tended to accumulate in the soil (Loehr *et al.*, 1992). Biodegradation rates would likely increase in soils that had received previous applications of WCOs because of acclimatization by micro-organisms (Neal *et al.*, 1977; Elsavage and Sexstone, 1989). In general, the relative order of biodegradability is n-alkanes > branched alkanes > low-molecular-weight-aromatics > cycloalkanes (Atlas, 1981; CDM, 1986; Leahy and Colwell, 1990).

Sewers. Waste crankcase oils disposed of to sewer water initially form a surface film (Hansen, 1975). Laboratory studies suggest that volatile organics, semivolatile organics, and metals partition from the oil phase to the aqueous phase in sewers (Surprenant *et al.*, 1983). In the aqueous phase, metals such as zinc, copper, and cadmium are in dissolved form, while most hydrocarbons are associated with particulate matter (Hunter *et al.*, 1979).

Metals and organics can be removed from wastewater treatment plants. Their removal efficiency, however, is dependent upon the type of compound and the specific treatment process (Monteith, 1987).

Spills. Weathering processes cause a number of physical and chemical changes to the initial surface film of WCOs formed after a spill to water (Hansen, 1975; Payne and Phillips, 1985). Organic compounds with high vapour pressures (*e.g.*, toluene, benzene) are volatilized to the atmosphere, while semi-volatile compounds (*e.g.*, benzo(a)pyrene, naphthalene) and metals partition to the water or sediment phases (Surprenant *et al.*, 1983). Other weathering processes include sinking, emulsification, agglomeration, photodegradation, and biodegradation (Payne and Phillips, 1985). In laboratory experiments, aromatic acids, methyl esters, polyphenols, and peroxides have been detected as photo- and biodegradation products of WCOs and other related petroleum

products (Hansen, 1975; Larson *et al.*, 1979; Payne and Phillips, 1985; Vazquez-Duhalt and Greppin, 1986; Literathy *et al.*, 1989). These compounds have an enhanced water solubility and consequently move from the surface film to the water column (Literathy *et al.*, 1989), where they act as co-solvents or surfactants that stabilize subsurface oil-in-water emulsions (Hansen, 1975; Bobra, 1992). Biodegradation also leads to the release of metals from WCOs which are then transferred to the water phase (Vazquez-Duhalt and Greppin, 1986). The rate of biodegradation of petroleum hydrocarbons varies depending on the hydrocarbon under consideration and prevailing environmental conditions. Half-lives of approximately 6 to 7 days were observed for *n*-alkanes with 24 or less carbon atoms, 11 to 12 days for *n*-alkanes with 25 to 29 carbon atoms, and greater than 12 days for *n*-alkanes with more than 30 carbon atoms (Literathy *et al.*, 1989).

Waste crankcase oils spilled on soil migrate downward by gravity through soil and possibly to groundwater, and spread laterally due to capillary forces and soil heterogeneity (Villaume, 1985; CDM, 1986). The more water-soluble, lower molecular weight fractions tend to migrate faster than the less soluble, higher molecular weight fractions (CH2M HILL ENGINEERING LTD., 1992). The concentrations of constituents of WCOs decline in soil and groundwater with distance from the spill source because of adsorption by soil, biodegradation, and dilution (Barker *et al.*, 1986; 1988a; Barker, 1987).

2.3.2 Concentrations

Re-refining. Little is known about the composition of air emissions from re-refineries in Canada or elsewhere. Model-estimated emissions from a re-refinery in Buffalo, New York indicated that hydrocarbon concentrations would vary from 4.87 to 10.56 $\mu\text{g}/\text{m}^3$ depending on atmospheric conditions at a distance of 150 m downwind from the source (Booth *et al.*, 1983). At a distance of slightly more than 5 km downwind, hydrocarbon concentrations were estimated to vary from 0.016 to 0.185 $\mu\text{g}/\text{m}^3$.

The composition of wastewater effluents from re-refineries depends on the type of re-refining process, the type of waste oil (*e.g.*, waste crankcase oils versus other types of waste oils), and the type of wastewater treatment process. The effluents can be expected to contain trace metals, dissolved phenols, chlorinated solvents, PAHs, and other organics, as well as suspended or emulsified oil (U.S. EPA, 1974; Franklin Associates Ltd., 1985; Surprenant *et al.*, 1983). A monitoring study of wastewater effluents from a waste oil re-refinery in the United States (location not specified) found that the mean concentration of metals varied from 0.34 mg/L for cadmium to 271 mg/L for lead (Franklin Associates Ltd., 1985). Other metals detected in wastewater were arsenic (3.4 mg/L), chromium (10 mg/L), barium (80 mg/L), and zinc (250 mg/L). For organic compounds, mean concentrations varied from below the detection limit (DL = 0.02 mg/L) for benzo(*a*)anthracene and benzo(*a*)pyrene to 1306 mg/L for toluene. Other organics detected in wastewater were naphthalene (283 mg/L), benzene

(364 mg/L), and several chlorinated solvents (309 to 666 mg/L). Monitoring data for effluents from other re-refineries or their receiving waters are not available.

The concentrations of metals and organic compounds in solid wastes from re-refineries vary according to the type of sludge or spent clay, and the treatment process. For example, the mean concentration of zinc in solid waste from a refinery in the United States (location not specified) was 230 $\mu\text{g/g}$ in spent clay, 568 $\mu\text{g/g}$ in settled sludge, 1361 $\mu\text{g/g}$ in distillation bottoms, and 2100 $\mu\text{g/g}$ in acid sludge (wet or dry weight not specified) (Franklin Associates Ltd., 1985; Weinstein *et al.*, 1982). No information was available on the concentrations of metals and organic compounds in areas where re-refinery solid wastes are disposed.

