
PETROLEUM IN THE FRESHWATER ENVIRONMENT

**AN ANNOTATED BIBLIOGRAPHY
1946 - 1993**

Health and Environmental Sciences Department
Publication Number 4640
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DOCUMENT CONTENTS

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Available scientific literature on the environmental fate and effects of inland petroleum spills was compiled and annotated to assist researchers and educators in locating pertinent references and information. Electronic and hardcopy versions have been prepared to reach a broad audience.

Two electronic infobase versions have been prepared: editable and non-editable. The VIP (editable) version of the infobase will allow the user to add new references, to make personal annotations (bookmarks, notes, highlights, and popups), and to delete unwanted references from the infobase. The non-editable infobase is read only. Both versions are completely searchable; each word in the bibliography is indexed.

THIS BINDER CONTAINS THE FOLLOWING MATERIALS:

1. The Petroleum in the Freshwater Environment annotated bibliography.
2. Four 3-1/2-inch diskettes containing the annotated bibliography (infobase formatted) on Folio® Views software.
3. The Manual for the Electronic Version of the annotated bibliography.

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Petroleum in the Freshwater Environment

An Annotated Bibliography 1946-1993

Health and Environmental Sciences Department

API PUBLICATION NUMBER 4640

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ABSTRACT

This document is a compilation of literature citations concerning the impact of petroleum and petroleum-related compounds on the freshwater environment. The annotated bibliography cites literature from 1946 through 1993. It was derived from three separate literature reviews completed for API. Two are literature reviews on oil in freshwater environments; one in 1984, by the Academy of Natural Sciences of Philadelphia, and a second in 1994, by Woodward-Clyde Consultants. These reviews are limited to the impact of specific petroleum products and oil spill cleanup agents on the biota of freshwater ecosystems, the chemistry and fate of petroleum and cleanup agents in freshwater and methods of oil cleanup in freshwater systems. A third literature review, completed by ENSR Consulting and Engineering in 1994, focused primarily on the effects of petroleum products and oil spill cleanup on birds.

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1.0 INTRODUCTION

Research on the fate and effects of spilled petroleum products has traditionally focused on estuarine and marine ecosystems. The perception of these habitats as being at risk from petroleum contamination stems from the occurrence of major spills over open seas or at coastal terminals during transportation of crude oils and refined products. However, many petroleum-handling facilities are located near freshwater ecosystems (e.g., rivers and lakes) through which petroleum products are transported.

Between 1977-1982, data compiled by the United States Coast Guard on discharges of oil and hazardous substances in and around the nation's waters (Pollution Incident Reporting System, PIRS) show that "inland" oil spills have regularly constituted more than 25 percent of spill events (USCG 1977-1982). Between 1983 and 1992, more than 30 percent of the spills occurred in coastal waters within 12 miles of U.S. shores; another 42 percent occurred in inland bodies of water. The rest occurred in other bodies of water under U.S. jurisdiction. In addition, the amount of petroleum hydrocarbons entering surface waters from industrial and municipal effluents and urban runoff has also been substantial (Hoffman *et al.*, 1982, 1983; Mackenzie and Hunter, 1979; Van Vleet and Quinn, 1977; Whipple and Hunter, 1979).

The growing concern for petroleum contamination in freshwater ecosystems led API to update this annotated bibliography. The document is designed to serve as a valuable resource of existing literature on petroleum and its impact on the freshwater environment. The companion infobase version of this bibliography has been prepared to enhance the value of the annotations for the reader. Infobase diskettes accompany this report.

This document is a compilation of literature citations concerning the impact of petroleum and petroleum-related compounds on the freshwater environment. The annotated bibliography cites literature from 1946 through 1993. It was derived from three literature reviews completed for API: one in 1984, by the Academy of Natural

Sciences of Philadelphia; and a second in 1994, by Woodward-Clyde Consultants; and a third in 1995, by ENSR Consulting and Engineering.

The citations in this bibliography were obtained through the use of computerized literature-searching services with access to both DIALOG and ORBIT bibliographic retrieval systems. Additional citations were obtained from literature cited in publications that were reviewed. In addition, a substantial number of documents were provided by API members.

The review was limited to the impact of specific petroleum products (crude oil, fuel oils, kerosene and gasoline) and oil spill cleanup agents on the biota of freshwater ecosystems; the chemistry and fate of petroleum and cleanup agents in freshwater; and a review of cleanup methods in freshwater systems. These subjects were used to screen articles for inclusion in the bibliography. Criteria for deleting references included papers published before 1946; marine or estuarine studies; citations pertaining to individual components of petroleum products such as xylene, naphthalene or benzene; studies on oil refinery effluents; environmental impacts of oil-sand and oil shale processing; or impacts of oil exploration.

The references in the annotated bibliography are organized by the following categories: general, introduction, chemical and physical aspects of petroleum, rivers, lakes, wetlands, soils, organism type, and spill cleanup. Citations are listed alphabetically, by first author, within each category. The annotation provided for each citation includes, but is not limited to, the research topic, organisms studied, habitat and whether the study was conducted in the field or the laboratory.

2.0 GENERAL

Baca, B.J., T.E. Lankford and E.R. Gundlach. 1986. Environmental Impacts of Oil and Hazardous Material Spills with Emphasis on Winter Conditions in the Upper Great Lakes Region. Coastal Science and Engineering, Inc. Columbia, SC. Available from National Technical Information Service, (703)487-4650 as AD-A214-349/3/XAB.

This report summarizes available literature on the effects of oil and related hazardous materials on freshwater organisms, concentrating on winter (ice) conditions.

Branion, R. 1987. Principles for the Separation of Oil Drops from Water in Gravity Type Separators. In J.H. Vandermeulen and S.E. Hrudey, eds. *Oil in Freshwater: Chemistry, Biology, Countermeasure Technology*. Pergamon Press, New York. p. 431. *Proceedings of the Symposium on Oil Pollution in Freshwater*. Edmonton, Alberta, Canada. October 15-19, 1984.

This paper presents a study of oil drop separation from water and describes a method to determine the effectiveness of fractional oil removal by gravity type oil-water separators. The application of the method to the design of batch separation tanks, pools, API and parallel plate separators is discussed.

Caughey, M.E. 1991. Stable Isotopic Analysis of Organic Carbon in Water and Sediment from the Houston Ship Channel, Texas, USA. *Contributions in Marine Science*. 32:1-8.

In July 1986, water and sediment samples were collected at 14 stations along the Houston Ship Channel. The stable isotope ratios (^{13}C : ^{12}C) of dissolved, particulate and sediment organic carbon are useful in estimating the degree and extent of petrochemical pollution. Comparisons of the 1986 water sample data with those from the same stations 18 years earlier support other evidence that water quality in the Houston Ship Channel has improved.

Cheremisinoff, P.N. 1989. Oil Spills and Oily Wastes. *Pollution Engineering*. 21(5):88-91.

The proper disposal of unwanted waste oils and wastewaters containing oils from lubrication/manufacturing operations, as well as from oil spills is discussed. Physical and chemical methods employed in waste oil recovery are outlined, including: differential gravity separation, vacuum filtration, acid treatment, temperature change, agitation, and ultrasonic vibration. Information on land disposal and incineration, as well as a discussion on controlling oil spills is provided.

General, continued

Davis, L.B. 1967. *Petroleum Microbiology*. Elsevier Publishing Co., Amsterdam, The Netherlands.

Comprehensive review of all aspects of hydrocarbon microbiology.

Delvigne, G.A.L. 1987. Laboratory Experiments on Oil Spill Protection of a Water Intake. In J.H. Vandermeulen and S.E. Hrudey, eds. *Oil in Freshwater: Chemistry, Biology, Countermeasure Technology*. Pergamon Press, New York. pp. 446-458. *Proceedings of the Symposium on Oil Pollution in Freshwater*. Edmonton, Alberta, Canada. October 15-19, 1984.

The threat of oil pollution to water intakes is a serious problem in areas with oil exploration and production activities, refineries and oil transport. The Delft Hydraulics Laboratory performed an extensive study of protective measures for a cooling water and drinking water intake channel in an area with a high oil-spillage risk. The tests analyzed different ways in which floating mechanical barriers and pneumatic barriers may fail to retain the oil. Results indicate that pneumatic barriers fail to retain oil at the entrance of the intake channel because of the entrainment of oil droplets from the oil slick. This occurs even when the water current velocity in the channel is as low as 0.10 m/sec. Floating barriers fail to retain high-viscous oil and emulsified oil independently of the draft when the normal component of the current exceeds 0.15 m/sec. However, oil can be trapped by a double-boom configuration across the intake channel by taking advantage of the circulation zone behind the first barrier.

Entrix, Inc. 1995. *A Critical Review of Toxicity Values and Evaluation of the Persistence of Petroleum Products for Use in Natural Resource Damage Assessments*. API Publication No. 4594. American Petroleum Institute. Washington, D.C.

This review addresses the quality and reliability of values used for denoting the acute toxicity of crude oils and petroleum products in aquatic environments. Indices of comparative toxicity are provided for different oil and taxonomic groups, salt water and freshwater forms, and are expressed in terms of free product absent or free product present. A generalized relative persistence scale is also presented for oil in the environment.

Farlow, J.S. and J.M. Cunningham. 1989. *Oil Spill Research and Development Needs for the 1990s*. EPA/600/D-88/278. National Technical Information Service, PB89-14665/XAB. Springfield, VA.

In the 1970s and the early 1980s the emphasis of Federally-sponsored oil spill

General, continued

research was on mechanical spill control devices and removal methods such as booms, skimmers, and sorbents, with later efforts also focused on dispersing agents. The preponderance of this work was directed toward oil spills in open ocean and coastal areas. Suggested spill response research for inland rivers includes: viscosity modifiers, underflow weirs, effective use of dams/locks, use of dispersants, toxicity/effectiveness of dispersants, water intake protection, river characterization, equipment performance testing, near shore cleanup techniques, alternate containment methods, chemical agency evaluation, cold climate control, existing technology transfer, new technology transfer, and freshwater guidance manual.

Fields T., Jr. 1990. EPA's Response to the Problems of Oil Spills. *Proceedings*, 1990 API Pipeline Conference. American Petroleum Institute. pp. 125-136.

This paper describes the government's response to past oil spills and their response in light of the new challenges posed by recent spills. It discusses the diversity and cost of spills and describes the EPA's role in several recent spills. Finally, the paper provides an update on recent EPA and Congressional actions taken in response to these spills.

Flaherty, L.M., W.B. Katz and S. Kaufmann. 1989. Dispersant Use Guidelines for Freshwater and Other Inland Environments. In *ASTM Special Technical Publication, 1018 (Oil Dispersants: New Ecological Approaches 61-2 (Water))*. Potomac, MD. pp. 25-30, 46 and 51.

Data collected from the USCG between 1977-1984 indicate that the number of inland spills varied between approximately 20-40% of the total spills recorded. The ASTM Committee F-20 on Oil and Hazardous Material Spill Response has produced a series of guidelines for the use of dispersants in saline waters. The Subcommittee F20.13 on Treatment is setting up guidelines covering the use of dispersants in non-saline environments, including freshwater ponds, lakes, and streams. The guidelines are to be patterned after those produced by an earlier task group of the same committee covering saline environments.

Foght, J.M. and D.W.S. Westlake. 1987. Biodegradation of Hydrocarbons in Freshwater. In J.H. Vandermeulen and S.E. Hrudey, eds. *Oil in Freshwater: Chemistry, Biology, Countermeasure Technology*. Pergamon Press, New York. p. 217. *Proceedings of the Symposium of Oil Pollution in Freshwater*. Edmonton, Alberta, Canada. October 15-19, 1984.

This paper examines the biodegradation of hydrocarbons in freshwater systems.