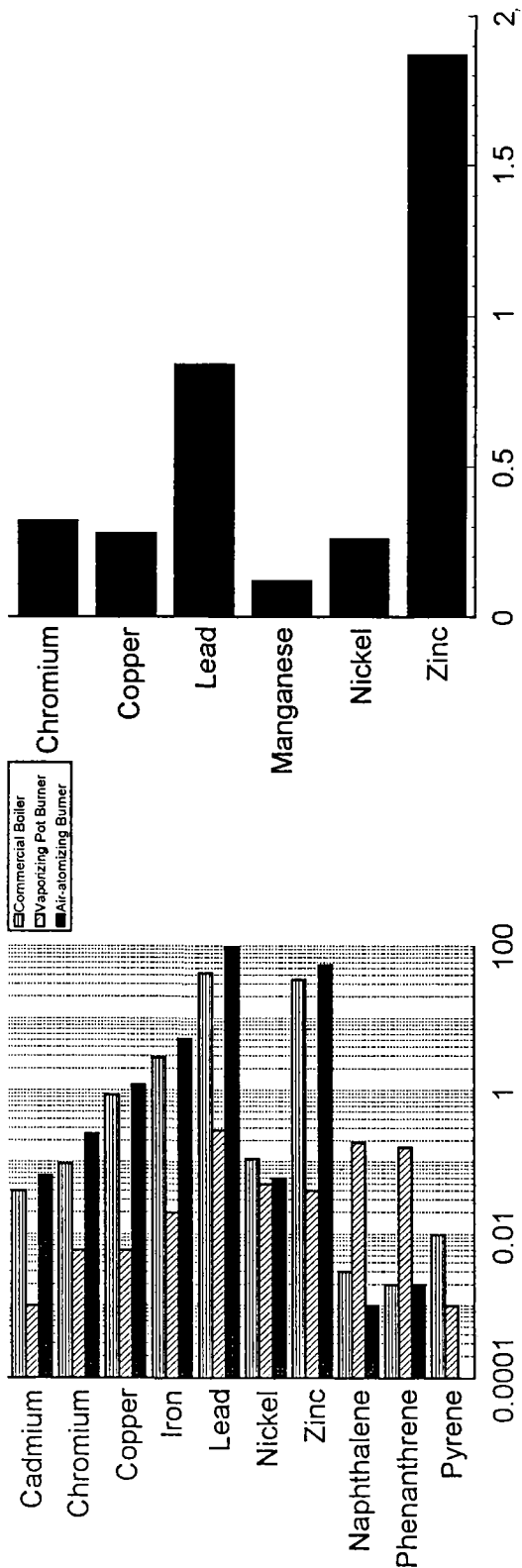
Fuel. Many factors influence the levels of metals and organic compounds in emissions from combustion units in which WCOs or other waste oils are used as fuel. These factors include composition of the waste oil, design and operation of the combustion unit, and size of the combustion unit (as indicated by heat input, *i.e.*, Gigajoules/hour (GJ/h)) (Surprenant *et al.*, 1983; CH2M HILL ENGINEERING LTD., 1992).

Two common designs of waste oil heaters use the vaporizing pot and the air-atomizing burners (Hall *et al.*, 1983). Monitoring of stack emissions in the United States has shown that the vaporizing pot burner (0.13 GJ/h to 0.26 GJ/h) retains the metals in the pot residue, while the air-atomizing burner (0.26 GJ/h) emits most of the metals in the stack flue gas (Hall *et al.*, 1983; Surprenant *et al.*, 1983). Conversely, levels of organic compounds are higher in stack emissions from vaporizing pot burners than from air-atomizing burners. Monitoring studies have also shown that commercial boilers (>26 GJ/h) emit lower levels of constituents of WCOs than smaller boilers and particularly, small heaters (approximately 0.26 GJ/h), because operators of the larger boilers usually pretreat WCOs and have better operating conditions for minimizing emissions (Surprenant *et al.*, 1983; Fennelly *et al.*, 1984).

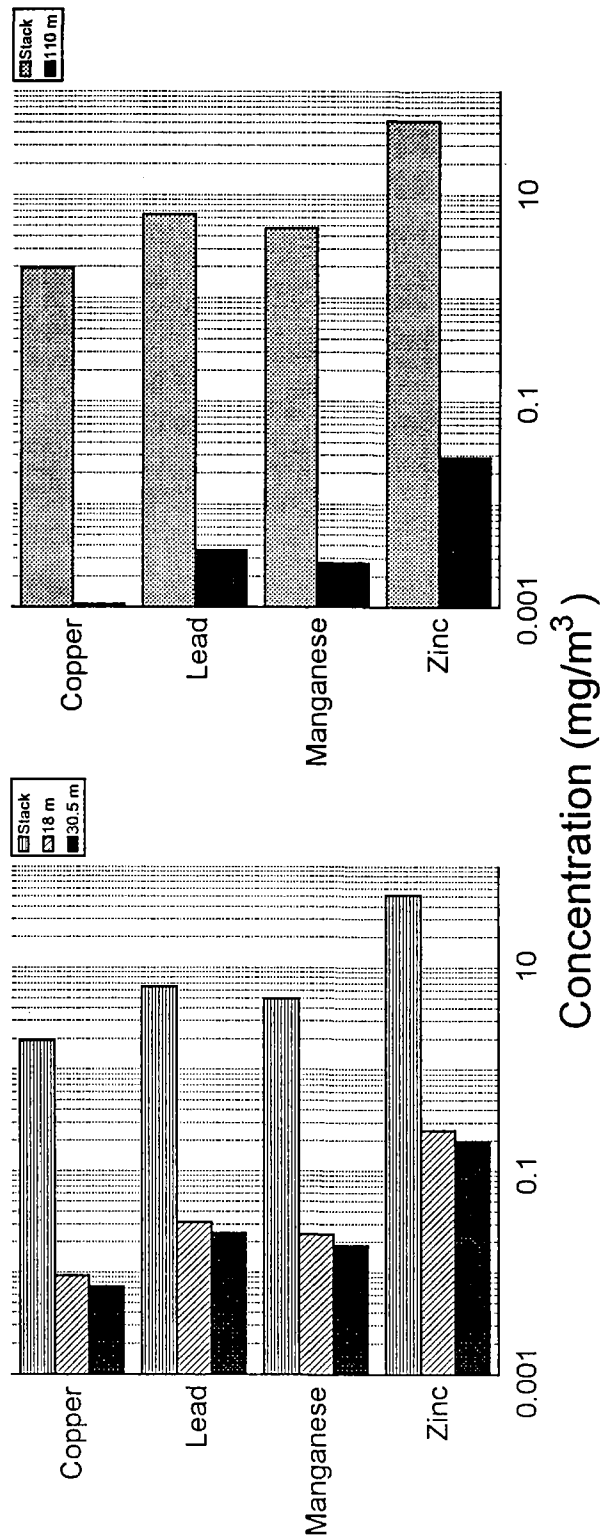
The results of a monitoring study of emissions from a commercial boiler (21 GJ/h) and two space heaters using a vaporizing pot burner (0.26 GJ/h) and an air-atomizing burner (0.26 GJ/h) located in the United States are shown in Figure 2a (Surprenant *et al.*, 1983). In this study, the mean measured concentration of zinc in the stack was 0.04 mg/m^3 for the vaporizing burner, 55.7 mg/m^3 for the air-atomizing burner, and 34.8 mg/m^3 for the commercial boiler (Figure 2a). A similar trend was observed for the other metals sampled. The results of a monitoring study of stack emissions from six burners (0.07 to 0.17 GJ/h) located in the Northwest Territories are presented in Figure 2b (British Columbia Research Corporation, 1990).