General, continued

Factors influencing biodegradation of hydrocarbons in freshwater are the same as those effecting oil degradation in the marine environment, including: the physical state and chemical properties of the oil, ambient temperature, nutrient supply, aeration, and pH. The net result from the introduction of hydrocarbons into the freshwater system is a reduction in the number of species present.

Franklin, A. 1990. *Compiler. Monitoring and Surveillance of Non-Radioactive Contaminants in the Aquatic Environment, 1984-1987*. MAFF Directions in Fisheries Research and Aquatic Environmental Monitoring. Rep. No. 22.

This report discusses the monitoring that occurs in the waters in and around England and Wales to ensure that fish and shellfish are safe to eat and the viability of the stocks is not affected by pollution. These monitoring studies help determine if any new legislation is needed to keep pollution levels down.

Gashev, S.N. 1992. Effect of Oil Spills on the Fauna and Ecology of Small Mammals from the Central Ob' Region. *Soviet Journal of Ecology* (Engl. Transl.). 23(2):99-106.

This paper discusses a study on the effects of oil spills on the fauna from the Ob' Region, one of the oil producing regions in the USSR. The study listed the small mammals that were affected in varying degrees by pollution. It concluded that, in general, it takes approximately eight to nine years for habitat restoration for these small mammals in a small or average size spill and much longer for a large spill.

Gatt, S., H. Bercovier and Y. Barenholz. 1991. Use of Liposomes for Combating Oil Spills and Their Potential Application to Bioreclamation. In R.E. Hinchee and R.F. Olfenbuttel, eds. *On-site Bioreclamation*. Butterworth Publishers, Stoneham, MA. pp. 293-312.

This article discusses the use of liposomes to aid in microbial degradation of oil spills. Liposomes are a source of carbon, hydrogen, phosphorous, and nitrogen, and because of their vesicular structure, they can be used as a reservoir of encapsulated nutrients, minerals, and growth factors. They modify the physical properties of oil or hydrophobic wastes, increasing their availability to microbial degradation, while concomitantly supplying nutrients essential for microbial growth.

Giddings, J.M., S.E. Herbes and C.W. Gehrs. 1985. *Releases of Coal Liquefaction Products in Inland Waters*. ORNL-TM-9535, Oak Ridge National Laboratory. Oak Ridge, TN. pp. 51. Available from National Technical Information Service, (703)487-4650 as DE86001467.

General, continued

Through laboratory studies, simulation modeling, and field experiments, information has been developed that supports a preliminary evaluation of the potential environmental impacts of coal-liquid spills. Releases of crude products into large rivers would probably cause relatively little immediate ecological damage, but spills in lakes, embayments, and other semi-enclosed water bodies could have serious effects. Product upgrading by hydro-treatment or distillation can be expected to reduce the environmental hazards of coal-derived oils.

Girling, A.E., R.K. Markarian and D. Bennett. 1992. Aquatic Toxicity Testing of Oil Products - Some Recommendations. *Chemosphere*. 24(10):1469-1472.

Current toxicity test method guidelines for aquatic organisms are generally not applicable to oil products. This paper provides recommendations to determine the aquatic toxicity of oil products, including: 1) test media should contain only the "water-soluble" fraction of the product; 2) to more accurately reflect exposure in the real world, tests should use mechanically or chemically maintained dispersions; 3) products which readily emulsify should be treated as special cases; 4) current internationally accepted testing methods should be followed when possible; 5) testing methods employed for monitoring the stability and composition of test media should be given special consideration; and 6) results should be expressed in terms of "loading rates."

Green, J. and M.W. Trett (eds.). 1989. *The Fate and Effects of Oil in Freshwater*. Elsevier Applied Science, New York.

This book provides a synthesis of the current understanding of the fate and effects of oil into freshwater environments as of 1988. The objectives are centered around four main themes: 1) to provide a comprehensive compilation, summary and critical evaluation of available scientific literature on the impact of petroleum on freshwater organisms; 2) to review procedures for the cleanup of petroleum from freshwater habitats and to examine restoration and recovery rates; 3) to provide background information on the chemistry and fate of petroleum in freshwater; and 4) to identify gaps in information on the effects of petroleum contamination of freshwater.

Gundlach, E.R., M. Murday and W.L. Fanning. 1986. *Review and Evaluation of Contingency Plans for Oil and Hazardous Substances in the Upper Great Lakes Region*. Coastal Science and Engineering, Inc. Columbia, SC. Available from National Technical Information Service, (703)487-4650 as AD-A205 209/0/GAR.

The purpose of this study was to update and supplement a contingency plan review conducted for the Army Corps of Engineers in 1979 by the St. Lawrence-

General, continued

Eastern Ontario Commission for handling oil and hazardous substance spills on the upper Great Lakes and their connecting channels. Special attention was given to cleanup and control methods described for ice conditions that may exist in the region in winter. The report identifies existing contingency plans in the study area; tabulates amounts, types, and locations of equipment and manpower that exist to implement the plans; describes methods to contain and recover oil in ice conditions; describes spill mitigation plans and techniques to protect natural resources; describes techniques of deflecting oil in swift flowing waters; and describes disposal plans identified in the contingency plans.

Heath, A.G. *Water Pollution and Fish Physiology*. CRC Press Inc., Boca Raton, FL.

This book provides a concise synthesis on the effect of pollutants on the physiological processes in fish and includes a literature review through early 1985. Various physiological processes are covered, including osmoregulation, energy metabolism, and reproduction.

Herdendorf, C.E. and L.A. Fay. 1988. Development of an Environmental Sensitivity Index for Coastal Areas of Lake Erie, North America. *Internationale Vereinigung fuer Theoretische und Angewandte Limnologie Verhandlungen*. 23(1):380-385.

A classification scheme for an Environmental Sensitivity Index (ESI) was developed to depict the sensitivity of the coast on U.S. Geological Survey topographic maps on which diverse resource data could be illustrated. The index incorporates geomorphological and sedimentological characteristics of the shoreline as well as biological and socioeconomic considerations. Ten sensitivity categories were established based on the sensitivity of coastal areas to oil spills and discharges of other hazardous materials. The scheme was tested by mapping the shoreline of Lake Erie and connecting waterways. Sixty-six topographic maps were prepared for inclusion in an atlas of coastal resources for use by field personnel involved in decision-making and spill clean-up operations. The Lake Erie ESI is designed as a pilot program for the other Great Lakes.

Hodgins, D.O., S.L.M. Hodgins and P.H. Leblond. 1991. A Formalized Risk Analysis Procedure for Oil and Chemical Spills in Coastal and Inland Waters. *Proceedings*, Arctic and Marine Oil Spill Program Technical Seminar, Vancouver, B.C. (Canada), 12-14 June 1991. pp. 377-390.

Generally, major hazardous commodity spills in coastal waters have significant environmental and economic impacts for the region. The degree of impact depends upon where the spill occurs, the type and volume of commodity, the time of day

General, continued

and season of the spill, and the environmental conditions prevailing at the time. The purpose of risk analysis is to attempt to quantify, in a formal way, the likelihood of incurring certain environmental and economic impacts, taking all of the above factors into account. Risk analysis for oil or chemical spill impacts provides a quantitative measure of damage in the event of an accident, and also provides valuable insight into the environmental conditions leading to large impacts, and which economic, recreational or wildlife resources are most susceptible to damage.

Hrudey, S.E. and S. Kok. 1987. Environmentally Relevant Characteristics of Oil-in-water Emulsions. In J.H. Vandermeulen and S.E. Hrudey, ed. *Oil in Freshwater: Chemistry, Biology, Countermeasure Technology*. Pergamon Press, New York. pp. 58-70. *Proceedings of the Symposium on Oil Pollution in Freshwater*. Edmonton, Alberta, Canada. October 15-19, 1984.

Successful treatment of oil-in-water emulsions requires adequate characterization of emulsion properties to allow efficient destabilization and oil-water separation. The theory of oil-water emulsion stability is reviewed by discussing the factors controlling proximity and factors controlling coalescence. Markedly different results were obtained in studies comparing the toxicity of oil-water dispersions with the toxicity of water soluble fractions prepared from the same reference oils. Much of the observed difference in toxicity was attributed to differences in chemical composition between oil-water dispersions and water soluble fractions.

Hurst, R.J., P.D. Watts and N.A. Oritsland. 1991. Metabolic Compensation in Oil-Exposed Polar Bears. *Journal of Thermal Biology*. 16(1):53-56.

Metabolism and temperature were monitored for three sub-adult polar bears before and after exposure to a pool covered with a 1 cm slick of Midale crude oil. In all study animals, thermoregulatory problems occurred following oil exposure: the increase in metabolic rate varied from 27 to 86% after oil exposure, whereas whole body thermal conductance increased 21-55%.

Katsumi, N. 1991. The Marine Transport of Oil and Other Noxious Substances in Canadian Coast Guard Central Region 1987-1989. *Proceedings, Arctic and Marine Oil Spill Program Technical Seminar*, Vancouver, B.C. (Canada), 12-14 June 1991. pp. 325-347.

This document is intended to aid the contingency planning for emergency situations within Canada's Central Region. Research has been conducted in order to gain information about the movement of hazardous material in the Great Lakes/St. Lawrence River system. Although the existing mandate includes

General, continued

hazardous materials, the Emergency Operations Branch response capabilities are currently restricted primarily to oil spills. This study has been initiated to acquire information about petroleum products and floating chemicals in preparation for a revised minimum level of Canadian Coast Guard response to emergency incidents in the Central Region.

Lane, P. and Associates Ltd. 1992. *Review of Natural Resource Damage Assessments in Freshwater Environments Task 1: Review of Case Histories*. API Publ. No. 4513. American Petroleum Institute, Washington, D.C..

This report reviews the effects of documented petroleum releases into freshwater habitats. It focuses on 80 studies of known spills documented in spill reports and published literature. Included and considered are results from toxicity tests of petroleum and various products to freshwater organisms. The review finds that mortalities frequently were high, and in some cases oil persistence was surprisingly long. However, in many cases the ecological impacts were often undetectable within the same growing season and impacts appeared to be fairly transient. Faster flowing waters tended to self-cleanse readily. Lakes and other slow flowing waters experienced more long-lasting effects. Shoreline vegetation is a major factor in prolonging the persistence of spilled oil, and is a possible major factor in observed mortalities of waterfowl. In northern areas the presence of snow and ice increases the persistence of spilled oil.

Latimer, J.S., E.J. Hoffman, G. Hoffman, J.L. Fasching and J.G. Quinn. 1990. Sources of Petroleum Hydrocarbons in Urban Runoff. *Water, Air and Soil Pollution*. 52(1-2):1-21.

Petroleum products as well as probable source materials were analyzed for hydrocarbons and trace metals and then compared to urban runoff samples from four different land use areas. The petroleum products considered were No. 2 and No. 6 fuel oils, used and virgin crankcase oils, and gasoline. Source materials included street dust, roadside soil, roadside vegetation, and atmospheric fallout; and the land use categories were commercial, residential, interstate highway, and industrial areas. Results indicated that the hydrocarbon content in runoff at all four land use sites originated primarily from used crankcase oil, with a small amount of No. 2 fuel oil detected at the industrial site. Only a small portion of the crankcase oil component came from the sources surveyed, and the majority of this oil probably came from oil drops within the driving lanes on the road surfaces or deposits in parking areas, and/or direct dumping of waste crankcase oil down storm drains.

General, continued

- Leighton, F.A. 1982. The Pathophysiology of Petroleum Oil Toxicity In Birds: A Review. *Proceedings, A Multidiscipline Symposium; The Effects of Oil on Birds: Physiological Research, Clinical Applications and Rehabilitation*, Wilmington, DE, 1982. pp. 1-24.