No monitoring data in Canada or elsewhere are available for areas downwind of stacks in which WCOs were used as fuel. A United States Environmental Protection Agency (U.S. EPA) SCREEN model (Phase 1) was used to estimate 24-h mean ambient air concentrations of metals emitted from a commercial boiler (CH2M HILL ENGINEERING LTD., 1992). The model assumed a worst-case scenario (*i.e.*, 100% of

A. Air Concentrations in Stack Emissions - U.S.A. B. Air Concentrations in Stack Emissions - Canada



C. Downwind Air Concentrations - 6.1 m Stack D. Downwind Air Concentrations - 11.4 m Stack



- (a) *Measured mean concentrations of metals and organic chemicals in flue gases of stacks from a commercial boiler (21 GJ/h), a vaporizing pot burner (0.26 GJ/h), and an air-atomizing burner (0.26 GJ/h) located in the United States that use waste crankcase oils as feed (Surprenant et al., 1983).*
- (b) *Measured mean concentrations of metals in flue gases from six burners (0.07 to 0.17 GJ/h) located in the Northwest Territories that use waste oils as feed (British Columbia Research Corporation, 1990).*
- (c) *Estimated air concentrations of metals in the stack of a commercial boiler (4 GJ/h), and 18 m and 30.5 m downwind of a 6.1 m high stack (CH2M HILL ENGINEERING LTD., 1992).*
- (d) *Estimated air concentrations of metals in the stack of a commercial burner (4 GJ/h) and 110 m from a 11.4 m high stack (CH2M HILL ENGINEERING LTD., 1992).*

Figure 2 Air Contaminant Concentrations in Stack Emissions and Downwind Concentrations from Combustion Units Using Waste Crankcase Oils as Fuel

metals in WCOs are emitted in flue gas, no air pollution control equipment installed). The results for stacks of two heights (6.1 m and 11.4 m) are shown in Figures 2c and 2d. The estimated concentrations of metals in air ranged from 0.001 mg/m³ for copper 110 m from the tall stack, to 0.251 mg/m³ for zinc 18 m from the short stack (CH2M HILL ENGINEERING LTD., 1992).

In addition to metals and organic compounds, the combustion of WCOs produces large quantities of gases such as carbon monoxide, sulphur dioxide, nitrous oxides, and hydrogen chloride (Hall *et al.*, 1983; Vazquez-Duhalt, 1989). Monitoring of stack emissions from the six burners in the Northwest Territories (0.07 to 0.17 GJ/h) indicated that the mean concentrations for these gases were 521 mg/m³ for sulphur dioxide, 117 mg/m³ for nitrous oxides, and 12.5 mg/m³ for hydrogen chloride (British Columbia Research Corporation, 1990). Considerably higher concentrations have been observed in stack emissions from larger burners (0.13 to 0.26 GJ/h) in the United States. For example, the mean concentration of sulphur dioxide in stack flue gas from an air-atomizing burner using WCOs from trucks was 3.3×10^5 mg/m³ (Hall *et al.*, 1983).

Metals and PAHs have been detected in the ashes from burners, particularly in the ashes from vaporizing pot burners. Monitoring of ashes from the six burners in the Northwest Territories (0.07 to 0.17 GJ/h) indicated mean metal levels of 4.3% for magnesium, 3.8% for zinc, 0.73% for lead, 0.31% for manganese, and 0.24% for copper (British Columbia Research Corporation, 1990). Polycyclic aromatic hydrocarbons were detected in ash samples in trace amounts (<0.4 µg/g dry weight). No monitoring data for constituents of WCOs in the environment as a result of disposal of ashes are available for Canada or elsewhere.

Dust Suppressant. A laboratory simulation study of constituents of WCOs in runoff from a prepared roadbed treated with WCOs demonstrated that the levels of metals (corrected for runoff from an untreated surface) (see Figure 3a) ranged from below the detection limit for arsenic (DL = 0.03 mg/L), lead (DL = 0.02 mg/L), and nickel (DL = 0.005 mg/L) to 1.0 mg/L for aluminum (Surprenant *et al.*, 1983). The same study estimated that the corrected concentrations of organic compounds would range from below the detection limit (DL = 0.01 mg/L) for several PAHs to 0.6 mg/L for phenol (Figure 3a).