This review of the pathophysiology of oil toxicity in birds emphasizes toxic effects of ingested oil, and was intended as a general overview of published studies. Details of individual experiments were not discussed except where necessary to make distinctions or to provide examples. Specific topics include: mortality due to petroleum, external oil, oil ingestion (i.e., effects on growth and body weight, endocrine and stress-related phenomena, osmoregulation, hepatic metabolism, nutrient uptake, hematologic change, morphological lesions), and toxic components of petroleum oils.

- Lockhart, W.L., D.A. Metner, D.A.J. Murray, R.W. Danell, B.N. Billeck, C.L. Baron, D.C.G. Muir and K. Chang-Kue. 1989. *Studies to Determine Whether the Condition of Fish from the Lower Mackenzie River is Related to Hydrocarbon Exposure*. Environmental Studies Report No. 61.

Fish from Fort Good Hope and other northern communities were found to contain low levels of several low-boiling point hydrocarbons, notably ethylbenzene and xylenes. These are the most abundant compounds of the water soluble fraction of Norman Wells crude oil and other crude and refined petroleums. Burbot and whitefish had higher levels of these compounds in the winter ice-covered conditions than under open-water conditions.

- Lockhart, W.L. and D.A. Metner. 1991. Oil-sensitive Biomarker Studies of Fish from Arctic Canada. *Proceedings, Ninth Annual Arctic and Marine Oil Spill Program Technical Seminar*, Vancouver, British Columbia, Canada, June 12-14, 1991. pp. 169-176.

Several field and laboratory studies on marine and freshwater fish have shown elevations in liver mixed-function oxidase (MFO) enzyme activities following exposures to petroleum oils or to a small number of other environmental contaminants (PCBs, chlorinated dioxins/furans, PAHs). Application of these techniques in an arctic context is limited by lack of background data on ranges in enzymatic activities to be expected in arctic animals in the absence of a pollution incident. The authors conducted experimental oil enzyme induction experiments with several northern species (burbot, char, harp seals) and confirmed the sensitivity of the animals using two activity measurements, aryl hydrocarbon hydroxylase (AHH), and ethoxyresorufin-O-deethylase.

General, continued

McKenna, E.J. and R.E. Kallio. 1965. The Biology of Hydrocarbons. *Annual Review of Microbiology*. 19:183-208.

In this review of the biology of hydrocarbons, the general metabolic pathways of saturated and unsaturated aliphatic hydrocarbons, alkynes, nonbenzenoid cyclic hydrocarbons and aromatic hydrocarbons, as well as the mechanisms of aliphatic and aromatic hydrocarbon oxidation are discussed. The co-oxidation and oxidation of non-assimilable substrates is mentioned.

Metcalf and Eddy, Inc. 1993. *Chemical and Physical Characteristics of Crude Oil, Gasoline, and Diesel Fuel: A Comparative Study. Report to the Western States Petroleum Association*. Sacramento, CA.

This report presents a summary of chemical, physical, and toxicological characteristics of crude oil, and compares crude oil with petroleum products such as gasoline and diesel fuel. Observations of health risk and environmental fate and transport in soil and groundwater, including solubilities in fresh water, are provided. The data compilation is intended to provide guidelines for soil cleanup.

Metzner, G. 1985. Abundance and Distribution of Crude Oil in Water. Pollution Impact and Ecosystem Conservation in the Aquatic Environment. *Muenchner Beiträge zur Abwasser-, Fischerei-, und Flussbiologie*. 39:94-113.

Petroleum in water usually stems from different sources. In the sea, oil is mostly discharged from ships or is spilled in tanker accidents. On land it mostly stems from different sources. Statistics reveal that oil pollution in freshwater originates mostly from pipeline or car accidents.

Molag, M. and C.M.A. Jansen. 1988. *Spills of Oil Products and Chemicals into Rivers*. Netherland Organization for Applied Research, Report to Center for Hazardous Material Research, Pittsburgh, Pennsylvania. TNO Report No. 8727-19241.

A statistical analysis of oil and chemical spills into rivers, canals and harbors was performed using the TNO-database FACTS (1972-1986). In the U.S. and other countries, most of the oil spills into rivers occur from pipelines. Spills from storage facilities account for 21% of all inland spills. Inland navigation of oil tankers and transshipment accounted for 15% of the number of inland spills. The prevailing cause for oil storage tank spills into rivers was from deliberate human action (29% in the U.S.).

General, continued

Muller, H. 1987. Hydrocarbons in the Freshwater Environment. *Archiv fur Hydrobiologie* (Ergebn. Limnol.) 24:1-69.

This report provides a summary and review of hydrocarbons of natural and anthropogenic origin in freshwaters. Topics include formation of hydrocarbons by biosynthesis, diagenesis and pyrolysis; routes into freshwater; efficiencies and limits of analytical techniques to determine concentrations and source identification; sorption; photo-oxidation; bioconcentration; biotransformation; biodegradation; and toxicity and carcinogenicity with emphasis on lethal and sublethal effects observed in aquatic organisms at the part per billion level.

National Technical Information Service. 1990. *Aquatic plants: Ecology and Environment. January 1977-November 1987*, a Bibliography from the Selected Water Resources Abstracts Database. National Technical Information Service, Springfield, VA.

This bibliography contains citations concerning growth of, and ecological and environmental effects on, benthic flora in lakes, rivers, and coastal areas. Effects of domestic sewage, industrial wastes, and oil spills on benthic ecosystems are discussed. Benthic algae vegetation in river and polluted areas is considered, and benthic algae as biological indicators of water quality is discussed.

National Technical Information Service. 1990. *Chromatography for Water Pollution Analysis. January 1977-October 1989*, Citations from the Energy Database. National Technical Information Service, Springfield, VA.

This bibliography contains citations concerning chromatographic analysis of water pollutants. Chromatographic determination, source identification, and characterization of pollutants generated by oil spills, industrial processes, and municipal wastes are discussed. Water pollution effects on aquatic ecosystems and pollutants in drinking water, groundwater, and lake, sea, and river water are evaluated and analyzed.

Norcross, B.L. 1992. Responding to an Oil Spill: Reflections of a Fisheries Scientist. *Fisheries* (Bethesda). 17(6):4-5.

This essay discusses conducting field fisheries studies in Prince William Sound following the *Exxon Valdez* oil spill. Because accidental oil spills are unexpected and unplanned events, there is no opportunity to develop a thorough sampling regime, there is inherent non-repeatability, and there is often no baseline data available for comparison. To try to overcome some of these problems, the author suggests developing a generic sampling plan that can be adapted for a specific

General, continued

spill and location. She maintains that a well-designed scientific contingency response plan can provide understanding about the effects of the spill as well as apply to spills in other locations.

Payne, J.F. 1984. Mixed-function Oxygenases in Biological Monitoring Programs: Review of Potential Usage in Different Phyla of Aquatic Animals. *Ecotoxicological Testing for the Marine Environment. Marine Toxicology*. 1:625-656.

Besides use in monitoring point sources such as around oil spills, sewage or industrial outfalls, MFO (mixed-function oxygenase enzymes) may have an expanded role in identifying or delineating broad geographical areas of mixed organic pollution. Field studies, both in Yugoslavia and the Netherlands, have linked MFO induction in various freshwater fish to mixed organic pollution originating from domestic and industrial sources. In general, invertebrates have been reported to be refractory to induction, but evidence has recently been reported elevated enzyme levels in populations of crabs and polychaetes found at old oil-spill sites. Laboratory studies indicate the possibility of ecological process of genetic selection for strains of animals with elevated MFO levels, at such old oil-spill sites.

Prince, H.H. 1983. Effects of Petroleum on Wildlife. Presented at USA/Czechoslovakian Seminar on Toxic Substances and Wildlife, October 3-4, 1983, Strbske Pleso, Czechoslovakia. *Michigan Agricultural Experiment Station Journal*. Article No. 11140.

A general overview is provided on history of oil pollution, impacts of oil pollution, the species oil pollution affects, studies conducted on different species, and summarizes the results. The article addresses many studies conducted with mallard ducks paying special attention to egg production and hatchability. It concludes that although safeguards to reduce oil pollution worldwide are urgently needed, serious damage to wildlife is seldom caused except at a temporary and local scale.

Public Review Panel on Tanker Safety. 1990. *Protecting Our Waters: Final Report*. SSC-EN21-91/1990E; MIC-91-05692/XAB. Public Review Panel on Tanker Safety and Marine Spills Response Capability, Ottawa (Ontario).

The Panel reviewed the measures currently in place to ensure the safe movement of oil and chemicals by tanker and tank barge through Canadian waters; Canada's ability to respond to marine spills of these products; and the Canadian and international legislation and conventions which regulate the movement of oil and

General, continued

chemicals, including the provisions for compensation for damages resulting from spills. This final report presents the issues for Canada as a whole, and specifically for Newfoundland and Labrador, the Maritimes, the St. Lawrence River, the Great Lakes, the Arctic and the West Coast. It includes funding information and general recommendations.

Readman, J.W., M.R. Preston and R.F.C. Mantoura. 1984. An Integrated Technique to Quantify Sewage, Oil and PAH Pollution in Estuarine and Coastal Environments. *Marine Pollution Bulletin*. 17(7):298-308.

An analytical protocol is described which allows parallel quantification of sewage, oil and PAH pollution on the same sample, thus maximizing the information gained. Capillary gas chromatography-flame ionization detection (GC-FID) was used as the method for quantification. This paper describes and evaluates the protocol and provides an analysis of sediments from estuaries of the Rivers Mersey, Dee and Tamar, UK.

Resh, V.H. and D.G. Price. 1984. Sequential Sampling: A Cost-effective Approach for Monitoring Benthic Macroinvertebrates in Environmental Impact Assessments. *Environmental Management*. 8(1):75-80.

Sequential sampling is a method for monitoring benthic macroinvertebrates that can significantly reduce the number of samples required to reach a decision, and consequently, decrease the cost of benthic sampling in environmental impact assessments. Rather than depending on a fixed number of samples, this analysis cumulatively compares measured parameter values (for example, density, community diversity) from individual samples, with thresholds that are based on specified degrees of precision. Sequential sampling can provide clear-cut decisions as to whether prior-defined changes in the measured parameter(s) have or have not occurred.

Rice, S.D. 1985. Effects of Oil on Fish. In F.R. Engelhardt, ed. *Petroleum Effects in the Environment*. Elsevier Applied Science Publishers, New York. pp. 157-182.

This paper summarizes the effects of oil on fish from laboratory and field studies. The review found that extensive fish kills after oil spills are generally not documented, primarily because toxic concentrations are seldom achieved even though large volumes of spilled oil may contaminate the surface. Sublethal effects of oil and its components on fish have been documented in the laboratory. Studies have found that concentrations of less than 1 ppm aromatic hydrocarbons caused reduced growth. Concentrations as high as a few ppm have rarely been observed

General, continued

after spills. Egg and larva are the most sensitive life stage of fish. Malformations or aberrations in development observed in many species probably occur at concentrations of less than 1 ppm aromatic hydrocarbons. Concentrations toxic to fish larvae could be generated in the surface waters at the spill site, yet massive kills of fish eggs and larvae have not been documented.

Rudolph E.K., M. Bianchini, G. Gilla, C. Beuillard and D. Lyons. 1988. *Performance of Oil Industry Cross-country Pipelines in Western Europe. Statistical Summary of Reported Spillages-1988*. Concawe, The Hague, Netherlands. Report Number 9/89.

This report documents spills from the pipelines in Western Europe. It covers the spills by cause and effectiveness of cleanup. It compares the number of spills and their cause to historical spills. The intent of the study was to ensure that the pipelines still provide a safe and reliable means for transporting oil.

Smalheer, D.L., S. Jacobson and R.S. Tjeerdema. 1992. *Oil Spill Cleanup Agent Efficacy, Toxicity, and Biodegradation: An Annotated Bibliography, 1984-1991*. University of California, Santa Cruz.

This bibliography presents literature published between 1984-1991 on the environmental fate of petroleum and on all aspects of petroleum and cleanup agent toxicology. Toxicity, effectiveness, biodegradation, and analytical methodology are included as keys in the review.

Szaro, R.C. 1977. Effects of Petroleum on Birds. *Transactions of the North American Wildlife and Natural Resources Conference*. 42:374-381.

Literature review of oil/petroleum effects on birds.

Teal, J.M. and R.W. Howarth. 1984. Oil Spill Studies: A Review of Ecological Effects. *Environmental Management*. 8:27-44.

This review of seven major oil spills (including bunker C, crude oil, and Nos. 2, 5, and 6 fuel oils) focused on the types of interactions between spilled oil and ecosystems. Topics discussed included persistence, transport of oil to the sediments, benthic and littoral effects, effects on plankton, effects on fish and fisheries, ecosystem level effects, and differences between effects of the types of oil.

General, continued

Treccani, V. 1962. Microbial Degradation of Hydrocarbons. *Progress in Industrial Microbiology*. 4:3-33.

This review article describes the metabolic pathways employed by microorganisms in the degradation of hydrocarbons and of their derivatives.

United States (U.S.) Coast Guard. 1977-1982. *Polluting Incidents In and Around U.S. Waters*. U.S. Coast Guard, Department of Transportation, Washington, DC.

The U.S. Coast Guard compiles data on discharges of oil and hazardous substances occurring in internal and coastal waters of the nation and on the high seas. Data include the time, location, source, cause, and volume (or weight) of material discharged, in addition to response and penalty information; summaries are published annually for 2 preceding years.

U.S. Department of the Army. 1988. Prediction of Oil Spill Transport. NTIS Technical Note. NTN88-0390. U.S. Department of the Army, Washington, D.C.

An oil spill model has been developed that provides the ability to simulate: the advection of a spill by water currents and wind velocity; the mechanical spreading of a spill due to gravity, viscous, and surface tension effects; the effect of evaporation and dissolution on the spill volume; open water and ice-covered water conditions; and the interaction of a spill with the shoreline. The model forecasts the movement of the spill on a two-dimensional grid that is superimposed over the river or lake system. The model output consists of maps showing the location of the spill at a user-selected time interval; river or lake boundaries and landmarks are labeled. Three different spill constituents are currently available: gasoline, bunker C oil, and No. 2 fuel oil. A menu-driven version of the model is available on a desktop PC which produces high-resolution maps. The program is currently set up for the Great Lakes connecting channels, but it is written in modular form and can be adapted to any waterway or lake.

Vandermeulen, J.H. 1987. Toxicity of Sublethal Effects of Petroleum Hydrocarbons in Freshwater Biota. In J.H. Vandermeulen and S.E. Hrudey, ed. *Oil in Freshwater: Chemistry, Biology, Countermeasure Technology*. Pergamon Press, New York. pp. 267-303. *Proceedings of the Symposium on Oil Pollution in Freshwater*. Edmonton, Alberta, Canada. October 15-19, 1984.

This paper summarizes the available research literature on freshwater organisms and presents the interpretations and conclusions on the impact and mechanism of the toxicology of petroleum hydrocarbons in freshwater environments. Included

General, continued

in this discussion are the acute lethal and sublethal toxicity of petroleum and petroleum compounds, mutagenicity, and effects on birds and freshwater algae. Toxicity of petroleum varies with the type of product and its state of weathering, its chemical composition, and degree of impact varies with the age and life cycle stage of the organism affected. The review includes summary tables of acute lethal and sublethal toxicities of petroleum as they have been determined on a range of freshwater organisms. The focus is on the literature published since 1979.

Vandermeulen, J.H. and S.E. Hrudey. 1987. *Oil in Freshwater: Chemistry, Biology, Countermeasure Technology*. Pergamon Press, New York.

This volume is a compilation of selected papers which were presented at an International Conference on Oil in Freshwater held in Edmonton, Alberta, Canada in October 1984. The papers are grouped under five chapters that describe various aspects of petroleum interaction and contamination in freshwater environments. [Annotations of the individual chapters are provided separately.]

Whipple, W., Jr. and J.V. Hunter. 1979. Petroleum Hydrocarbons in Urban Runoff. *Water Resource Bulletin*. 15:1096-1105.

Petroleum hydrocarbons in urban runoff from four sites were measured to estimate non-point source contributions to the Delaware Estuary. Values obtained from this study are compared to estimated loadings from spills and municipal and industrial effluents to indicate that urban runoff is a major present and proportionately increasing source of total hydrocarbon input to the estuary. Constituent classes of compounds in runoff and potential sources are compared.

ZoBell, C.E. 1946. Action of Microorganisms on Hydrocarbons. *Bacteriological Reviews* 10:1-49.

Comprehensive review of records of ability of microbes to degrade and/or utilize hydrocarbons derived from petroleum, petroleum products and rubber. Environmental and nutritional requirements of hydrocarbon utilizers and their occurrence in natural environments are considered.

3.0 CHEMICAL AND PHYSICAL ASPECTS OF PETROLEUM

Bassin, N. and T. Ichiye. 1977. Flocculation Behavior of Suspended Sediments and Oil Emulsions. *Journal of Sedimentary Petrology*. 47(2):671-677.

Laboratory study of emulsions of crude oil and clay particles in fresh and brackish waters determined a difference in flocculation between emulsions in distilled water and emulsions in distilled water containing 10 ppt NaCl.

Burris, D.R. and W.G. MacIntyre. 1987. Water Solubility Behavior of Hydrocarbon Mixtures - Implications for Petroleum Dissolution. In J.V. Vandermeulen and S.E. Hrudehy, eds. *Oil in Freshwater: Chemistry, Biology, Countermeasure Technology*. Pergamon Press, New York. p. 85. *Proceedings of the Symposium on Oil Pollution in Freshwater*. Edmonton, Alberta, Canada. October 15-19, 1984.

Water solubilities of various hydrocarbon mixtures were determined at 20 degrees Celsius to clarify the role of the dissolution process in a petroleum spill in the aquatic environment. The results indicate that equilibrium aqueous phase concentrations can be predicted using knowledge of the hydrocarbon phase composition, water solubilities of single components and hydrocarbon phase interactions.

Butler, J.N. 1975. Evaporative Weathering of Petroleum Residues: The Age of Pelagic Tar. *Marine Chemistry*. 3:9-21.

A model of the rate of evaporative weathering of a component of crude oil residue is tested using literature data on normal paraffin profiles of crude oils weathered artificially and gas chromatographic data on crude oil residues weathered on rocky shores.

Chen, E., B. Keevil and R. Ramseier. 1976. Behavior of Crude Oil Under Freshwater Ice. *Journal of Canadian Petroleum Technology*. 15(2):79-83.

A laboratory study was conducted to investigate the behavior of crude oil when released under a layer of freshwater ice in calm or turbulent water. The thermal effects and the formation of emulsions were studied.

Chen, E., J.C.K. Overall and C.R. Phillips. 1974. Spreading of Crude Oil on an Ice Surface. *Canadian Journal of Chemical Engineering*. 52:71-74.

Quantitative data are presented for the gravity-viscous spreading of five crude oils on artificially prepared ice at different temperature, roughness, and oil volume regimes.

Chemical and Physical Aspects, continued

Clark, R.C., Jr. and D.W. Brown. 1977. Properties and Analyses in Biotic and Abiotic Systems. In D.D. Malins, ed. *Effects of Petroleum on Arctic and Subarctic Marine Environments and Organisms*, Vol. 1. Academic Press, New York. pp. 1-26.

The physical and chemical characteristics of crude petroleum and refined petroleum products are discussed.

Edgerton, S.A., R.W. Coutan and M.V. Henley. 1987. Hydrocarbon Fuel Spill Dispersion on Water. A Literature Review. *Chemosphere*. 16(7):1475-1487.

The literature concerning the fate of light hydrocarbon fuel spills on water is reviewed. The review focuses on jet fuels and contains some discussion of gasoline, diesel, marine and kerosene fuel spills. The two major fates of light hydrocarbon spills on water are evaporation and dissolution, although biodegradation, photo-oxidation and adsorption onto suspended sediments can also be of some importance.

Fallah, M.H. and R.M. Stark. 1976. Literature Review: Movement of Spilled Oil at Sea. *Marine Technology Society Journal*. 10:3-17.

An overview of some of the important works on oil spills at sea. Topics covered include spreading, drift, diffusion and dissipation of oil on water. A comprehensive, bibliography, organized by topics is also included.

Greene, G.D., P.J. Leinonen and D. MacKay. 1977. An Exploratory Study of the Behavior of Crude Oil Spills Under Ice. *Canadian Journal of Chemical Engineering*. 55(6):696-700.

The slick thickness, heat and mass transfer of crude oil spilled under ice in an artificial pond was studied. Some oil was recovered and methods of disposal were tested.

Hanby, J.D. 1988. New Method for the Detection and Measurement of Aromatic Compounds in Water. *Proceedings*, Second National Outdoor Action Conference on Aquifer Restoration, Ground Water Monitoring and Geophysical Methods. Vol. 1. National Water Well Association, Dublin, Ohio, pp. 493-504.

A Field Test Kit procedure for the rapid analysis of petroleum aromatic hydrocarbons over a wide range of concentrations in water and soil has proven very useful in accurate assessments at spill sites, hazardous waste areas, and underground storage tank locations. The kit combines the advantage of immediate

Chemical and Physical Aspects, continued

results with simplicity of analysis. The technique involves extracting aromatic hydrocarbons with a reagent, a Friedel-Crafts reaction is incurred by the addition of another reagent, and the resulting color development is compared to a chart of standard colors for eleven typical aromatic compounds. A variation of the method can be used to analyze for alkyl halides such as trichloroethylene.

Hazel, C.R., F. Kappendahl, N. Morgan and W. Thomsen. 1971. *Evaluating Oil Spill Cleanup Agents. Development of Testing Procedures and Criteria*. Publication No. 43. California State Water Resources Control Board, Sacramento.

A literature review and laboratory testing program was conducted to test procedures and criteria for evaluating oil-spill cleanup agents. The report covers such areas as recommendations and discussions on oil and dispersants, toxicity, dispersant biodegradability, and effectiveness of oil dispersing agents.

Hepler, L.G., C. Dobrogowska and K. Kasperski. 1987. Water Soluble Substances from Heavy Oils and Tar Sands Bitumens - An Overview. In J.H. Vandermeulen and S.E. Hrudey, eds. *Oil in Freshwater: Chemistry, Biology, Countermeasure Technology*. Pergamon Press, New York. *Proceedings of the Symposium on Oil Pollution in Freshwater*. Edmonton, Alberta, Canada. October 15-19, 1984.

The primary components of oil are only slightly soluble in water. Partial oxidation and hydrolysis reactions of oils yield products that are moderately soluble or even highly soluble in water. Water soluble substances will be formed from oils and bitumens during various production, upgrading, and refining processes. Largely because of their effects on interfaces, these water soluble substances have an important influence on oil production efficiencies, on the properties of large accumulations of tailings, and on treatment of aqueous process streams to permit cycling or disposal of water.

Hubbard, E.H. 1975. Fate and Effects of Oil on Land and in Fresh Waters. *Proceedings, Ninth World Petroleum Congress*. Tokyo, Japan. May 5-11 1975. pp. 289-296.

Information is presented on the fate and effects of oil on land, groundwater and inland surface waters. Oil transport mechanisms in soil are discussed, as well as effects of spilled oil on fresh water such as spreading and movement, fire and explosion risks, taste and odor, toxicity, biodegradability, oxygen balance and nutrient value.

Juettner, F. and J.J. Henatsch. 1986. Anoxic Hypolimnion is a Significant Source of Biogenic Toluene. *Nature*. 323(6091):797-789.