An Ontario field study of a road treated with waste oil demonstrated that the water-soluble fraction (WSF) (in this study, the WSF was measured for water-soluble hydrocarbon content) concentration in a nearby stream increased from 23 mg WSF/L of water before application, to 60 mg WSF/L of water one week after application (L.S. Love and Associates Canada Ltd., 1978). Three months after the waste oil application, a concentration of 350 mg WSF/L was found in runoff water from the road. In a follow-up study, L.S. Love and Associates Canada Ltd. (1979) observed that the WSF concentration in a nearby stream increased from 24 mg WSF/L before application to 50 mg WSF/L in upstream samples, and from 17 mg WSF/L before application to 63 mg WSF/L in downstream samples one month after application. The lead concentration in runoff water from the road was 0.06 mg/L about two months after application of WCOs.

Similarly, a lead concentration of 0.1 mg/L was detected in a stream located approximately 500 m from the road, four months after application (L.S. Love and Associates Canada Ltd., 1979). Four months after application, the hexane-extractable material (*i.e.*, constituents of WCOs soluble in hexane) concentration in soil where runoff entered the field was higher (0.34 mg/g dry weight) than the concentration observed in a control site (0.15 mg/g dry weight) (L.S. Love and Associates Canada Ltd., 1979).

A modelling study predicted that the concentrations of constituents of WCOs in runoff and nearby streams increase with increasing amounts of runoff (Figure 3b) (Metzler and Jarvis, 1985). With low runoff, soluble constituents of WCOs are present in runoff, while with higher runoff, both soluble and adsorbed compounds are present in the runoff. The estimated concentrations of constituents of WCOs under conditions of 5% and 25% oil runoff (5% and 25% of applied waste oil is washed off the road) in a stream adjacent to lightly and heavily oiled roads are shown in Figure 3b.

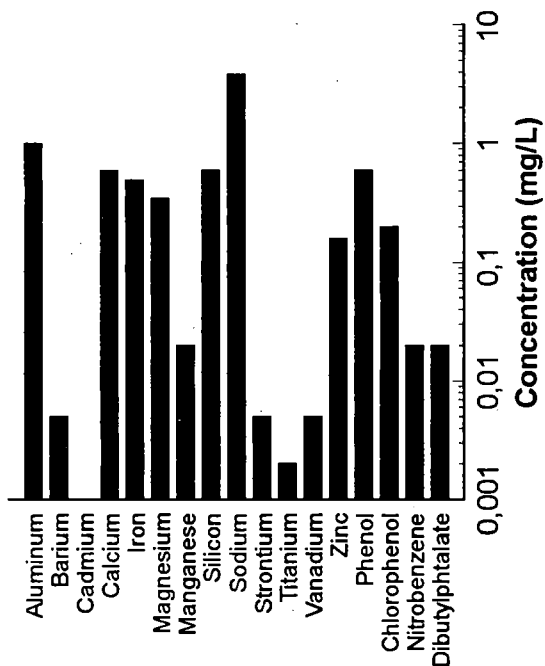
The worst-case conditions for entry of constituents of WCOs to air is hot and dry weather immediately following an application of WCOs to a road. Metzler and Jarvis (1985) used these conditions to model the eight-hour airborne concentrations of selected volatile compounds above an oiled road (Figure 3c). The results indicated that the 90th percentile** airborne concentrations varied from 0.127 mg/m³ for xylene to 0.602 mg/m³ for toluene. Under these conditions, complete evaporation of the volatile compounds shown in Figure 3c was expected within eight hours following application of the WCOs to the road.

Metzler and Jarvis (1985) also used worst-case conditions (minimal runoff due to no rainfall, minimal evaporation due to low temperatures) to estimate concentrations of constituents of WCOs on airborne dust particles following road oiling. The estimated concentrations of metals and organic compounds on airborne dust are quite low (maximum concentrations were <1 µg/m³ ten metres from the road) for the 30-day period following low and high rates of application of WCOs (Figure 3d). No monitoring data were available to confirm the concentrations estimated by Metzler and Jarvis (1985).

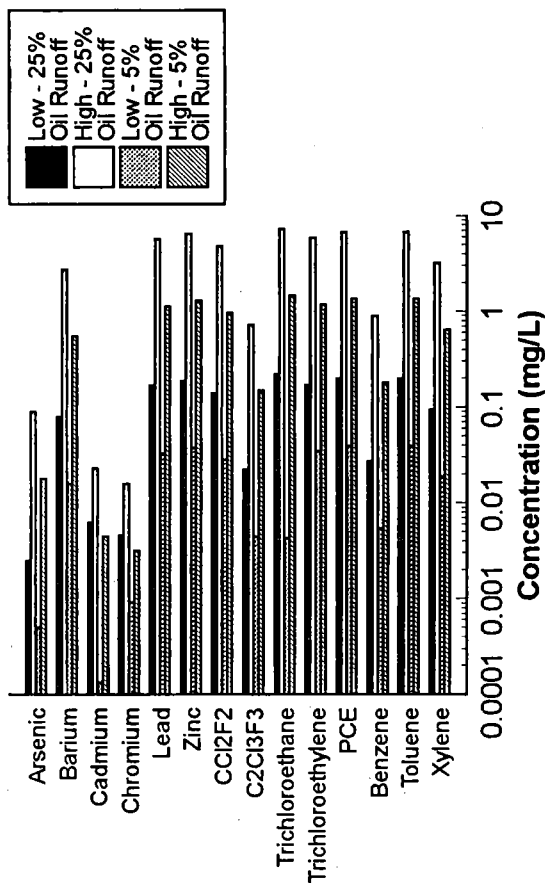
Landfill, Land Disposal, Sewers, and Spills. There is no information available concerning the concentrations of any of the constituents of WCOs in leachates or soil as a result of landfilling or land disposal of waste crankcase oils. Several studies have demonstrated that a variety of compounds, many of which are in WCOs, are in landfill leachates and groundwater (Cherry, 1983; Reinhard *et al.*, 1984; Barker, 1987; Barker *et al.*, 1986; 1988a; 1988b). However, these compounds are not unique to WCOs and therefore their presence may be due to a variety of domestic and industrial wastes. A similar situation exists for constituents of WCOs detected in effluents and receiving waters from storm sewers and wastewater treatment plants (Farrington and Quinn, 1973; Tanacredi, 1977; Wakeham, 1977; Hunter *et al.*, 1979; Hoffman *et al.*, 1985). No data are available in Canada or elsewhere concerning the concentrations of constituents of WCOs in soil or water following a spill of WCOs.

** Ninety percent of the waste oil samples had estimated contaminant concentrations below the given value.

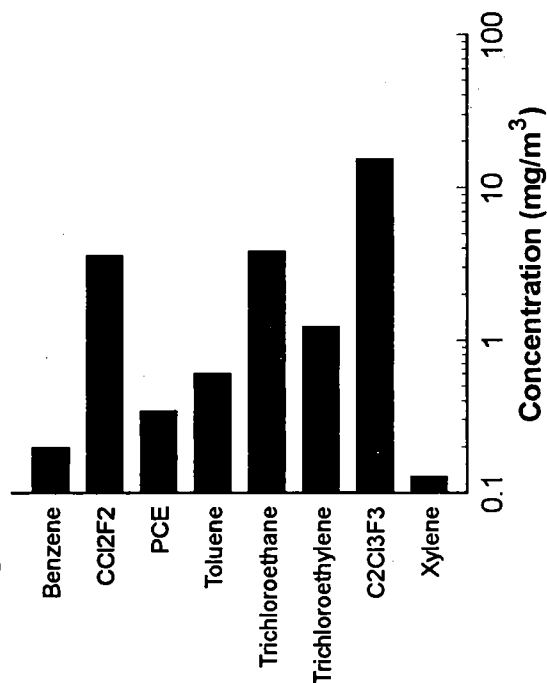
A. Concentrations in Rainfall Runoff



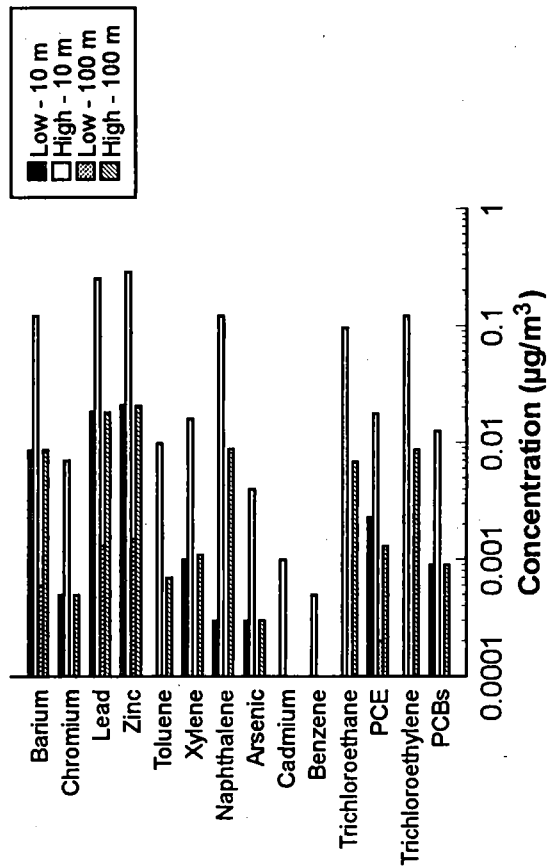
B. Concentrations in a Stream Adjacent to an Oiled Road



C. Eight-Hour Airborne Concentration



D. Ambient Air Concentrations Due to Dust



- (a) *Measured concentrations of metals and organic compounds in rainfall runoff from a road following an application of WCOs (samples were corrected for runoff from unoiled roads) (Surprenant et al., 1983).*
- (b) *Estimated concentrations of constituents of WCOs in a stream adjacent to a heavily oiled road (high) and a lightly oiled road (low) assuming 25% oil runoff (high rainfall) and 5% oil runoff (moderate rainfall)(Metzler and Jarvis, 1985). Abbreviations are CCl₂F₂ = dichlorodifluoromethane, C₂Cl₃F₃ = trichlorotrifluoroethane, PCE = tetrachloroethylene, and PCBs = polychlorinated biphenyls.*
- (c) *Estimated eight-hour airborne concentration (90th percentile) for selected volatile compounds above a road following an application rates of WCOs (Metzler and Jarvis, 1985)*
- (d) *Estimated average 30-day air concentrations of metals and organic compounds due to contaminated dust following low and high application rates of WCOs (Metzler and Jarvis, 1985). The estimates are for samples 10 m and 100 m from a heavily oiled road (high) and a lightly oiled road (low).*

Figure 3 Contaminant Concentrations Released in Runoff and to the Atmosphere from a Road Treated with Waste Crankcase Oils

2.4 Effects-related Information

There are four categories of studies that could be used to determine the effects of waste crankcase oils on the environment:***

- (i) *in-situ* studies of community structure, population survival, or other biological endpoints that compared responses between sites exposed to WCOs and sites not exposed to WCOs (*e.g.*, studies comparing community structure in streams near roads treated with WCOs for dust suppression, and in streams near untreated roads);
- (ii) tests of whole WCOs (*e.g.*, to estimate the effects of spills of WCOs on land or water);
- (iii) tests with fractions of WCOs that are relevant to the entry scenarios described earlier (*e.g.*, tests with the water-soluble fraction of WCOs to estimate the effects of runoff from roads treated with WCOs for dust suppression); and
- (iv) tests with single substances found in WCOs.