Chemical and Physical Aspects, continued

Toluene is the predominant aromatic compound found in freshwater lakes in Central Europe and in seawater. Its concentration exceeds those of the xylene and ethyltoluene isomers which occur in comparable concentrations. Toluene is also the most important aromatic compound in the air of Europe, North America and Australia. Anthropogenic sources are held to be responsible for the high concentrations. Significant amounts have been introduced by oil spillage, emissions of petrol and diesel-fuelled vehicles and other combustion processes. The authors report that while investigating the VOC (volatile organic compounds) in a stratified lake, appreciable amounts of toluene can be biogenically produced in the anoxic hypolimnion.

Larson, R.A., T.L. Bott, L.L. Hunt and K. Rogenmuser. 1979. Photo-oxidation Products of a Fuel Oil and Their Antimicrobial Activity. *Environmental Science and Technology*. 13(8):965-969.

Laboratory study of the toxicity of some of the compounds formed upon the photo-oxidation (mercury arc light or sunlight) of the water-soluble components of No. 2 fuel oil. Both acid fractions of the irradiated extract and identified pure compounds (hydroperoxides, phenols, carboxylic acids) were tested to determine effects on the growth of a yeast and selected algal cultures and algal photosynthesis ($^{14}\text{CO}_2$ - incorporation).

Larson, R.A., L.L. Hunt and D.W. Blankenship. 1977. Formation of Toxic Products From No. 2 Fuel Oil by Photo-oxidation. *Environmental Science and Technology*. 11(5):492-496.

The ultraviolet (UV) irradiation of No. 2 fuel oils was investigated to determine the products formed and the resulting toxicity to yeast cultures.

MacKay, D. 1987. Chemical and Physical Behavior of Hydrocarbons in Freshwater. In J.H. Vandermeulen and S.E. Hrudey, eds. *Oil in Freshwater: Chemistry, Biology, Countermeasure Technology*. Pergamon Press, New York. p. 10. *Proceedings of the Symposium on Oil Pollution in Freshwater*. Edmonton, Alberta, Canada. October 15-19, 1984.

This paper reviews the behavior of hydrocarbons in freshwater systems. There are two ways to view the behavior of hydrocarbons: the simpler one is to quantify the bulk behavior of the oil which is controlled by the interacting processes of evaporation, dissolution, photolysis, water-in-oil emulsification (mousse formation), and oil-in-water emulsification (dispersion). The second way is to quantify the fates of individual hydrocarbons. A framework for conducting laboratory tests which may

Chemical and Physical Aspects, continued

be used for prediction of environmental fate of specific hydrocarbons is suggested. This shows that evaporation and dissolution are competitive processes, with evaporation being more rapid for all but the polycyclic aromatic hydrocarbons and photolysis products.

Mackay, D., M. Charles and C. Philips. 1975. The Physical Aspects of Crude Oil Spills on Northern Terrain. Publication No. QS 8060-000-EE-AL. Canadian Department of Indian and Northern Affairs. pp. 1-20.

The physical properties of two crude oils were investigated, and the effects of evaporation and temperature on these properties were reported.

Mackay, D., M. Medir and D.E. Thornton. 1976. The Interfacial Behavior of Oil Under Ice. *Canadian Journal of Chemical Engineering*. 54(1/2):72-74.

The effect of interfacial tension on an oil slick at the ice-water interface was investigated to determine if it assisted or retarded the spread of the oil.

Miyahara, S. 1987. Formation of Water-in-oil Emulsions. In J.H. Vandermeulen and S.E. Hrudey, eds. *Oil in Freshwater: Chemistry, Biology, Countermeasure Technology*. Pergamon Press, New York. pp. 71-84. *Proceedings of the Symposium on Oil Pollution in Freshwater*. Edmonton, Alberta, Canada. October 15-19, 1984.

When crude oil is spilled on water, a variety of complex interactions occur. The chemical and physical processes involved determine the fate and effect of the oil spill on the aquatic environment. Research on these processes is reviewed with an emphasis on relevant Japanese studies.

Osamor, C.A. and R.C. Ahlert. 1981. *Oil Slick Dispersal Mechanics*. Report EPA-600/2-81-199. Municipal Environmental Research Laboratory, Office of Research and Development, U.S. Environmental Protection Agency.

Laboratory studies investigating the spreading behavior of small oil slicks formed from spills of 12 oils. Spreading behavior of oils was characterized by equations containing the physical properties of oil and water phases, volume of oil spilled, and time. The rates of dissolution of these oils in tap water at 25°C were also studied.

Phillips, C. and V. Groseva. 1977. The Spreading of Crude Oil Spills Across a Lake. *Water, Air and Soil Pollution*. 8:353-360.

Chemical and Physical Aspects, continued

Experiments were conducted which studied the spreading velocity of two crude oils on a lake in Canada. Compositional changes of both slicks were investigated.

Regnier, Z.R. and B.F. Scott. 1975. Evaporation Rates of Oil Components. *Environmental Science and Technology*. 9(5):469-472.

Gas chromatographic studies determined the rate constants for the n-alkane components of Arctic Diesel 40, a No. 2 fuel oil, at constant wind speed and variable temperature. Arrhenius activation energies and the amounts of alkanes present at various time intervals were calculated as an aid in determining the amount of oil remaining after spills on water and ice.

Rossi, S.S. and W.H. Thomas. 1981. Solubility Behavior of Three Aromatic Hydrocarbons in Distilled Water and Natural Seawater. *Environmental Science and Technology*. 15(6):715-716.

The solubilities of three aromatic hydrocarbons, toluene, acenaphthene and pyrene were determined in natural seawater and in distilled water at 25°C. The solubility of each was less in seawater than in distilled water. This "salting out" effect, as well as the temperature effect (at 15, 20 and 25°C), were directly related to molar volume.

Shaw, D.G. and S.K. Reidy. 1979. Chemical and Size Fractionation of Aqueous Petroleum Dispersions. *Environmental Science and Technology*. 13(10):1259-1263.

The effects of different modes of mixing on droplet formation and chemical fractionation of crude oil are reported. The consequences of these modes of mixing and how they may influence the impact of an oil spill on the biological community are discussed.

Thüer, M. and W. Stumm. 1977. Sedimentation of Dispersed Oil in Surface Waters. *Progress in Water Technology*. 9(1):183-194.

The authors investigated the sedimentation and flotation of No. 2 fuel at several pH ranges controlled by the addition of a colloid (Al_2O_3).

Weiskopf, F.B. and M.S. Ulzuner. 1977. Oil Slick Spreading Beneath a Uniform Ice Cover in the Presence of a Current. *Proceedings*, 1977 International Oil Spill Conference, New Orleans, LA, March 8-10, 1977. API Publication No. 4284. American Petroleum Institute, Washington, D.C. pp. 297-300.

Chemical and Physical Aspects, continued

The movement of No. 2 fuel oil and crude oil under ice in the presence of a current is discussed. Equations are developed predicting the spreading of the two oils.

Yapa, P.D. and T. Chowdhury. 1990. Spreading of Oil Under Ice Covers. *Journal of Hydraulic Engineering*. pp. 1468-1483.

This paper presents a new set of equations for calculating the spreading of oil under ice. The calculations can be used for oils with different viscosities, ice covers with different roughness, and for a variety of discharge conditions.

4.0 EFFECTS ON RIVERS

Baker, J.H. and R.Y. Morita. 1983. A Note on the Effects of Crude Oil on Microbial Activities in a Stream Sediment. *Environmental Pollution*. 31(A):149-157.

Effects of oil on microbial activity in freshwater stream mud were examined by determining rates of CO₂ production, nitrogen fixation and methanogenesis, $V_{\max}$ for glucose, phosphatase levels, and Eh. Nitrogen fixation was significantly reduced in the 1% oiled stream sediment after 8 and 16 weeks, and may be less sensitive to crude oil than in marine sediments. Denitrification may be enhanced with crude oil. Methane and CO₂ production were generally greater in oiled sediment than in controls. Phosphatase levels and $V_{\max}$ for glucose mineralization reduced with increasing oil concentration. There were no differences in Eh.

Bass, M.L., J.R. Voshell, Jr. and R.W. Young, 1987. Assessment of Damage to Aquatic Communities Resulting From a Refined Oil Products Spill. In J.H. Vandermeulen and S.E. Hrudey, eds. *Oil in Freshwater: Chemistry, Biology, Countermeasure Technology*. Pergamon Press, New York. pp. 353-378. *Proceedings of the Symposium on Oil Pollution in Freshwater*. Edmonton, Alberta, Canada. October 15-19, 1984.

In March 1980, two simultaneous breaks on Colonial Pipeline Company's refined oil products line in Northern Virginia spilled approximately 340 m³ of No. 2 fuel oil into Mine Run Creek and approximately 120 m³ of kerosene into Bull Run Creek. Damage to these streams was assessed by analyzing water chemistry, sediment total chromatographable organics (TCO), periphyton and macrobenthic community structures. The effects of the refined products spill were most evident in Mine Run Creek. The low density of the examined communities and the reduction or absence of certain functional groups in Mine Run Creek indicate continued perturbation. Increased bacterial biomass directly correlated with the increased scrapers at impacted stations.

Bedair H.M. and H.T. Al-Saad. 1992. Dissolved and Particulate-absorbed Hydrocarbons in the Waters of Shatt al-Arab River, Iraq. *Water, Air and Soil Pollution*. 61(3-4):397-408.

This paper outlines a study that was conducted on the petroleum content and origins in the Shatt Al-Arab River in Iraq. The study was conducted to establish baseline parameters in the event there was a spill, as there are extensive drilling and transportation activities in that area. The study showed that the hydrocarbons detected in the water were both naturally produced, biogenic, and anthropogenic from industry-related discharges.

Effects on Rivers, continued

Berkey, E., S.M. Creeger and R.L. Price. 1988. Environmental Effects of the January 2, 1988, Diesel Oil Spill into the Monongahela River - Progress Report. In P. Bockholts and I. Heidebrink, eds. *Chemical Spills and Emergency Management*. Kluwer Academic Publishers. pp. 435-444.

Studies of the physical, chemical, and biological aspects of the Ashland oil spill which occurred in 1988, were conducted to assess the short- and long-term environmental impacts. The spill involved the loss of over 750,000 gallons of diesel fuel into the Monongahela River. Studies include fate, oil settlement and resuspension, short-term impacts on fish and waterfowl, and an assessment of potential long-term effects which were expected to be minimal. The spill created only small to moderate environmental effects over the first 185 miles down river. The majority of the spill was initially deposited over this region. Subsequent heavy rains resuspended and carried away much of the oil except in localized areas.

Biedenbender, P.L. and J. Michel. 1989. Response Strategies in a High Tidal Range Estuarine System: The Savannah River Oil Spill. *Proceedings*, 1989 International Oil Spill Conference, San Antonio, TX, February 13-16, 1989. American Petroleum Institute Publication No. 4479. pp. 95-97.

500,000 gallons of No. 6 fuel oil was spilled into the Savannah River in Georgia. The source was identified as the vessel AMAZON VENTURE, which was berthed at the Garden City Terminal about 30 km from the Savannah River mouth. This paper details the spill, difficulties with the response, and the different ecological areas that were impacted. Problems and suggestions for improved protection and recovery methods for the area are discussed.

Birkholz, D.A., S.E. Hrudey, B.J. Kimble, M. Rawluk and M. Gray. 1987. Characterization of Water Soluble Components of a Waste Water Oil Sample From an Oil Sands Bitumen Upgrading Plant. In J.V. Vandermeulen and S.E. Hrudey, eds. *Oil in Freshwater: Chemistry, Biology, Countermeasure Technology*. Pergamon Press, New York. p. 42. *Proceedings of the Symposium on Oil Pollution in Freshwater*. Edmonton, Alberta, Canada. October 15-19, 1984.

Following a fire and a series of equipment failures at the Suncor surface mining oil sands and bitumen upgrading plant in Alberta, a release of more than 50 tons of raw coke distillate oil and grease into the ice covered Athabasca River occurred. Oil was collected from the plant's wastewater pond and subjected to numerous tests to determine if any water soluble compounds from the oil might affect the fish present in the river.

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- Bitton, G., D.A. Chuckran, I. Chet and R. Mitchell. 1979. Resistance of Bacterial Chemotaxis to Blockage in Petroleum Waters. *Marine Pollution Bulletin*. 10(2):48-49.

Laboratory study of effect of kerosene on chemoreception in a bacterium isolated from a subtropical freshwater creek in Florida, which had been affected by an oil spill.

- Blahm, T.H., J. Durkin, G. Snyder, T. Coley and R.L. Emmett. 1980. *Columbia River Oil Spill Study, June/July 1978*. Northwest and Alaska Fisheries Center. Seattle, WA.

Field studies of the impact of a spill of approximately 60,000 gallons of Bunker C fuel oil on the Columbia River fishery are described. Data from collections made prior to the spill are compared to post-spill data.

- Bott, T.L. and K. Rogenmuser. 1978. Effects of No. 2 Fuel Oil, Nigerian Crude Oil, and Used Crankcase Oil on Attached Algal Communities: Acute and Chronic Toxicity of Water-Soluble Constituents. *Applied and Environmental Microbiology*. 36(5):673-682.

Attached algal communities in a stream microcosm were exposed to water extracts of No. 2 fuel, Nigerian crude, and used crankcase oils. Criteria for toxicity were changes in community biomass, species composition and ^{14}C bicarbonate uptake.

- Bott, T.L., K. Rogenmuser and P. Thorne. 1978. Effects of No. 2 Fuel Oil, Nigerian Crude Oil, and Used Crankcase Oil on Benthic Algal Communities. *Journal of Environmental Science and Health. Part A*. 13(10):751-779.

Benthic algal communities in a stream microcosm were exposed to simulated spills of No. 2 fuel, Nigerian crude, or used crankcase oils. Community metabolism (oxygen flux measured by respirometer) and biomass were measured just after the spill and for several weeks following the spill.

- Brandon, D.L., C.R. Lee, J.W. Simmers, H.E. Tatem, and J.G. Skogerboe. 1991. *Information Summary, Area of Concern: Saginaw River and Saginaw Bay. Final Report, Aug-Dec 88*. U.S. Army Engineer Waterways Experiment Station, Vicksburg, MS.

This report summarizes the information obtained for the Saginaw River and Saginaw Bay areas of concern in Michigan. Research was conducted on the various aspects of contaminant mobility in the aquatic environment. Data tables

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include information on discharge, volume and migration of contaminants, sediment transport, oil spills, hazardous materials, superfund sites, bioassay data and biological data (i.e. fish, wildlife habitats, plankton, fish and endangered species). Information collected from this study as well as others will be used to guide the development of Remedial Action Plans for 42 identified Great Lakes areas of concern as well as lake-wide management plans.

Buckley, E.N., R.B. Jonas and F.K. Pfaender. 1976. Characterization of Microbial Isolates from an Estuarine Ecosystem: Relationship of Hydrocarbon Utilization to Ambient Hydrocarbon Concentrations. *Applied and Environmental Microbiology*. 32(2): 232-237.

Species composing natural planktonic bacterial populations in low-salinity reaches of the Neuse River estuary (North Carolina) were isolated and tested for ability to utilize kerosene as a growth substrate. The proportions of species at each location able to grow on kerosene were compared to ambient hydrocarbon concentrations.

Bugbee, S.L. and C.M. Walter. 1973. The Response of Macroinvertebrates to Gasoline Pollution in a Mountain Stream. *Proceedings, Joint Conference on Prevention and Control of Oil Spills*, Washington, D.C., March 13-15, 1973. API Publication No. 4172. American Petroleum Institute, Washington, D.C. pp. 725-731.

Observation of fish mortality and reduction in macroinvertebrate populations following a spill of gasoline are discussed. Follow-up investigations on the recolonization of the impact area by macroinvertebrates after 1 and 3 years are presented.

Bury, R.B. 1972. The effects of Diesel Fuel on a Stream. *California Fish and Game*. 58(4):291-295.

A study was conducted in Hayfork Creek, California, at the site of a 2,000 gal diesel fuel spill. The impact on invertebrates, fish, amphibians, reptiles and waterfowl is discussed.

Campbell, K.W. 1985. Effects of the 1982 Amoco-Dome Brazeau River Gas Well Blowout on the Subsurface Environment. In *Hazardous Wastes in Ground Water: A Soluble Dilemma*. National Water Well Association, Dublin, OH. pp. 225-232.

In 1982, a gas well near Lodgepole, Alberta, experienced a 67-day period of uncontrolled flow of reservoir fluids, depositing hydrocarbon condensate over an area of approximately 10 km² (4 mi²) adjacent to Zeta Creek near its confluence

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with the Pembina River. A series of strategically located ditches, trenches, keyed-in-dikes and pits permitted collection of large volumes of condensate and proved cost-effective in confining and collecting free condensate on the lease site. The project demonstrates the importance of understanding the geological conditions on a spill site and the cost-effectiveness of relatively simple cleanup and containment procedures.

Center for Hazardous Materials Research (CHMR). 1990. *Assessment of Environmental Effects from the January 2, 1988 Diesel Oil Spill into the Monongahela River, Final Report on the Two Year Study*. Report C49-398-2. Pittsburgh, PA.

Studies of the physical, chemical, and biological aspects of a 700,000 gallon diesel spill into the Monongahela River were conducted to assess short- and long-term environmental impacts. Reviews of the effects of oil spills on fish, waterfowl, invertebrates, microorganisms, plants, and mammals are presented and compared to observed effects from this spill on the Monongahela River. Synthesis reports on the public perception of health and environmental risk from spills and on causes of oil spills into rivers are provided.

Chong, C.V., J.C. Jordon and R. Gutierrez. 1983. TEXACO CONNECTICUT's Oil Spill Incident in the Panama Canal. *Proceedings*, 1983 International Oil Spill Conference, San Antonio, TX. February 28-March 3, 1983. API Publication No. 4356. American Petroleum Institute, Washington, D.C. pp. 369-370.

The US tanker TEXACO CONNECTICUT struck the east bank of Gaillard Cut in the Panama Canal, ripping its number 1 and 2 cargo tanks filled with Alaskan crude. An estimated 4000 barrels of crude oil were spilled over approximately 35 miles. A multi-agency effort was immediately able to recover a total of 1,361 bbl of the oil. The environmental impact of the spill was observed by Panama Canal Commission biologists as well as by the Smithsonian Tropical Research Institute (STRI). Although no baseline data exists for comparison, it is apparent that no far reaching negative effects were imposed on the fauna and flora of Gatun Lake.

Clark, R.M., A.H. Vicory and J.A. Goodrich. 1988. *Great Ohio River Oil Spill of 1988: A Case Study*. Environmental Protection Agency, Ohio River Valley Water Sanitation Commission, Cincinnati, OH.

This paper discusses the Ashland Oil spill of 750,000 gallons into the Monongahela River in January 1988, and emphasizes how vulnerable the drinking water utilities are to upstream industrial spills and discharges. During the spill, dissemination of information and monitoring the spill were effective and very few

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hardships occurred. However, the spill did reinforce the need for better techniques for predicting oil spill movement and oil concentrations on the Ohio River.

Clark, R.M., A.H. Vicory and J.A. Goodrich. 1990. Ohio River Oil Spill: A Case Study. *Journal of the American Water Works Association*. 82(3):39-44.

This study discusses the sensitivity of the drinking water utilities to upstream point and non-point sources of pollution. The Ashland Oil spill that occurred on the Monongahela River illustrated the need for better information regarding the time of passage versus discharge levels for various stages of Ohio River flow. Computer models should be developed that can better predict both travel time and concentration of contaminants in the event of future spills.

Colvin, J.W. and R.C. Gordon. 1976. Interactions Between Crude Oil and Subarctic River Bacteria. *Proceedings of the Alaska Science Conference*. 27:159-160.

Laboratory study of samples collected from polluted and unpolluted segments of a subarctic Alaskan river. Planktonic populations of total heterotrophic and hydrocarbon-utilizing bacteria were monitored (plate counts) after addition of Prudhoe Bay crude oil; bacterial isolates from each site were tested for ability to utilize Prudhoe Bay crude as sole carbon source.

Creeger, S.M. and R.L. Price. 1988. Environmental Effects of the January 2, 1988, Diesel Oil Spill into the Monongahela River-Progress Report Edgar Berkey (University of Pittsburgh, PA). In *Chemical Spills and Emergency Management at Sea, First International Conference, Amsterdam, the Netherlands (Kluwer), November 15-18, 1988*. pp. 435-445.

This study includes an analysis of the physical, chemical and biological aspects of the spill to assess short- and long-term impacts. Results indicate that the spill created only small to moderate environmental effects over the first 307 km (185 mi) downriver, where most of the oil was deposited. Further heavy rains resuspended and carried away much of the oil. More subtle environmental effects are being considered for future study.

Crunkilton, R.L. and R.M. Duchrow. 1990. Impact of a Massive Crude Oil Spill on the Invertebrate Fauna of a Missouri Ozark Stream. *Environmental Pollution*. 63(1):13-31.

The benthic macroinvertebrate fauna of Asher Creek were monitored following a 1.5 million liter domestic crude oil spill. Effects on aquatic insects, crustaceans,

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segmented worms, roundworms, flatworms, snails, freshwater mussels and other benthic organisms in the oil impacted area were summarized. The visible appearance of oil in the stream substrate was a simple predictor of the status of the benthic invertebrate community. Areas protected with surface skimming siphon dams were less severely impacted and recovered more rapidly than areas where the stream substrate was inundated with oil. The most apparent factors controlling the recovery were the total volume of water passing through the contaminated area and the occurrence of scouring floods.

Cummings, B.A. and R.C. Gordon. 1982. *Microbiologically Mediated Mutagenic Activity of Crude Oil*. EPA-600/S3-81-053. U.S. Environmental Protection Agency, Environmental Research Laboratory, Corvallis, OR.

Samples of raw and sterile water from the Chena River, Alaska, were incubated with Prudhoe Bay crude oil and crude oil fractions. Mutagen and toxin production were detected by the Ames test and bacteriocidal effect on *Escherichia coli* K-12.

Eger, C.K., W. Fang, J. Maybriar and K. Sims. 1993. Implementation of Field Techniques to Stabilize Abandoned Oil Wells. *Proceedings*, 1993 International Oil Spill Conference, Tampa, FL, March 29-April 1, 1993. API Publication No. 4580. American Petroleum Institute, Washington, D.C. pp. 83-88.

Two abandoned wells were identified as flowing into nearby streams. Construction of temporary underflow dams down-gradient from the oil spills were used to minimize impacts on Boyd's Creek and its adjoining tributaries, and the burning of spilled product in temporary holding pits was done to minimize associated cleanup cost.

Forrest, R.G., D. Lopez, R. Peckham, and F. Gorry. 1985. A Major Oil Barge Pollution Incident on the Arkansas River. *Proceedings*, 1985 International Oil Spill Conference, Los Angeles, CA, February 25-28, 1985. Publication No. 4385. American Petroleum Institute, Washington, D.C. pp. 319-323.