This subsection will focus on the first three categories, since they can provide the most direct evidence of the effects of WCOs on the Canadian environment. Test results from studies of single substances are not considered relevant to this assessment because the fate and effects of substances in whole WCOs and their relevant fractions are expected to differ considerably from the fate and effects of component substances by themselves.

2.4.1 Dust Suppressant, Landfill, Land Disposal, and Spills

Field Data. No studies were available on the *in-situ* effects to biota of WCOs released to the environment by the four entry scenarios. A field study of road runoff containing several PAHs and metals, most of which are found in WCOs, was reported by Boxall *et al.*, (1993); Forrow *et al.*, (1993); and Maltby *et al.*, (1993). These contaminants may be present on road surfaces because of oil leaks from crankcases, exhaust emissions, deposition from air, or other possible sources. Because of the numerous sources of these contaminants, it is not possible from this study to estimate toxicity effects produced by WCOs alone.

Between 1990 and 1991, sediment samples taken from water immediately downstream from a motorway in England revealed significantly elevated levels of inorganics (*e.g.*, lead, zinc, chromium, copper, nickel, aluminum, calcium, and

*** It is expected that lead concentrations in WCOs have been reduced since December 1, 1990, due to the Gasoline Regulations that came into effect on that date (Environment Canada, 1990). Therefore, effects levels from studies conducted with WCOs from engines running on leaded gasoline may overestimate the current toxicity of WCOs.

magnesium), total aromatic hydrocarbons, and PAHs (e.g., naphthalene, pyrene, fluoranthene, fluorene, benzantracene) (Boxall *et al.*, 1993; Forrow *et al.*, 1993; and Maltby *et al.*, 1993), all of which have been detected in waste crankcase oils (Bethea *et al.*, 1973; Whisman *et al.*, 1974a; 1974b; Raymond *et al.*, 1976; Grimmer *et al.*, 1981; Vazquez-Duhalt and Greppin, 1986; Van Donkelaar, 1990; CH2M HILL ENGINEERING LTD., 1992).

The number of macroinvertebrate taxa was significantly reduced downstream. The change in community structure resulted in a shift from a mixed trophic community (e.g., gammarid shrimps and snails) at the upstream control station to a community dominated by collectors (e.g., chironomid larvae and tubificid worms) at the downstream station. Also, the consumption of leaf material by the shredder *Gammarus pulex* placed *in-situ* at the downstream station was significantly reduced compared to the upstream station. Toxicity tests performed with sediment samples collected from the upstream and downstream stations demonstrated that downstream sediment was significantly more toxic to the amphipod *Gammarus pulex* than the upstream sediment. The observed toxicity was attributed to the presence of aromatic hydrocarbons in the sediments.

Laboratory: Whole Waste Oil. Bird eggs have been found to be highly sensitive to WCOs applied directly to the eggshell surface (Hoffman *et al.*, 1982; Hoffman and Albers, 1984). During the breeding season, sublethal amounts of WCOs on the breast feathers or feet of adult birds or on nesting materials (from contact with contaminated water and soil) may be readily transferred to the eggs (Albers, 1980). In addition, exposure can occur by other topical application routes such as spraying, immersion, or ambient air deposition (Hoffman, 1990).

Hoffman (1990) applied various concentrations of WCOs to eggshells of mallard ducks (*Anas platyrhynchos*) and bobwhite quail (*Colinus virginianus*). Waste crankcase oils were highly embryotoxic to both species and resulted in dose-dependent mortality, reduced growth, and abnormal survivors by 18 days of fetal development. Eggshell application of 15 μ L of WCOs per egg resulted in 84% mortality in mallard duck embryos, and application of 3 μ L WCO/egg resulted in 88% mortality in bobwhite quail embryos. Abnormal survivors had subcutaneous edema, incomplete ossification, and eye and brain defects. In addition, hemoglobin concentration, and red blood and liver δ -aminolevulinic acid dehydratase (ALAD) activities were significantly reduced in embryos and hatchlings of both species.

The effects on 1-week-old mallard (*A. platyrhynchos*) ducklings and pheasant (*Phasianus colchicus*) chicks fed diets of WCOs were investigated by Eastin, Jr. *et al.* (1983). Red blood cell ALAD activity was significantly inhibited by 50 to 60% after one week of being fed a diet of 0.5% WCOs [weight(w) of oil/weight (w) of food]. Also observed was an increase in plasma aspartate aminotransferase (AST) activity in mallards after three weeks of ingesting a diet of 4.5% WCOs (w oil/w food). Growth, hematocrit, and hemoglobin were not significantly affected by the end of the three-week exposure period.

The environmental effects of application of WCOs (3 L/m², mixed into the top 10 to 15 cm of soil) to nematodes and plants in field plots consisting of three types of soil (*i.e.*, silt loam, sandy loam, and clay loam) were studied by Raymond *et al.* (1976). Approximately nine months after application of WCOs, nematode (species not specified) abundance was reduced (average of 38%) in all plots, while nematode abundance more than doubled in control plots. Approximately nine months after application of WCOs, the plots were seeded with vegetables (*e.g.*, radishes, turnips, beans). Although most seeds germinated in the plots, none survived at the silt and sandy loam plots, while those in the clay loam plots had below normal growth and the leaves and stalk were yellow.