On June 27, 1982, a barge was impaled by ice breakers on Lock and Dam No.4 on the Arkansas River, discharging 8,000 bbl (336,000 gal) of No.6 (bunker C) fuel oil downstream of Pine Bluff, Arkansas. This paper discusses the incident and response, including risk assessment protection, recovery, disposal, barge salvage, and residual impact. A lengthy cleanup was necessary at an ox bow lake when oil passed through a rock revetment constructed across the mouth. The locks and dams contained floating oil, but high river flow limited their use. Heavy debris posed problems and high river currents complicated barge salvage operation. No

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major adverse environmental effects were observed.

Frink, L. and M.J. Dalton. 1989. Establishing a Wildlife Response After the Ashland Oil Spill. *Proceedings*, International Oil Spill Conference, San Antonio, TX, February 13-16, 1989. API Publication No. 4479. American Petroleum Institute, Washington, D.C. pp. 77-80.

This paper focuses on the need for rapid response, adherence to protocols, interagency communication, and hands-on experience in establishing a successful response to wildlife contaminated by oil. In particular, it discusses the response to impacted wildlife during the Ashland Oil spill of 750,000 gallons of #2 diesel fuel into the Monongahela River.

Graves, N.A. 1985. A Northern Idaho Gasoline Spill and Cleanup Using Stream Bed Agitation. *Proceedings*, 1985 International Oil Spill Conference, Los Angeles, CA, February 25-28, 1985. API Publication No. 4385. American Petroleum Institute, Washington, D.C. pp. 189-191.

On June 4, 1983, a pipeline break released gasoline into Wolf Lodge Creek in Idaho. The spill killed all fish in the main channel above the containment area, as well as several beaver and ducks. Side channels and wetlands near the mouth appeared to be unaffected and little gas reached Lake Coeur d'Alene. The heavy spray of gasoline during the rupture saturated vegetation and soil. The greatest amount of gasoline was trapped in the gravel bed of the creek, which was mechanically removed using stream bed agitation. The agitation did not appear to affect fish.

Guiney, P.D., J.L. Sykora and G. Keleti. 1987. Environmental Impact of an Aviation Kerosene Spill on Stream Water Quality in Cambria County, Pennsylvania. *Environmental Toxicology and Chemistry*. 6(12):977-988.

This paper discusses a study that was conducted following an aviation kerosene leak into a small watershed. The study examined how long it took for recolonization of habitat and indicated that several factors affected recolonization. These included: the swift and effective initial cleanup, a plentiful source of unpolluted dilution water, the drift of benthic organisms available for recolonization, and the immigration of fish from the unpolluted sections of the watershed.

Guiney, P.D., J.L. Sykora and G. Keleti. 1987. Qualitative and Quantitative Analyses of Petroleum Hydrocarbon Concentrations in a Trout Stream Contaminated by an Aviation Kerosene Spill. *Environmental Toxicology and Chemistry*. 6(2):105-114.

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Kerosene-range hydrocarbons were monitored in a small central Pennsylvania stream watershed, over two years (1982 to 1984) after a pipeline leak of about 1,310 barrels of aviation kerosene. The concentration of kerosene-range hydrocarbons and total organic carbon in the water typically decreased. Elevated concentrations of hydrocarbons, however, were detected in sediment samples and tissues of fish collected from two impacted bridge locations up to 14 months afterwards. These two bridges were primary boom recovery sites during spill cleanup activities. No kerosene-range hydrocarbons were detected after 21 months, and other stream water quality parameters remained within normal limits.

Hardy, R. 1972. Diesel Oil Contamination of Brown Trout (*Salmo trutta* L.). *Environmental Pollution*. 3(1):9-16.

Brown trout collected in the region exposed to a diesel fuel spill were analyzed to determine whether hydrocarbon uptake had occurred. Gas-liquid chromatography and mass spectroscopy were used to identify contaminants.

Harrel, R.C. 1985. Effects of a Crude Oil Spill on Water Quality and Macrobenthos of a Southeast Texas Stream. *Hydrobiologia*. 124(3):223-228.

On December 6, 1981 a crude oil spill of 160 barrels (25,440 liters) occurred in a small southeast Texas stream. Water quality changes, other than the presence of oil, were not evident until six months later when water temperature increased and stream flow ceased. A thick film of oil and plant detritus covered the surface of the stream. Eleven months after the spill, stream flow had resumed and water temperature decreased, but oxygen concentrations remained low. No clean-water taxa were collected and complete recovery had not occurred within 26 months.

Hoehn, R.C., J.R. Stauffer, M.T. Masnik and C.H. Hocutt. 1974. Relationships Between Sediment Oil Concentrations and the Macroinvertebrates Present in a Small Stream Following an Oil Spill. *Environmental Letters* 7(4):345-352.

Benthic macroinvertebrate populations and oil residues in sediments were correlated in a stream subjected to a spill of No. 2 fuel oil.

Kaj, L. and C. Lehtinen. 1986. Oil Pollution from Rivers. Swedish Environmental Research Institute. Stockholm, Sweden. Available from National Technical Information Service, (703)487-4650 as DE88753695.

Concentrations of petroleum hydrocarbons in ten Swedish rivers have been measured. Total emission of hydrocarbons to Swedish coastal waters is estimated

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at 2000-2900 ton/year (GC-analysis) and 2500-3800 ton/year (fluorometric analysis). [In Swedish.]

Krahn, M.M., L.J. Kittle, Jr. and W.D. MacLeod, Jr. 1986. Evidence for Exposure of Fish to Oil Spilled into the Columbia River. *Marine Environmental Research*. 20(4):291-298.

On March 19, 1984, over 170,000 gallons of oil were spilled into the Columbia River. The spill provided an opportunity to field test analytical methods for estimating the exposure of fish to aromatic compounds by measuring the concentrations of metabolites of these contaminants in fish bile. Findings indicate that, within 5 days after the spill, mean concentrations of metabolites of aromatic compounds in the bile of white sturgeon *Acipenser transmontanus* captured 57 miles downstream were significantly higher than those of sturgeon caught upriver.

Lock, M.A., R.R. Wallace, D.R. Barton and S. Charlton. 1981a. The Effects of Synthetic Crude Oil on Microbial and Macroinvertebrate Benthic River Communities - Part I: Colonization of Synthetic Crude Oil Contaminated Substrata. *Environmental Pollution Series A*. 24(3):207-217.

Field simulation of substrate coating by synthetic crude oil spill in Muskeg River, Alberta, Canada, using artificial substrates. Bacterial numbers (direct counts) and biomass (ATP), algal density, species and biomass (chlorophyll a), and macroinvertebrate taxonomic composition and relative abundance were determined on oiled and non-oiled (control) substrates, in both light and dark locations, one month after placement *in situ* to examine effects of oil contamination on benthic community development.

Lock, M.A., R.R. Wallace, D.R. Barton and S. Charlton. 1981b. The Effects of Synthetic Crude Oil on Microbial and Macroinvertebrate Benthic River Communities: Part II - The Response of an Established Community to Contamination by Synthetic Crude Oil. *Environmental Pollution Series A*. 24(4):263-275.

Field simulation of effects of spill of synthetic crude oil (including separate treatments of naphtha, kerosene and gas/oil components) on benthic communities. Colonized artificial substrates were treated with oil, and submerged in riffle habitat in Muskeg River, Alberta, Canada. Estimates of bacterial abundance, algal community composition and biomass (chlorophyll a) and macroinvertebrate community composition and relative abundance were made to evaluate the response of benthic lotic communities to oil contamination.

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Lock, M.A., R.R. Wallace and D.W.S. Westlake. 1982. Biodegradation of Synthetic Crude Oil in Two Rivers of Northern Alberta, Canada. *Water Research*. 16(4):497-500.

Study of ability of naturally occurring microbes from water column and bottom rubble substrate to degrade the saturated fraction of synthetic crude oil. Samples of indigenous microbial flora were obtained from the Muskeg and Steepbank rivers, Northern Alberta, Canada, including sites within and outside oil sand deposits.

Lockhart, W.L., D.A. Metner, D.A.J. Murray and D.C.G. Muir. 1987. Hydrocarbons and Complaints About Fish Quality in the Mackenzie River, Northwest Territories, Canada. Water Quality Monitoring in Canada North of 60 degree. *Water Pollution Research Journal of Canada*. 22(4):616-628.

The Mackenzie River in northwestern Canada is the largest North American source of freshwater to the Arctic Ocean. There are continuous discharges of petroleum into the river from an oil field at Norman Wells both from refinery and natural seepage sources. Recently, the liver of burbot *Lota lota* was reported to have become small and dark. This investigation found levels of oil (below 2% oil-in-medium) increased neonatal production, apparently by inducing premature births of neonates, while allowing the neonates to survive.

Masnik, M.T., J.R. Stauffer, C. Hocutt and J. Wilson. 1976. The Effects of an Oil Spill on the Macroinvertebrates and Fish in a Small Southwestern Virginia Creek. *Journal of Environmental Science and Health Part A. Environ. Sci. Eng.* 11(4/5):281-296.

Four months of field observations and collections of fish and macroinvertebrates were made along a stretch of stream exposed to a spill of No. 2 fuel oil.

McCart, P. and J. Denbeste. 1987. Colonization of Experimentally Oiled Substrates by Periphyton and Benthic Macroinvertebrates in Two Arctic Streams. In J.H. Vandermeulen and S.E. Hrudey, eds. *Oil in Freshwater: Chemistry, Biology, Countermeasure Technology*. Pergamon Press, New York. pp. 388-402. *Proceedings of the Symposium on Oil Pollution in Freshwater*. Edmonton, Alberta, Canada. October 15-19, 1984.

The recolonization by periphyton and benthic macroinvertebrates onto cleaned natural surfaces oiled with Prudhoe Bay crude oil and placed into the streambeds of two streams located within the Trans Alaska Pipeline Corridor in northern Alaska is described. Non-oiled natural surfaces served as controls. The sites were revisited and sampled at 45 days and 90 days after the placement of the oiled surfaces in the streams. Oil residue was still evident on the surfaces in both

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streams after 90 days exposure. Recolonization by both the periphyton and macroinvertebrate communities was little influenced by the presence of oil on the settling substrates.

McCauley, R.N. 1966. The Biological Effects of Oil Pollution in a River. *Limnology and Oceanography*. 11(4):475-486.

Following a spill of heavy bunker fuel oil into Muddy River, Massachusetts, a 2-year study was made of the effects of the oil on biological activity in the water and sediments. Slow decomposition of the oil by microorganisms was indicated and the oil was toxic to the plankton and to the macrofauna of the sediments.

Michaelis, F.B. 1983. Effect of Turoa Oil Spill on Aquatic Insects in the Mangawhero River System. *New Zealand Entomology*. 7(4):447-455.

Seventeen thousand liters of oil were spilled on Mt Ruapehu and entered the headwaters of the Mangawhero and Makotuku Rivers where it persisted for up to 5 months. Brown trout, rainbow trout, long-finned eels, and blue duck were not killed. However, in the upper reaches, aquatic insects were disturbed and killed by the oil spill within 2 weeks. The total numbers of aquatic insects were not significantly affected at the lower stations within Tongariro National Park over the following year. Mayflies were significantly reduced in numbers in the Mokotuku River following the oil spill and may be indicator species for oil pollution.

Mikhajlova, L.V. 1991. The Present-day Hydrochemical Regime and Effect of Pollution on the Aquatic Ecosystem and Fisheries of the Ob' River Basin (review). *Gidrobiologicheskii Zhurnal/Hydrobiology Journal*. 27(5):80-90.

The paper (in Russian) summarizes all available information on the state of the Ob' River Basin under conditions of intensively developing gas and oil complex in West Siberia.

Miklaucic, E.A. and J. Saseen. 1989. The Ashland Oil Spill, Floreffe, PA History and Response Evaluation. *Proceedings*, 1989 International Oil Spill Conference, San Antonio, TX, February 13-16, 1989. API Publication No. 4479. American Petroleum Institute, Washington, D.C. pp. 45-51.