A similar study by Giddens (1976) demonstrated that WCOs applied to soil (1.3 L/m², depth not specified) produced a 46% reduction in corn yield at the end of the season compared to controls. The author noted that a chlorosis effect observed in corn plants resembled that caused by nitrogen deficiency. When the nitrogen content of the soil was improved by adding fertilizer, corn yields increased above those of controls. In greenhouse experiments, WCOs applied (0.9 L/m² and 3.1 L/m²) to the top 10 cm of soil supplemented with nitrogen had no significant effect on the growth of peanuts (*Arachis hypogaeae*), cotton (*Gossypium hirsutum*), soybeans (*Glycine max*), and corn (*Zea mays*) compared to the controls (Giddens, 1976). However, the growth of sorghum (*Sorghum vulgare*) and weeds [primarily pigweed (*Amaranthus retroflexus*)] in peanuts, cotton, and sorghum plots was significantly reduced by both oil application rates (except for sorghum weeds with the lower application rate) compared to the controls. Sorghum decreased in growth by 48% and 76% for the low and high application rates, respectively.

Laboratory: Water-soluble Fraction of Waste Crankcase Oils. The water-soluble fraction (WSF) of WCOs is defined as that fraction (*e.g.*, organics and inorganics) of WCOs that dissolves in water. The toxicity of the water-soluble fraction of WCOs has been investigated in the laboratory (U.S. EPA, 1974; Byrne and Calder, 1977; Bott and Rogenmuser, 1978; Hedtke and Puglisi, 1980; Bate and Crafford, 1985; MacLean and Doe, 1989). The effects of runoff of WCOs from roads following dust suppression treatment, spills of WCOs on land and water, and runoff of WCOs following disposal to land or landfilling can be estimated by comparing the toxicity of the water-soluble fraction of WCOs to the concentrations of the water-soluble fraction of WCOs in the Canadian environment.

For freshwater species, the 96-h LC₅₀s for American flagfish (*Jordanella floridae*) and fathead minnow (*Pimephales promelas*) ranged from 1 to 9.5 mg WSF/L water (flow-through - measured for water-soluble hydrocarbon and metal contents) (U.S. EPA, 1974; Hedtke and Puglisi, 1980), while *Daphnia magna* had a 48-h EC₅₀ (immobilization) of 4.65 mg WSF/L and a 48-h LC₅₀ of 4.87 mg WSF/L of water (static - measured for water-soluble aromatic hydrocarbon content) (MacLean and Doe, 1989). The most sensitive effects observed for freshwater species involved algal communities exposed to WCOs under natural light during summer and autumn in a greenhouse in New Jersey, United States (Bott and Rogenmuser, 1978). Under flow-through conditions, a five-week summer exposure to the WSF of WCOs (0.038 mg WSF/L) resulted in decreases in chlorophyll *a* and chlorophyll *c* concentrations (in this study,

chlorophyll *c* is used as an indicator of diatom biomass) and a slight increase in phycocyanin concentration (indicative of blue-green algal abundance). As a result, a shift in community structure (*e.g.*, reduction in diversity and abundance) was observed after the exposure period. When exposed to the WSF (0.065 mg WSF/L water) of WCOs for five weeks under autumn conditions, similar effects were observed. In this study, the WSF was measured for water-soluble hydrocarbon content.

Invertebrates are the most sensitive marine species to the water-soluble fraction of WCOs. The clam *Mercenaria* sp. had a 48h-LC₅₀ of 0.04 mg WSF/L (measured for water-soluble hydrocarbon content) for the embryo and a 48-h LC₅₀ of 0.1 mg WSF/L water (measured for water-soluble hydrocarbon content) for the larvae under static conditions (Byrne and Calder, 1977). The photosynthetic rates of five phytoplankton species were inhibited following treatment with 1.67 mg WSF/L for one day under static conditions (Bate and Crafford, 1985). In this study, the WSF of WCOs was measured for water-soluble aromatic hydrocarbon content.

In a review of petroleum photochemistry in water, Payne and Phillips (1985) concluded that photo-oxidation causes physical and chemical changes in oil that enhance dissolution of its oxidized products, thus increasing the toxicity of the water-soluble fraction. Photo-induced toxicity of crude and refined oils on yeast, algae, and cod and sea-urchin eggs has been confirmed by many studies (Larson *et al.*, 1979; Karydis, 1982; Sydnese *et al.*, 1985a; 1985b). It is likely that similar results would be obtained for waste crankcase oils.

2.4.2 Re-refining, Fuel, and Sewers

No effects data are available to determine the toxicity of air emissions, effluents, or solid wastes produced by re-refineries of waste crankcase oils. It should be noted that the water-soluble fraction toxicity tests described previously are not applicable to re-refinery effluents because the composition of WCOs and re-refinery effluents differ.

No toxicity data are available for stack emissions or unburned residues produced by the combustion of WCOs used as fuel.

Substances in sewers originate from various sources (*e.g.*, domestic, commercial, industrial, others). Therefore, it is not possible to determine the contribution of WCOs to the toxicity of sewer discharges (treated or untreated) in Canada.

3.0 Assessment of “Toxic” Under CEPA

In 1990, the volume of waste crankcase oils (WCOs) generated was estimated to be 229.3×10^6 litres (L) or 56% of the 413.3×10^6 L of crankcase oils sold in the automotive sector in Canada. Estimates of generation of WCOs from the railway, and marine and aviation transportation sectors, and the transportation and operations of the mining and forestry, and agricultural sectors are not available. Based on the available information regarding entry and fate, the following four of the seven scenarios by which WCOs enter the Canadian environment are considered to be of concern (percentages reported are 1990 estimates for automotive sector only):

- re-refining (50.6%);
- burning as fuel (33.6%);
- road-oiling for dust suppression (3.0%); and
- land disposal (2.8%).

These scenarios are of concern because they involve either direct releases to the environment (dust suppression and land disposal) or the volumes of WCOs involved are large (fuel and re-refining). The quantities of WCOs spilled in Canada in the last decade are small, primarily because WCOs are stored and transported in small drums and small tanker trucks. Most of the WCOs spilled is subsequently recovered. Although the quantity of WCOs disposed of in sewers in Canada is relatively large in total (1.7%), the individual amounts released are small and are usually treated before release to the receiving environment. Similarly, disposal of WCOs in landfills (7.2%) generally involves small individual releases and it is expected that most of the released WCOs will adsorb to the refuse present in the landfills. Therefore, the spills, sewer disposal, and landfilling scenarios will not be considered further in this assessment.

3.1 CEPA 11(a) Environment

Waste crankcase oils and their constituents may be released to air, water, and soil depending on the entry scenario involved. Burning of WCOs leads to air emissions of metals and PAHs (the constituents of WCOs of most concern) that are generally adsorbed to particulate matter and deposited on soil and water. Waste crankcase oils released to water lead initially to the formation of a surface film. Physical and chemical changes to the surface film release constituents of WCOs and their breakdown products to the environment via volatilization, emulsification, solubilization, partitioning to sediments, photodegradation, and biodegradation. Release of WCOs to soil leads to entry of their constituents to the environment via volatilization, adsorption to solid organic matter, leaching through soil to groundwater, or runoff to surface waters.

One or more of the following types of information was considered necessary to determine whether waste crankcase oils are causing harmful effects to the Canadian environment:

- *in-situ* studies comparing environmental effects at sites exposed to WCOs and at unexposed sites;
- estimated effects thresholds for whole WCOs (*e.g.*, for soil biota following application of WCOs to soil) and the corresponding estimates of exposure (*e.g.*, application rates for land disposal in Canada); and/or
- estimated effects thresholds for fractions of WCOs relevant to the entry scenarios described above (*e.g.*, aquatic biota exposed to the water-soluble fraction of WCOs) and corresponding estimates of exposure (*e.g.*, water-soluble fraction concentrations in streams close to roads treated with WCOs for dust suppression).

No *in-situ* studies were available for WCOs released to the Canadian environment by any of the entry scenarios. For each of the four scenarios of concern by which WCOs may enter the Canadian environment, limited information was available to estimate exposure or to estimate effects thresholds for whole WCOs and their relevant fractions.

Dust Suppressant. The only information available to estimate concentrations of volatile hydrocarbons and metals adsorbed to dust following road oiling with WCOs for dust suppression is from a modelling study that assumed worst-case conditions following an oiling application (*e.g.*, dry conditions) (Metzler and Jarvis, 1985). As this model has not been validated, the information from this study was not considered sufficient to estimate exposure of biota to these substances. Further, no *in-situ* or laboratory toxicity data are available for terrestrial biota that have been exposed to the volatile or dust-adsorbed constituents of WCOs in air.

Limited field monitoring has been conducted to determine levels of constituents of WCOs in road runoff, and nearby streams and soil following application of WCOs. In the only available Canadian study, L.S. Love and Associates (1979) determined concentrations of water-soluble fractions in samples upstream and downstream of a road treated with WCOs. The ranges of WSF concentrations in upstream samples and downstream samples exposed to WCOs in this monitoring study were similar, and thus the WSF attributable to WCOs is unknown. The most sensitive effect observed for freshwater biota exposed to the water-soluble fraction of WCOs in the laboratory was a change in algal community structure at 0.038 mg WSF/L following a five-week exposure under flow-through conditions (Bott and Rogenmuser, 1978).

Land Disposal. No modelling estimates or monitoring data are available for air, water, or soil at sites in Canada or elsewhere where WCOs are disposed of on land. The application rates of WCOs to soil during land disposal are also unknown. A study by Giddens (1976) showed that the growth of sorghum decreased by 48% at an application rate of 0.9 L WCO/m² (top 10 cm of soil).

Re-refining. The composition of air emissions from re-refineries in Canada or elsewhere is unknown. Similarly, no monitoring or relevant effects data are available for

receiving waters near wastewater discharges or soils following land and lagoon disposal of solid wastes from re-refineries in Canada or elsewhere.

Fuel. During combustion of WCOs, compounds may be released to the environment as atmospheric emissions and unburned residues may be released following disposal. Monitoring data downwind of combustion units that use WCOs as a fuel are not available. The available data for levels of constituents of WCOs or breakdown products in flue gas are limited (*i.e.*, Surprenant *et al.*, 1983; British Columbia Research Corporation, 1990) and were not sufficient to estimate exposure to biota in the surrounding environment. Similarly, no monitoring or modelling data are available to quantify or estimate levels in the environment following disposal of unburned residues from combustion units using WCOs as a fuel. No effects data are available to determine if stack emissions or unburned residues are causing harmful effects to the environment as a result of burning WCOs as a fuel.

3.2 Conclusion

Therefore, it is not possible to estimate exposure of aquatic and terrestrial biota to waste crankcase oils for any of the four entry scenarios of concern for waste crankcase oils. Further, no field effects data are available to determine the potential for effects of waste crankcase oils to the environment. Based on these considerations, it has been determined that there is insufficient information to conclude whether waste crankcase oils are entering the environment in a quantity or concentration or under conditions that are having a harmful effect on the environment.

4.0 Recommendations for Research and Evaluation

The available information was not sufficient to reach a conclusion for waste crankcase oils. Therefore, the research recommendations listed below are considered to be of high priority.

- (1) Field toxicity testing and monitoring of air emissions, effluents, and solid wastes released to the environment from re-refineries should be conducted.
- (2) Field toxicity testing and monitoring should be conducted downwind of combustion units using WCOs as fuel. Similarly, toxicity testing and monitoring should be conducted in areas where unburned residues are disposed.
- (3) Field toxicity testing and monitoring of the constituents of WCOs in nearby streams and fields should be conducted before and after applications of WCOs to roads for dust suppression.
- (4) Field toxicity testing and monitoring of the constituents of WCOs should be conducted in streams and fields adjacent to areas where WCOs are disposed of on land.

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