Following the Ashland Oil spill, river monitoring included: 1) overflight tracking of the oil mass movement; 2) sampling water quality at intakes; and 3) monitoring effects on wildlife. Response activities and problems, water supply protection, testing, and alternate sources, spill tracking, wildlife rehabilitation and losses, and

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recommendations for improved response structure and testing procedures are discussed.

Miller, M.C., J.R. Stout and V. Alexander. 1986. Effects of a Controlled Under-ice Oil Spill on Invertebrates of an Arctic and a Subarctic Stream. *Environmental Pollution*. 42(2):99-132.

The short-term drift of macroinvertebrates was documented following two controlled oil spills under ice in an arctic and a subarctic stream just as ice covered the water in early winter. Although no mortality was observed, several species responded by differentially drifting from the affected areas during the days following the spill. Colonization of artificial substrates in the arctic creek during the winter was almost nonexistent; in the subarctic creek, much colonization took place over the winter, with significantly more occurring on unsoiled rocks as compared with oiled rocks.

Nauman, J.W. and D.R. Kernodle. 1975. The Effects of a Fuel Oil Spill on Benthic Invertebrates and Water Quality on the Alaskan Arctic Slope, Happy Valley Creek, Near Sagwon, Alaska. *Journal of Research, U.S. Geological Survey*. 3(4):495-501.

The impact of a spill of Arctic diesel fuel on macroinvertebrates in an Alaskan stream is described.

Nichols, A.B. 1989. The Ashland Spill: One Year Later. *Journal Water Pollution Control Federation*. 61(3):284,286.

This is a report on the Center for Hazardous Materials Research study following the 1988 Ashland oil spill in the Monongahela River. This study concluded that the Ashland spill created only small to moderate environmental effects over the first 185 miles downriver from the spill site. Subsequent heavy rains resuspended and carried away much of the oil except in localized areas such as back channels where river velocity was low. In these low velocity areas, the oil has adsorbed to sediment deposits.

Nwadiaro, C. 1990. Hydrobiological Survey of the Chanomi Creek System, Lower Niger Delta, Nigeria. *Limnologica*. 21(1):263-274.

Chanomi Creek, an estuarine system in the lower Niger delta of Nigeria, was evaluated between December 1984 and April 1985, to assess long-term recovery from a crude oil spill three years earlier. Zooplankton density was high, with populations of adult calanoid and cyclopoid copepods, copepod nauplii, barnacle nauplii, larvaceans, and larvae of polychaetes, gastropods, and shrimp. There is

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some evidence that Chanomi Creek has recovered from the 1982 oil spill.

- Ogan, M.T. 1991. Studies on the Ecology of Aquatic Bacteria of the Lower Niger Delta: Populations of Viable Cells and Physiological Groups. *Archives of Hydrobiology*. 121(2):235-252.

The viable cells and physiological groups of bacteria in lotic waters of the Niger Delta were counted in the Port Harcourt area, and were related to indices of organic pollution. Cell recovery by two viable count media, were compared in an initial study. Nitrifying and iron bacteria were undetected even after incubations for 4 months and 30 days respectively.

- Onuoha, G. 1985. Oil Pollution and the Brackish Environment. In B.H.R. Wilcox and C.P. Powell, eds. *The Mangrove Ecosystem of the Niger Delta: Proceedings of a Workshop*. Port Harcourt, Nigeria. May 19-23, 1980. pp. 123-132.

Toxicity tests were carried out with Trans Niger crude oil and the dual-purpose kerosene on the oyster *Crassostrea gasar*, the periwinkle *Tympanotonus fuscatus*, the shrimp *Penaeus duorarum* and the fish *Tilapia heudeloti*. The shrimps were most sensitive, followed by the oysters, young fish and adult fish. Periwinkles were the most resistant.

- Perry, J.J. 1979. Microbial Cooxidations Involving Hydrocarbons. *Microbiology Review*. 43:59-72.

Reviews of technical studies reported in the literature on the oxidation of non-growth hydrocarbon substrates by microorganisms, and on the oxidation of co-substrates other than hydrocarbons during growth of microbes on hydrocarbon substrates. Enzymatic mechanisms for co-oxidation and documented co-oxidation of paraffins, cycloparaffins and aromatic compounds are considered.

- Pimentell, E.M. 1985. Oil Spill Cleanup and Habitat Restoration - Little Panoche Creek, California. *Proceedings*, 1985 International Oil Spill Conference, Los Angeles, CA, February 25-28, 1985. API Publication No. 4385. American Petroleum Institute, Washington, D.C. pp. 331-334.

In September 1983, an underground pipeline break resulted in a 31,000 barrel crude oil spill into Little Panoche Creek, California. The spill saturated soil and vegetation for two miles along the creek. Slow water flow in the creek, easy equipment access to the creek, and a natural oil collection area provided for favorable cleanup conditions. Contaminated soil was stockpiled and allowed to

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biodegrade, rather than using the costly alternative of landfill disposal. The creek habitat was near full recovery one year afterwards. Recovery was assessed by the regrowth of marsh and shrub vegetation in the creek and adjacent banks.

Pontasch, K.W. and M.A. Brusven. 1988. Diversity and Community Comparison Indices: Assessing Macroinvertebrate Recovery Following a Gasoline Spill. *Water Research*. 22(5):619-626.

Diversity and community comparison indices were evaluated to determine their utility in quantifying macroinvertebrate response to a catastrophic gasoline spill into Wolf Lodge Creek, Idaho. The Bray-Curtis and average Chi-square community comparison indices were more effective in quantifying differences in macroinvertebrate composition between gas-impacted and reference areas of Wolf Lodge Creek following the spill. These indices tracked the progressive spatial recolonization of macroinvertebrates during the 16 month recovery period. Other indices tested failed to adequately quantify macroinvertebrate community response to the gasoline spill.

Pontasch, K.W. and M.A. Brusven. 1988. Macroinvertebrate Response to a Gasoline Spill in Wolf Lodge Creek, Idaho, USA. *Archives of Hydrobiology*. 113(1):41-60.

A post-impact survey study of an unleaded gasoline spill into Wolf Lodge Creek in northern Idaho was undertaken to determine the temporal and spatial recovery of the benthic macroinvertebrate community. High drift densities of mayflies and chironomids contributed to their rapid recolonization.

Pontasch, K.W. and M.A. Brusven. 1989. Macroinvertebrate and Periphyton Response to Streambed Agitation for Release of Substrate-Trapped Hydrocarbons. *Archives of Environmental Contamination and Toxicology*. 18(4):545-553.

Following a spill of unleaded gasoline into Wolf Lodge Creek in northern Idaho, impacted areas were mechanically agitated to release substrate-trapped hydrocarbons. Portions of two riffles were left unagitated to determine if differential recovery of benthic macroinvertebrates and periphyton in cleaned versus uncleaned areas of the stream would occur. In spite of the similar recovery times of macroinvertebrates and periphyton in raked and non-raked areas, the cleaning process is viewed as beneficial because it minimized possible chronic effects on the biota without causing substantial additional impact.

Prairie Regional Oil Spill Containment and Recovery Advisory Committee. 1988. Ice Slotting Oil Spill Exercise. Research and Development Subcommittee, Canadian

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Petroleum Association, Calgary (Alberta). MIC-92-02800/XAB.

On March 3, 1988 a joint ice slotting exercise was held on the North Saskatchewan River at Devon, Alberta for training in the recovery of oil under ice; to evaluate actual ice-slotting techniques; to evaluate safety procedures on ice during an exercise and precautions for actual spill situations; and to evaluate any equipment available to monitor flow rates under ice. This report describes the classroom session and the afternoon exercise.

Qiu, Y.J., M. Bigot and A. Saliot. 1991. Non-aromatic Hydrocarbons in Suspended Matter from Changjiang (Yangtse River) Estuary: Their Characterization and Variation in Winter and Summer (low- and high-flow) Conditions. *Estuarine and Coastal Shelf Science*. 33(2):153-174.

A study of non-aromatic hydrocarbons in suspended particles from the Changjiang River mouth and adjacent East China Sea was conducted. The analysis of different hydrocarbon species indicated large differences between the two periods investigated (winter and summer 1986) corresponding to low and high runoff of the river. According to several criteria such as n-alkane distribution pattern and ratio of unresolved to resolved compounds, the petroleum contamination of Changjiang estuary was low in 1986, for both low- and high-flow seasons.

Rosenberg, D.M. and N.B. Snow. 1975. Effect of Crude Oil on Zoobenthos Colonization of Artificial Substrates in Subarctic Ecosystems. *Internationale Vereinigung fuer Theoretische und Angewandte Limnologie Verhandlungen*. 19(3):2172-2177.

Oil-soaked artificial substrate samples and controls were placed in four Canadian rivers to determine the impact of Norman Wells crude oil on colonization by benthic macroinvertebrates. Samples were placed in the rivers for 1- and 2-month periods.

Rosenberg, D.M. and A.P. Wiens. 1976. Community and Species Responses of Chironomidae (Diptera) to Contamination of Fresh Waters by Crude Oil and Petroleum Products, with Special Reference to the Trail River, Northwest Territories. *Journal of the Fisheries Research Board of Canada*. 33(9):1955-1963.

Effects of crude oil on the colonization of artificial substrates by chironomids was studied in the Trail River, Northwest Territories. The numbers of species, the numbers of individuals and the species diversity index were determined for oiled and unsoiled artificial substrates.

Effects on Rivers, continued

Rosenberg, D.M., A.P. Wiens and O.A. Saether. 1977. Responses to Crude Oil Contamination by *Cricotopus* (*Cricotopus*) *bicinctus* and *C. (C.) mackenziensis* (Diptera: Chironomidae) in the Fort Simpson Area, Northwest Territories. *Journal of the Fisheries Research Board of Canada*. 34(2):254-261.

The effects of Norman Wells crude oil on two species of chironomids colonizing artificial substrates in the Trail River, Northwest Territories, were determined.

Roubal, G., A. Horowitz and R. Atlas. 1979. Disappearance of Hydrocarbons Following a Major Gasoline Spill in the Ohio River. *Developments in Industrial Microbiology*. 20:503-507.

After a gasoline spill on the Ohio River, some of the gasoline reached the sediment. The gasoline quickly disappeared from the sediment due to microbial degradation.

Rutgers University and the Academy of Natural Sciences of Philadelphia. 1977. The Effect of Hydrocarbons on Natural Processes of Bacterial and Algal Attached Communities. In *Petroleum Industry in the Delaware Estuary. A Report to the National Science Foundation RANN Program*. Rutgers University and the Academy of Natural Sciences. pp. 302-354

Study of effects of water-soluble extracts of Nigerian crude oil and No. 2 fuel oil on the metabolism of glucose and phenylalanine by naturally occurring microbial communities. The microbial test populations colonized artificial substrates in the Delaware River, Pennsylvania, and a tidal freshwater tributary, Oldman's Creek (New Jersey). Total heterotrophic bacteria were enumerated in experiments with No. 2 fuel oil.

Schloesser, D.W., T.A. Edsall, B.A. Manny, S.J. Nichols and M. Munawar. 1991. Distribution of *Hexagenia* Nymphs and Visible Oil in Sediments of the Upper Great Lakes Connecting Channels. Environmental Assessment and Habitat Evaluation of the Upper Great Lakes Connecting Channels. Symposium on Environmental Assessment and Habitat Evaluation in the Upper Great Lakes Connecting Channels (at) 31st Conference on Great Lakes Research, Hamilton, Ont. (Canada), 1988. *Hydrobiologia*. 219:345-352.

The occurrence of *Hexagenia* (burrowing mayfly) nymphs and visible oil in sediments at 250 stations throughout the St. Mary's River and the St. Clair-Detroit River system was investigated. A comparison of nymph density at 46 stations where oil was observed in sediments physically suitable for nymphs showed that